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AND8160/D

Compandor Cookbook

ON Semiconductor®

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APPLICATION NOTE

Compandors 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 compandors for signal level control.

So what is companding? Why do it at all? What happens when we do it? Compandor is the contraction of the two words compressor and expandor. 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 maximum 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 3.0 kHz tone is riding on the 1.0 kHz 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).

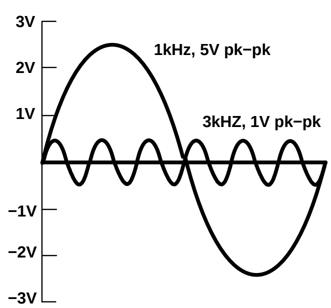

Figure 1. Original Signal Input

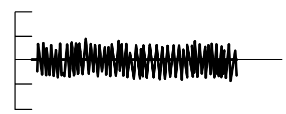

Figure 2. Wide−Band Noise Floor of Transmission Line

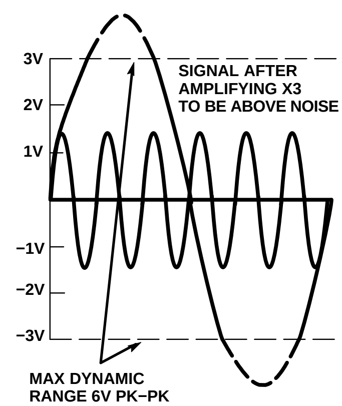

Figure 3.

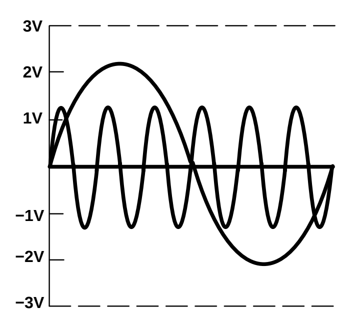

Figure 4. Signal After Compression

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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 ON Semiconductor Compandor 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.

The basic blocks in a compandor are the current-controlled variable gain cell (ΔG), voltage-to-current converter (rectifier), and operational amplifier. Each ON Semiconductor compandor 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.

