Continuing biasing improves clamping amplifier

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A clamping amplifier can be made faster and more accurate by biasing its zener clamping element so that it is always on. This biasing technique also results in reduced clamp capacitance, sharper turn-on, broader bandwidth, and lower thermal drift.

Clamping amplifiers or feedback limiters are frequently used to provide amplitude limiting for signal clipping, signal squaring, or overload protection. One of the simplest clamping elements for these applications is a zener diode.

A zener diode connected across the feedback resistor of an operational amplifier will conduct when the op-amp output level reaches the zener voltage. The zener overrides the feedback resistor and limits the op-amp output swing at the zener voltage. To obtain bipolar amplitude limiting, two zener diodes are generally connected, in series-opposing fashion, across the feedback resistor, as shown in (a).

Zener diodes used in this way, however, impose serious limitations on the clamp because of their large capacitance, insufficiently sharp turn-on characteristic, high leakage current, and undesirable thermal drift.

Zener parasitic capacitance, which is typically a comparatively high 700 picofarads, can result in a long turn-on time for the clamp, as well as restricted signal bandwidth. For the zener to turn on, its capacitance must be charged through resistor R_1, which is often a large value, to preserve the circuit's input resistance. Signal bandwidth is limited because resistor R_2 is capacitively shunted by the zener.

When the zener conducts, it goes from a high-resistance state to a low one. But since this transition is not abrupt, sharp limiting cannot be achieved, and the clamping is rounded. Even in its high-resistance state, the zener, through its leakage current, introduces error into the amplifier's summing junction. Furthermore, when the zener is on, the clamp level it sets is subject to thermal drift since the zener will probably not be held at its zero-temperature-coefficient current.

All of these limitations can be overcome to a significant extent with the biased zener clamp of (b). Here, the zener is continuously biased on so that it does not limit the op-amp output swing until the diode bridge places the zener in the feedback path.

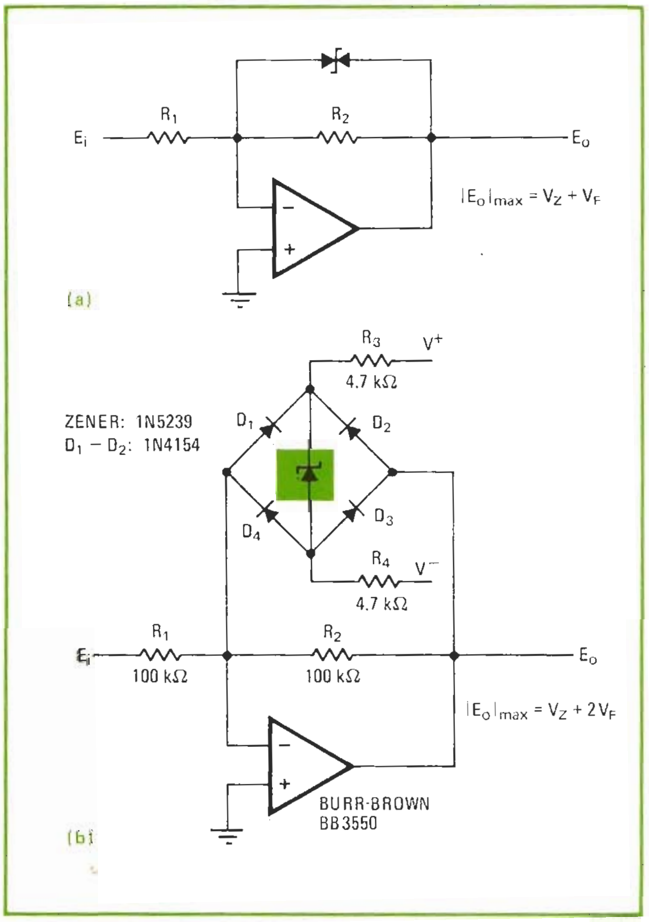
Clamping occurs when the voltage across resistor R_2 can support the zener voltage as well as forward-bias two of the bridge diodes. Positive-polarity signals are clamped when diodes D_1 and D_3 conduct, connecting the zener across the feedback path. When diodes D_2 and D_4 conduct, the zener limits signals of the opposite polarity. Since the same zener is used for both signal polarities, the output clamping will be symmetrical.

The continuous zener bias dramatically reduces the clamp's shunt capacitance, sharpens the clamping response, and often means lower thermal drift. To reduce thermal drift, resistor R_3 is chosen to produce a zener thermal variation that is canceled by that of two bridge diodes. When the clamp is on, the zener current is approximately:

$$I_Z = (V^+ + V_F)/R_3 \text{ or } (-V^- + V_F)/R_3$$

where V_F is the forward voltage of a junction diode, and V^+ and V^- are the supply voltages. (This equation neglects the signal current from resistor R_1, which is generally small compared to the zener current.)

Sharper clamping is achieved by avoiding the zener turn-on characteristic and leakage current. The clamping circuit is now turned on by the bridge diodes, and the sharper turn-on of these junction diodes improves



Whetting sharpness of zener clamp. Standard zener-type clamping amplifier (a) can be slow and sloppy because of large zener capacitance and zener leakage. But a dramatically faster and crisper response can be obtained by adding a bridge of junction diodes to keep the zener always biased on, no matter the input signal polarity. The improved clamp (b) also provides more bandwidth and less drift.

clamping sharpness by around 8:1. Zener leakage current no longer reduces signal current as the clamping level is approached. Leakage to the amplifier summing junction is now the much smaller leakage of junction diodes D_1 and D_4.

Additionally, the capacitance of the clamping circuit is reduced by avoiding the charging and discharging of the zener capacitance. Only small voltage changes, the ones produced by signal current flow in the continuously biased zener, occur across the zener capacitance. Large voltage changes are restricted to the junction diodes, which have a far lower capacitance than the zener. The equivalent clamp capacitance that must now be charged through resistor R_1 is merely the combined capacitances of diodes D_1 and D_4. Typically, this represents a 100:1 reduction from the basic zener clamp capacitance so that turn-on time is faster.

And lastly, the bandwidth-limiting capacitive shunt on resistor R_2 is reduced by more than 100:1. Amplifier signals that do not turn the clamp on are not even affected by the small bridge-diode capacitance. When the bridge diodes are off, fixed voltages are established at one end of diodes D_1 and D_4 by the zener and its bias resistors. The only signal swing on these two input shunting diodes, then, is the very small summing junction signal. The equivalent capacitive shunt of resistor R_2 is reduced to $2C_F/A$, where C_F is the forward capacitance of a junction diode, and A is the open-loop gain of the op amp. (This capacitance is negligible compared to other parasitic capacitances.)

For the components shown in the figure, large- and small-signal bandwidths are boosted from 3 kilohertz to 400 kHz; clamping sharpness error is reduced from 0.8 volt to 0.1 V; clamp leakage current is decreased from 400 nanoamperes to 7 nA; and clamp-level thermal drift is brought down from 7 mV/°C to 0.6 mV/°C. □

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