

## To Chop or Auto-Zero: That Is the Question

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### IDEA IN BRIEF

Choppers are a good choice for low power, low frequency applications (<100 Hz), whereas auto-zero amplifiers are better for wideband applications. A combination of auto-zero and chopping techniques is ideal for applications that require low noise, no switching glitch, and wide bandwidth.

### ZERO-DRIFT AMPLIFIERS

Zero-drift amplifiers dynamically correct their offset voltage and reshape their noise density. Two commonly used types—auto-zero amplifiers and choppers—achieve nanovolt-level offsets and extremely low offset drifts due to time and temperature. The amplifier’s  $1/f$  noise is also seen as a dc error; therefore, it is removed as well. Zero-drift amplifiers provide many benefits to designers because temperature drift and  $1/f$  noise, always nuisances in the system, are otherwise very difficult to eliminate. In addition, zero-drift amplifiers have higher open-loop gain, power-supply rejection, and common-mode rejection as compared to standard amplifiers; and their overall output error is less than that obtained by a standard precision amplifier in the same configuration.

### APPLICATIONS FOR ZERO-DRIFT AMPLIFIERS

Zero-drift amplifiers are used in systems with an expected design life of greater than ten years and in signal chains

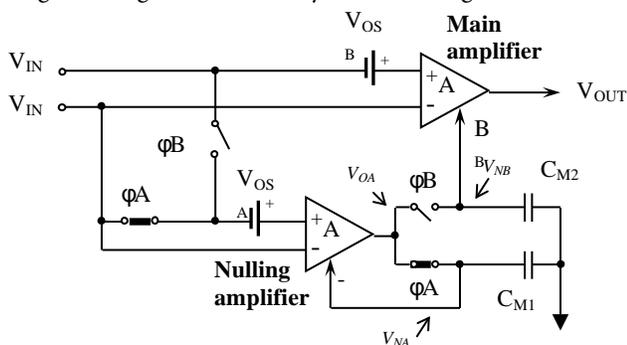


Figure 1. Phase A of Auto-Zero Amplifier: Nulling Phase

that use high closed-loop gains (>100) with low frequency (<100 Hz), low amplitude level signals. Examples can be found in precision weigh scales, medical instrumentation, precision metrology equipment, and infrared-, bridge-, and thermopile-sensor interfaces.

### AUTO-ZERO TECHNIQUE

Auto-zero amplifiers usually correct for input offset in two clock phases. During Clock Phase A, switches labeled  $\phi_A$  are closed, while switches labeled  $\phi_B$  are open, as shown in the diagram of the AD8571 in Figure 1. The offset voltage of the nulling amplifier is measured and stored on Capacitor  $C_{M1}$ .

During Clock Phase B, switches labeled  $\phi_B$  are closed, while switches labeled  $\phi_A$  are open, as shown in the AD8571 diagram in Figure 2. The offset voltage of the main amplifier is measured and stored on Capacitor  $C_{M2}$ , while the stored voltage on Capacitor  $C_{M1}$  adjusts for the offset of the nulling amplifier. The overall offset is then applied to the main amplifier while processing the input signal.

The sample-and-hold function turns auto-zero amplifiers into sampled-data systems, making them prone to aliasing and fold-back effects. At low frequencies, noise changes slowly; therefore, the subtraction of two consecutive noise samples results in true cancellation. At higher frequencies this correlation diminishes, with subtraction errors causing wideband components to fold back into the baseband. Thus, auto-zero amplifiers have more in-band noise than standard op amps. To reduce low frequency noise, the sampling frequency must be increased, but this introduces additional charge injection. The signal path includes only the main amplifier; therefore, relatively large unity-gain bandwidth can be obtained.