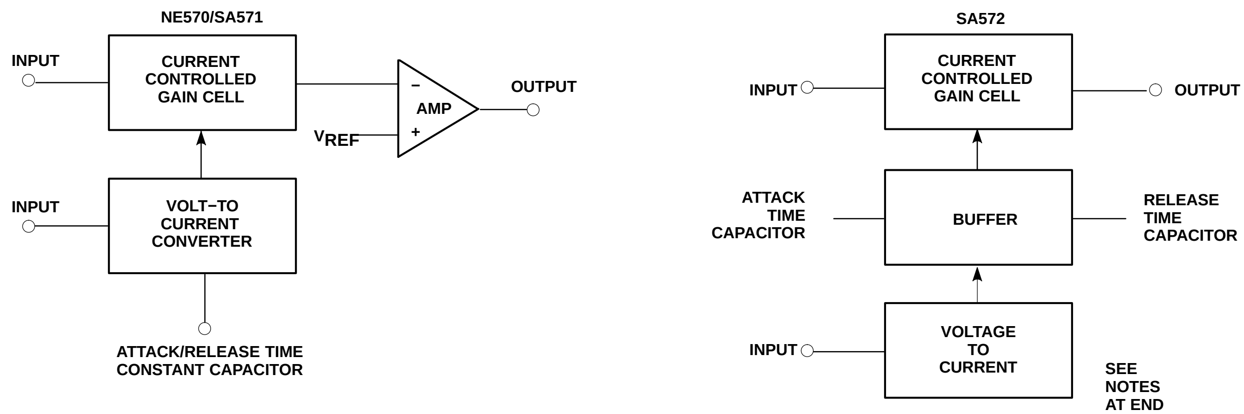

Figure 5. Block Diagrams

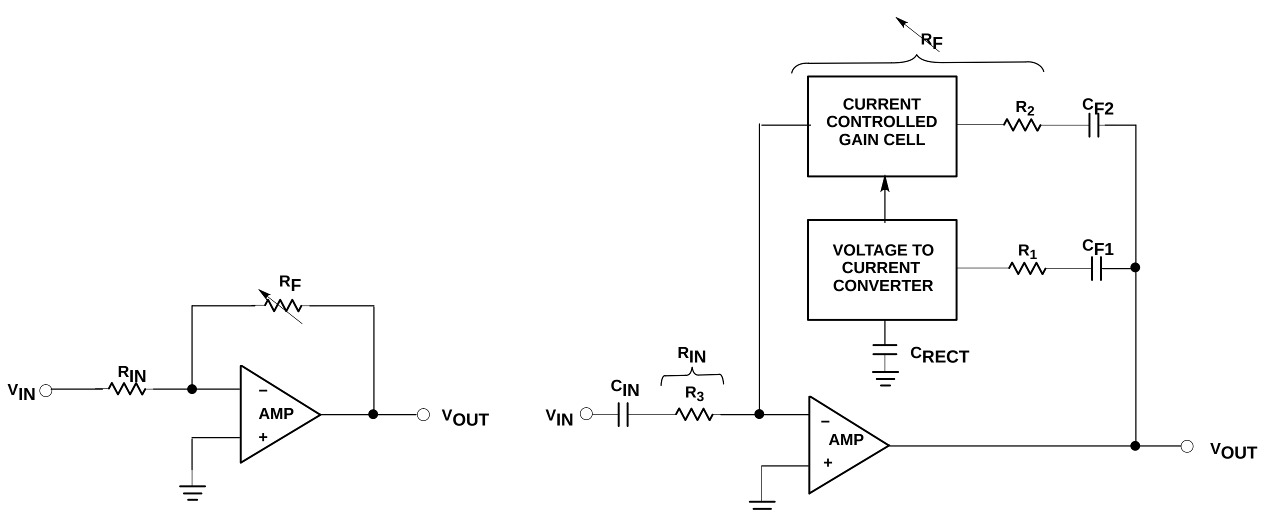

Figure 6. Basic Compressor

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, Expandor, and Automatic Level Controller or as a complete compressor/expandor 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/expandor 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, expandor, and automatic level control application information. A SA571 has been used in all of the circuits. If high-fidelity audio or separately programmable attack and decay time are needed, the SA572 with a low noise op amp should be used.

Compressor

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 0 dB, the variable resistor decreases in value. This causes the gain to decrease, thus limiting the output amplitude.

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

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

The complete equation for the compressor gain is:

$$\text{Gain comp.} = \left[\frac{R_1\, R_2\, I_B}{2\, R_3\, V_{IN}\,(\text{avg})}\right]^{\frac{1}{2}}$$

where:
$R_1 = 10\ k\Omega$
$R_2 = 20\ k\Omega$
$R_3 = 20\ k\Omega$
$I_B = 140\ \mu A$

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

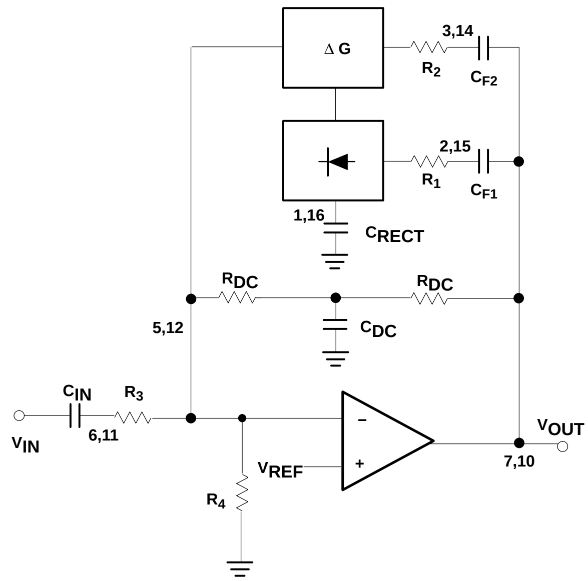

Figure 7. Basic Compressor (NE570/SA571 pinout)

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 6.0 V, thus the output DC level should be 3.0 V.

