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APPLICATION BULLETIN
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FEEDBACK CIRCUIT CLAMPS PRECISELY

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A limiter circuit consisting of an input buffer (A_1), an output-scaling amplifier (A_2), two zener diodes (Z_1 and Z_2), and several other components can supply sharp, precise, bipolar clamp levels with continuous variable control, from 0 to ±11V. See Figure 1. A feedback loop enclosing the amplifiers and zeners generates the high clamping accuracy.

Within the limit range of the clamp ($\pm V_L$), the zener diodes are off, and A_2 feeds back its output to the inverting input of A_1 through R_4. At the same time A_1 drives A_2 through the voltage divider R_V. The feedback forces the inverting input of op amp A_1 to equal E_I at the noninverting input terminal.

The circuit forces the inverting input of A_2 also to follow E_I. There's no signal voltage drop across R_4, because no current can flow from it into A_2's inverting input. Consequently, the noninverting input of A_2, which defines the potentiometer output at feedback equilibrium, must also track E_I. A resistor voltage divider can replace the control potentiometer R_V in fixed-level limiting applications.

Amplifier A_2 then delivers an output:

$$E_O = (1 + R_3/R_2)\ E_I$$

when

$$-V_L < E_O < V_L$$

and

$$V_L = x\ [(1 + R_3/R_2)]\ (V_Z + V_F)$$

where x is the setting fraction of R_V, and V_Z and V_F are the zener and forward voltages, respectively. The overall circuit response, then, is simply that of a voltage amplifier when the output signal is within the limit boundaries.

Amplifier A_1 generates small deviations from an ideal response because A_2's circuit gain $(1 + R_3/R_2)$ amplifies any offset voltage and noise from A_1. Similarly, this loop gain mitigates the clamping error by sharpening its clamping response. The zener drive increases during the transition to the clamping state.

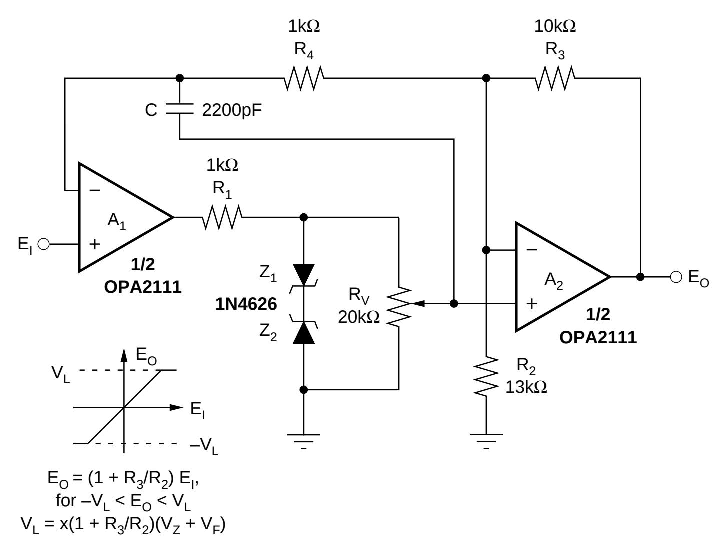

FIGURE 1. Amplifier A_1 Buffers and Amplifier A_2 Scales Input Signals Under Feedback Control. Zener diodes and a potentiometer or voltage divider in the feedback loop supply a continuously variable bipolar-clamping limit.

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In the clamping mode, when the voltage across the two zeners reaches $\pm(V_Z + V_F)$, the circuit goes from acting as a voltage amplifier to acting as a voltage reference; the voltage across R_V is fixed and the potentiometer output is $\pm x(V_Z + V_F)$. Further increase in the magnitude of the signal at E_I can't change this potentiometer value until it drops below the limit point V_L.

Thus, clamping is no longer limited to the fixed levels of available zener voltages. Even clamping levels as low as 5mV become practical when offset-trimmable OPA111 op amps replace the OPA2111. However, available zener voltages and the closed-loop gain of A_2 set the maximum clamping level.

Use of 10 –V zeners and a gain of one for A_2 can cover the voltage range of most analog-signal processing. Unfortunately, the voltage temperature coefficients of 10 –V zeners would produce thermal drift in the clamping level. With 5.6 –V zeners, however, the temperature coefficients of the zener and forward voltages tend to cancel. For such zener diodes $V_Z + V_F = 6.2V$, and the net drift is near zero. Then, with A_2 set to a gain of 1.77, the maximum limit voltage V_L is 11V.

The 5% tolerances of the zener voltages determine the basic accuracy of the clamp levels. The gain-setting resistors R_2 and R_3 impose additional tolerance error. However, adjusting the gain with these resistors can compensate for any zener-voltage error and resistor tolerances. With matched zeners, the adjustment can readily reduce the clamp-level errors to less than 1%. Without matching, the 5% error of simple zener clamping prevails, but the circuit still clamps sharply.

For frequency stability, resistor R_4 and capacitor C supply a frequency roll-off in A_1. At high frequencies, the capacitor shorts the output of A_1 to its inverting input. Then A_1 and A_2 operate with independent feedback loops, and the overall circuit requires stability in the individual amplifiers.

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