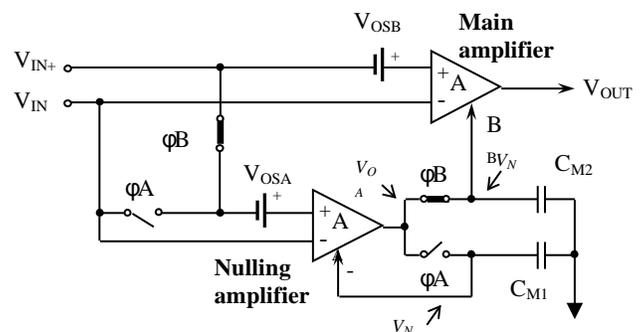


Figure 2. Phase B of Auto-Zero Amplifier: Auto-Zero Phase

**CHOPPING TECHNIQUE**

Figure 3 shows the block diagram design of a chopper amplifier, the ADA4051, that uses a local autocorrection feedback (ACFB) loop. The main signal path includes an input chopping network (CHOP1), transconductance amplifier (Gm1), output chopping network (CHOP2), and transconductance amplifier (Gm2). CHOP1 and CHOP2 modulate the initial offset and 1/f noise from Gm1 up to the chopping frequency. The transconductance amplifier, Gm3, senses the modulated ripple at the output of CHOP2. The

chopping network, CHOP3, demodulates the ripple back to dc. All three chopping networks switch at 40 kHz. Finally, the transconductance amplifier, Gm4, nulls the dc component at the output of Gm1—which would otherwise appear as ripple in the overall output. The switched capacitor notch filter (SCNF) selectively suppresses the undesired offset-related ripple without disturbing the desired input signal from the overall output. It is synchronized with the chopping clock to perfectly filter out the modulated components.