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

where:
$R_4 = 30\ k\Omega$
$V_{REF} = 1.8\ V$
R_{DC} is external

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 3.0 V 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 ($X_C = 1/(2\pi f \bullet C)$).
4. The C_{RECT} should be 1.0 μF to 2.0 μF 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 noisepumping, breathing, etc., if present. See the SA571 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 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.)

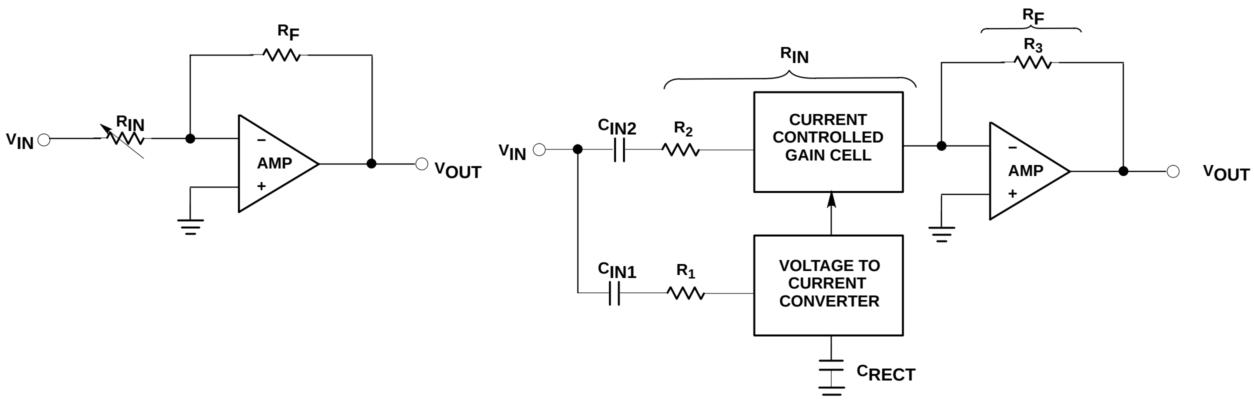

Figure 8. Basic Expandor

Expandor

The EXPANDOR utilizes all the basic building blocks of the compandor (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 0 dBM, 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 expandor gain is:

$$\text{Gainexpandor} = \left(\frac{2\, R_3\, V_{IN}\, (\text{avg})}{R_1\, R_2\, I_B} \right)^2$$

where:
$R_1 = 10\ k\Omega$
$R_2 = 20\ k\Omega$
$R_3 = 20\ k\Omega$
$I_B = 140\ \mu A$

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

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

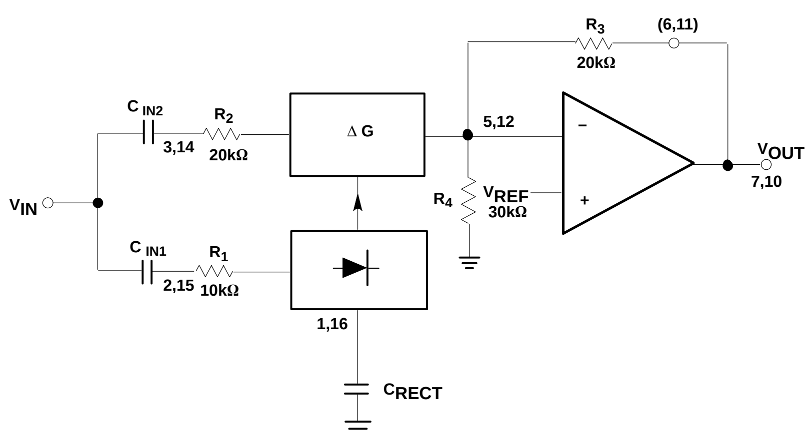

Figure 9. Basic Expandor (NE570/SA571 pinout)

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 6.0 V so the output DC level should be 3.0 V.