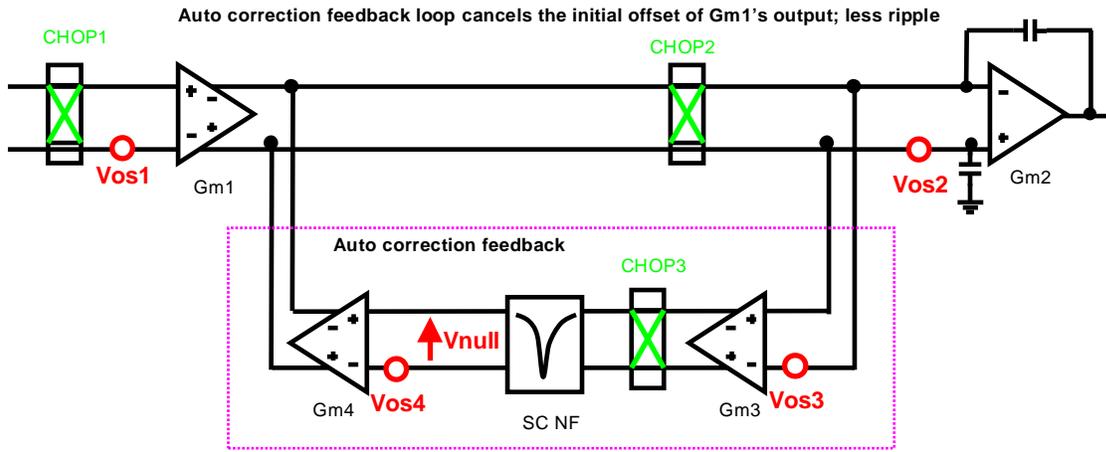


Figure 3. Chopping Scheme

**COMBINING THE TWO TECHNIQUES**

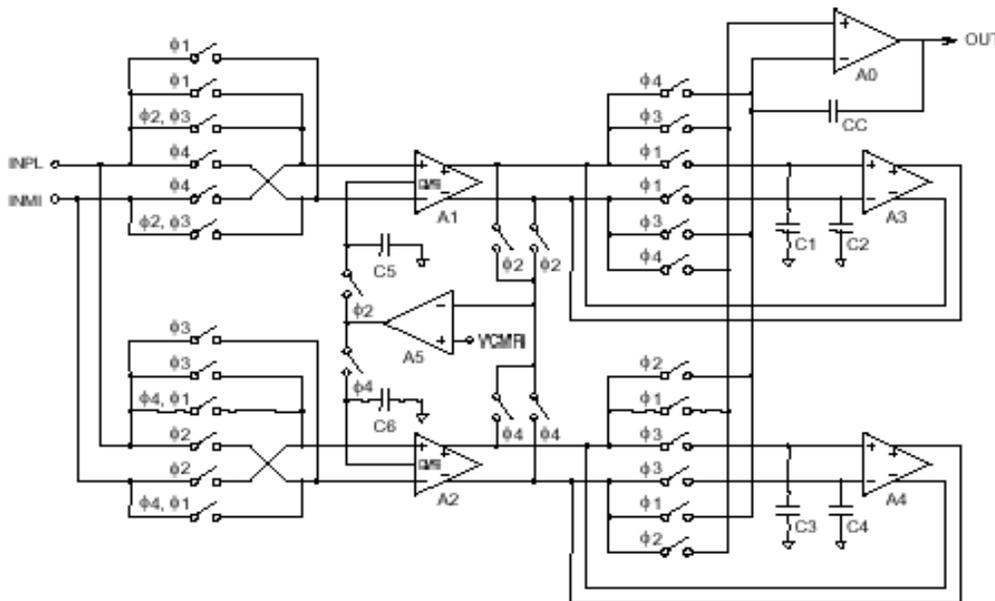


Figure 4. Combining Auto-Zero with Chopping to Achieve Wider Bandwidth

The zero-drift amplifier, such as the AD8628 shown in Figure 4, uses both auto-zeroing and chopping to reduce the energy at the chopping frequency, while keeping the noise very low at lower frequencies. This combined technique allows wider bandwidth than is possible with conventional zero-drift amplifiers.

**DIFFERENCES BETWEEN AUTO-ZEROING AND CHOPPING**

Auto-zeroing uses sampling to correct offset, whereas chopping uses modulation and demodulation. Sampling

causes noise to fold back into the baseband; therefore, auto-zero amplifiers have more in-band noise. To suppress noise, more current is used; therefore, the devices typically dissipate more power. Choppers have low frequency noise consistent with their flat-band noise but produce a large amount of energy at the chopping frequency and its harmonics. Output filtering may be required; therefore, these amplifiers are most suitable in low frequency applications. The typical noise characteristics of auto-zero and chopping techniques are shown in Figure 5.

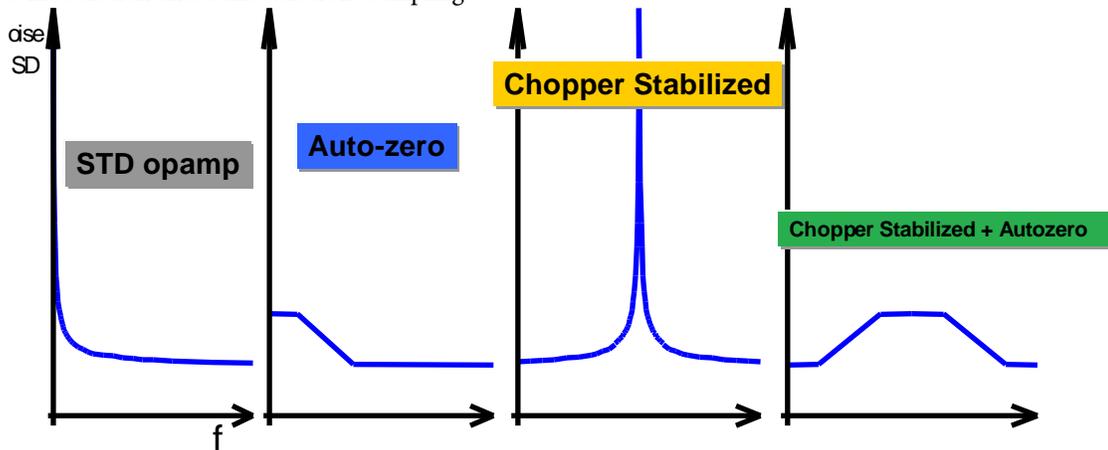


Figure 5. Typical Noise of Various Amplifier Topologies vs. Frequency

**APPLICATION SUGGESTION**

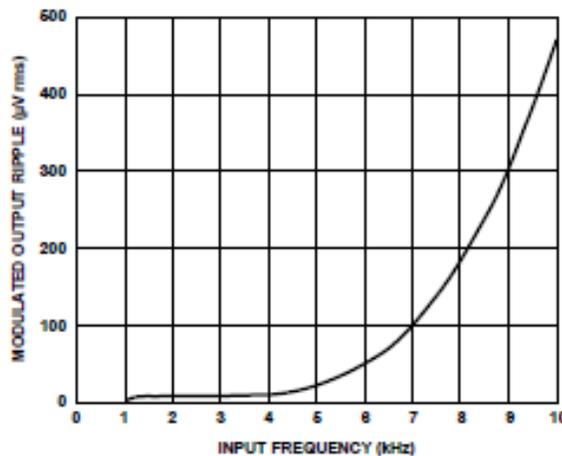
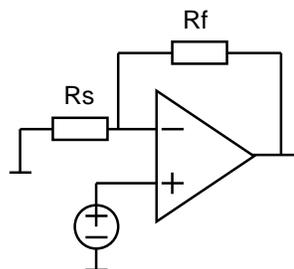


Figure 6. Output Ripple Caused by Charge Injection as a Function of Input Frequency

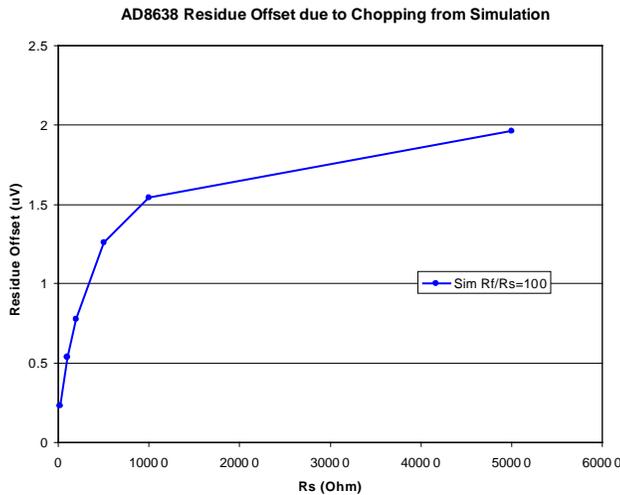


Figure 7. Offset Voltage vs. Source Resistance for the AD8638 Auto-Zero Amplifier

Zero-drift amplifiers are composite amplifiers that use digital circuitry to dynamically correct for analog offset errors. The design techniques discussed so far tremendously improve a number of op amp parameters, including offset voltage, offset drift with time and temperature, and the shape of the noise curve—at the expense of a few others. This tradeoff, common in amplifier design, is one reason that no ideal amplifier exists. When using zero-drift amplifiers, application issues that must be considered include charge injection, clock feedthrough, intermodulation distortion, and overload recovery time. Charge injection, due to the switching action of choppers and auto-zero amplifiers, appears at the amplifier inputs. For example, if a zero-drift amplifier is configured in a noninverting configuration as shown in Figure 6, small ripples appear on the output due to input switching action.

The magnitude of the charge injection is independent of temperature but increases as the gain of the circuit is increased, the source resistance is increased, or the gain setting resistor is increased. Figure 7 shows the error voltage due to charge injection vs. source resistance.

Application level solutions can easily reduce the contribution of this error. Some suggested ways to reduce the effects of charge injection include

1. Add a capacitor in the feedback to limit the signal bandwidth.
2. Use lower source and feedback resistors.
3. Build an active or passive filter after the amplification stage.