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

where: $R_3 = 20\ k\Omega$
$R_4 = 30\ k\Omega$
$V_{REF} = 1.8\ V$

Note that when using a supply voltage higher than 6.0 V 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 expandor's AC gain and thus cause a mismatch in a companding system.)

2. Analyze the input signal's anticipated amplitude:
   a) If larger than 2.8 V peak, R_2 needs to be increased (see INGREDIENTS section).
   b) If larger than 3.0 V 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 1.0 μF to 2.0 μF 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).
7. Distortion (THD) trim pins are available if the already low distortion needs to be further reduced. Note that if not used, the THD trim pins should have 200 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 expansion at low input levels.)

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:

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

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

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

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:

$$\text{Gain max.} = \frac{\left(\frac{R_1 + R_x}{V_{REF}}\right) \cdot R_2 \cdot I_B}{2\ R_3}$$

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

Ingredients

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

R_1 (10 kΩ) limits input current to the rectifier. This current should not exceed an AC peak value of ±300 μA. An external resistor may be placed in series with R_1 if the input voltage to the rectifier will exceed ±3.0 V peak (i.e., 10 k × 300 μA = 3.0 V).

R_2 (20 kΩ) limits input current to the variable gain cell. This current should not exceed an AC peak value of ±140 μA. Again, an external resistor has to be placed in series with R_2 if the input voltage to the variable gain cell exceeds ±2.8 V (i.e., 20 k × 140 μA).

R_3 (20 kΩ) 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 (30 kΩ) acts as the input resistor (R_{IN}) in the standard non-inverting op amp circuit. (Its value can only be reduced.)

$$V_{OUT\ DC} = (1 + (R_3/R_4))\ V_{REF} \quad \text{(for the Expandor)}$$

$$V_{OUT\ DC} = (1 + (2R_{DC}/R_4))\ V_{REF} \quad \text{(for the Compandor, ALC)}$$

[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).]

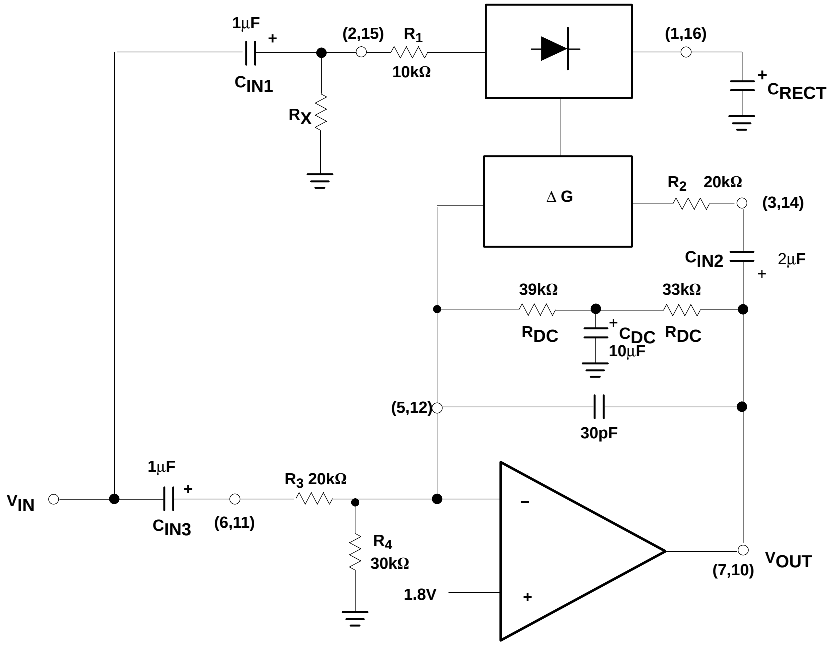

Figure 10. Automatic Level Control (NE570/SA571 pinout)

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

C_{IN}, 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: 10 k$\Omega \times C_{RECT}$.

The total harmonic distortion (THD) is approximated by:

$$THD \cong (1.0\ \mu F/C_{RECT})\ (1.0\ kHz/freq.) \times 0.2\%$$

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 +16 dB and minimum amplitude of −80 dB.