4. Add a resistor equal to the parallel combination of  $R_f$  and  $R_s$  to the noninverting input to help cancel the  $I_B$  effect.
5. Use a device, such as the [ADA4051](#), that has ACFB.

Clock feedthrough may occur if the amplifier is not designed well or if it uses a pure chopping technique. Figure 8 shows the artifacts of the internal clock over the frequency spectrum.

Signals with frequencies greater than the auto-zero frequency can be amplified. The speed of an auto-zeroed amplifier depends on the gain-bandwidth product, which is dependent on the main amplifier, not the nulling amplifier; the auto-zero frequency gives an indication of when switching artifacts will start to occur. As the input approaches the chopping or auto-zero frequency, intermodulation distortion (IMD) is introduced as shown in Figure 9, with larger errors occurring as the input frequency gets closer to the clock frequency. IMD between the high-frequency input signal and the chopping frequency creates tones at frequencies  $f_{\text{CHOP}} - f_{\text{IN}}$  and  $f_{\text{CHOP}} + f_{\text{IN}}$ . By applying clever design techniques and a combination of chopping and auto-zeroing schemes, the intermodulation distortion of the [AD8628](#) is reduced by 12 dB as compared to the [AD8551](#) family.

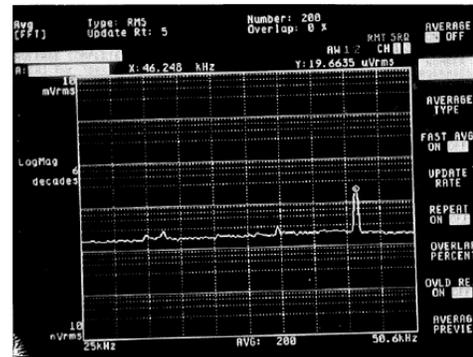


Figure 8. Clock Artifacts vs. Frequency

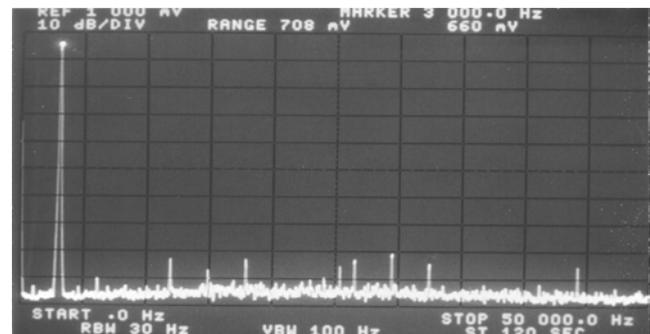


Figure 9. Intermodulation Distortion

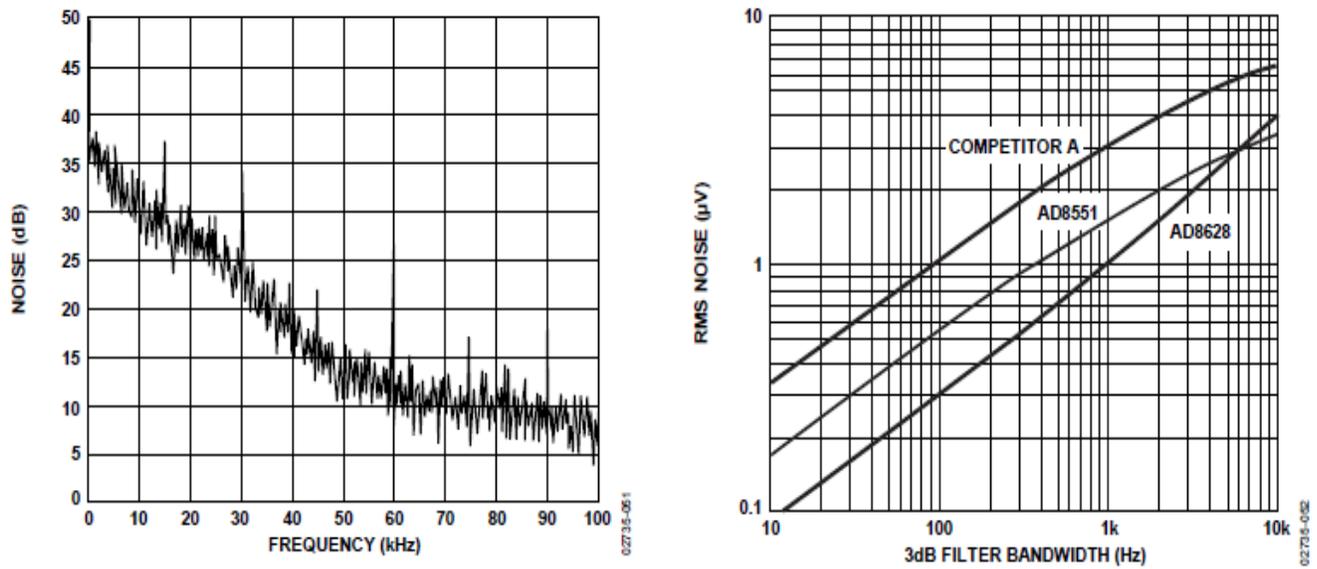


Figure 10. Noise vs. Frequency Improvement by Adding a Filter

One way to improve IMD is to use a pseudorandom auto-zero frequency. The [AD8571](#) family, for example, uses a clock that varies between 2 kHz and 4 kHz. Another possibility is to add filters around the amplifier, as shown in Figure 10, where the clock noise is shown before and after filtering. Selecting the right cutoff frequency can improve the response of the circuit. The overload recovery time of zero-drift amplifiers is typically longer than that of standard CMOS amplifiers.

If the inputs of an auto-zero amplifier are separated by a large amount for any reason, the output saturates. The nulling amplifier treats this as an offset, and tries to null the error. This sends the main amplifier further into saturation and prolongs the recovery time. Amplifiers such as the [AD8628](#) have built-in intelligence that recognizes overload, allowing it to recover in as little as 30 µs. Devices without this technology can take as long as 40 ms to recover from an overload condition.

### SELECTING A ZERO-DRIFT AMPLIFIER

All zero-drift amplifiers offer

1. Low offset voltage (<10 µV max) over the entire  $V_{CM}$
2. Super low offset voltage drift (<40 nV/°C) over time and temperature
3. Reshaped noise that eliminates 1/f noise
4. Very high open-loop gain, CMRR, and PSRR
5. High input impedance
6. Extreme temperature operation (up to 200°C)
7. No need for external trimming

Choppers are a good choice for low power, low frequency applications (<100 Hz), whereas auto-zero amplifiers are better for wideband applications. For instance, the [AD8628](#), which combines auto-zero and chopping techniques, is ideal for applications that require low noise, no switching glitch, and wide bandwidth. Table 1 shows some of the design tradeoffs.

Table 1.

Auto-Zero	Chopper Stabilized	Chopper Stabilized and Auto-Zero
Very low offset, $TC_{VOS}$	Very low offset, $TC_{VOS}$	Very low offset, $TC_{VOS}$
Sample/hold	Mod/demod	Sample/hold plus mod/demod
Higher low frequency noise due to aliasing	Similar noise to flat band (no aliasing)	Combined noise shaped over frequency
Higher power consumption	Lower power consumption	Higher power consumption
Wide bandwidth	Narrow bandwidth	Widest bandwidth
Lowest ripple	Higher ripple	Lower ripple level than chopping
Little energy at auto-zero frequency	Lots of energy at chopping frequency	Little energy at auto-zero frequency

## CONCLUSION

Many of the old myths about choppers have been overcome by clever techniques in new product offerings, and zero-drift amplifiers now take op amps closer to the so-called ideal amplifier. System engineers can take advantage of the benefits that these products provide to build super precision systems.

## REFERENCES

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