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

Point C represents the input signal to the expandor.

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

NOTES:

The SA572 differs from the 570/571 in that:
1. There is no internal op amp.
2. The attack and release times are programmed separately.

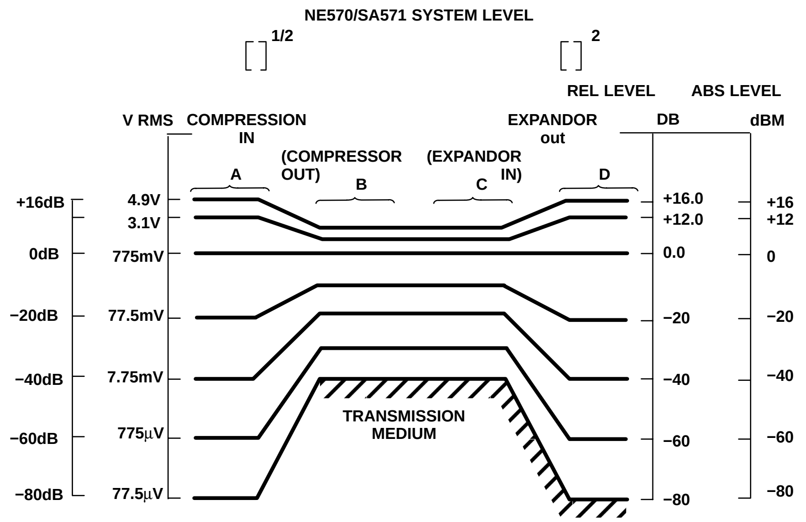

Figure 11. System Levels of a Complete Companding System

Application Board

Shown below is the schematic (Figure 12) for NE570/SA571 evaluation/demo board. This board provides one channel of Expansion and one channel of Compression (which can be switched to Automatic Level Control).

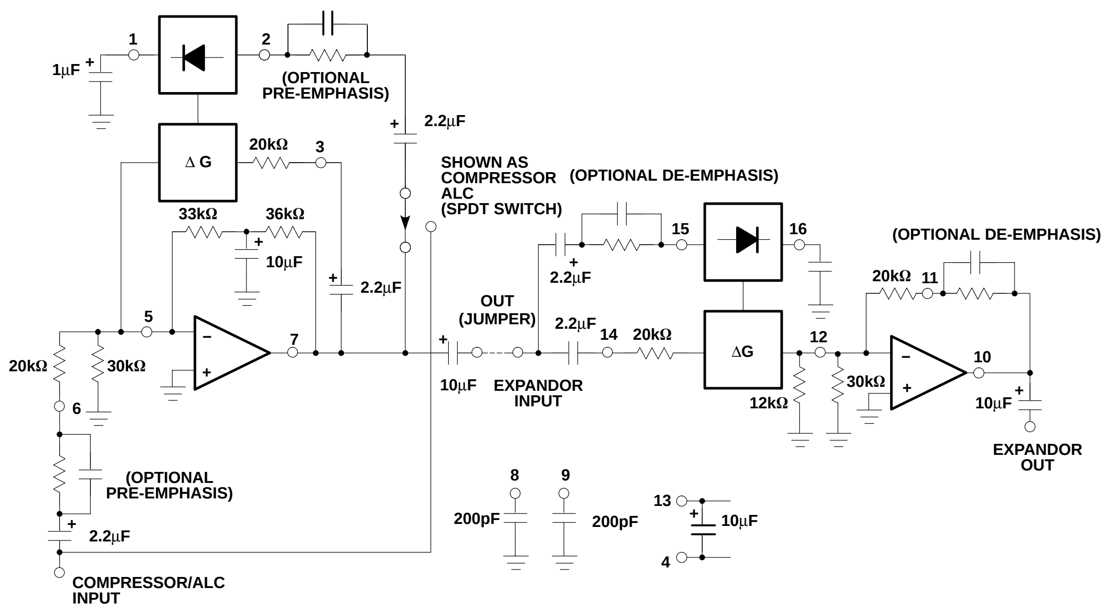

Figure 12.

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