ANALOG DEVICES

AN-25 APPLICATION NOTE

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Applying the OP-06 Op Amp As a High Precision Comparator

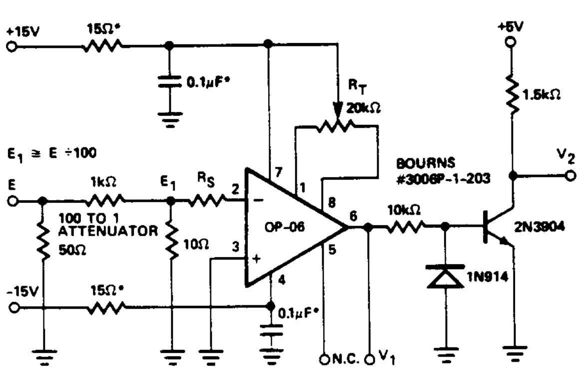
INTRODUCTION

The Analog Devices OP-06 op amp makes an excellent comparator. In fact, for submillivolt signals, there is simply no comparator that performs as well. Using an external nulling potentiometer, the offset drift is typically 0.6μV/°C. With its high open loop gain to 1 million, only 30μV is required at the input to drive the output from one saturation level to the other. A 50°C change in temperature produces a 30μV change in V_{OS}; thus a *total* error band of 100μV *including temperature effects* is quite conservative. This performance is an order of magnitude better than other comparators. 100μV sensitivity is nice to have in 12-bit A/A converters, but it is essential in 14-bit converters. Where preamplifiers are typically needed with thermocouples and strain guages, the OP-06's sensitivity allows *direct* comparison of these low-level outputs. As a result system costs decrease, and reliability increases.

LOW-LEVEL PERFORMANCE MEASUREMENTS

The low-level capabilities of the OP06 comparator are graphically illustrated in Figures 1 and 2 using the test circuit below. Comparator voltage input, applied through a 100 to 1 attenuator, is $100\mu V_{p-p}$ in Figure 1 and $40\mu V_{p-p}$ in Figure 2. Note that the op amp output still reaches both positive and negative saturation.

TEST CIRCUIT



*DECOUPLING COMPONENTS NECESSARY TO PREVENT SPURIOUS OSCILLATION

PROCEDURE:
1. REDUCE E TO ZERO VOLTS
2. ADJUST R_T TO BRING V_1 INTO LINEAR RANGE (USE SCOPE)
3. APPLY E THAT IS SYMMETRICAL ABOUT GROUND, IE +E / -E
4. MEASURE V_1 AND V_2 WITH SCOPE

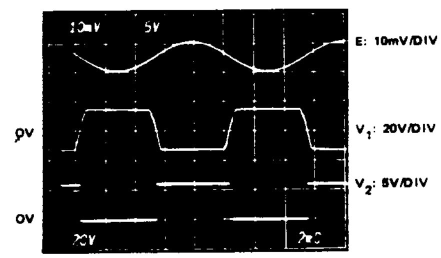


Figure 1. $100\mu V_{p-p}$ Sine Wave Response (R_S: 100Ω)

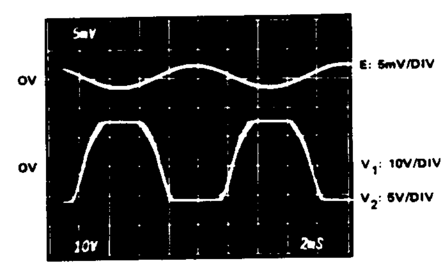


Figure 2. $40\mu V_{p-p}$ Sine Wave Response (R_S: 100Ω)

COMPARATOR RESPONSE TIME

While most comparators are specified for 2mV to 5mV overdrive, the OP06 operates very reliably with only 0.5mV overdrive. Figures 3 and 4 show the response times for both positive going and negative going inputs with 500μV and 5mV overdrives as measured at the logic output.

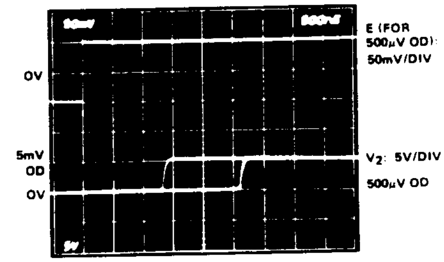


Figure 3. Positive Going Response Time (5mV and 500μV Overdrives)

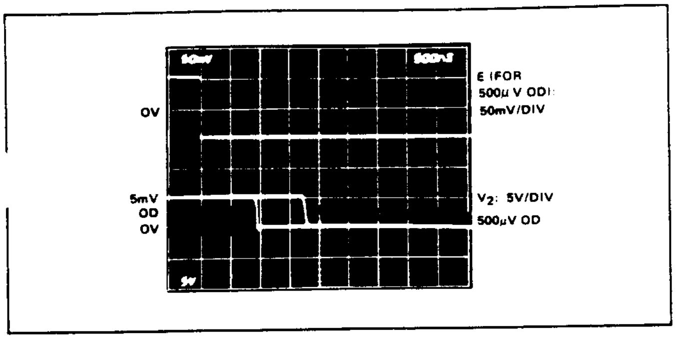


Figure 4. Negative Going Response Time (5mV and 500μV Overdrives)

OP AMP RESPONSE TIME

Primarily, the very high open loop gain (A_{VO}) of the OP06 — over one million — is responsible for its success as a comparator. The DC gain, as specified on op amp data sheets, is important for comparison sensitivity (V_{DET}). However, it is the shape of the gain curve with frequency that dictates how fast the op amp will switch as it passes through its linear region. When operated as a comparator the OP06 spends most of its time in either positive or negative saturation (see Figures 5 and 6). Saturation effects are discussed later; but for now notice the difference in slew rates for the overdrive levels.

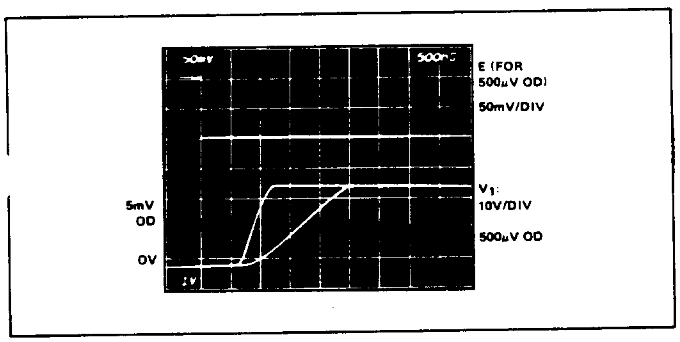


Figure 5. Positive Going Op Amp Response Time vs Overdrive

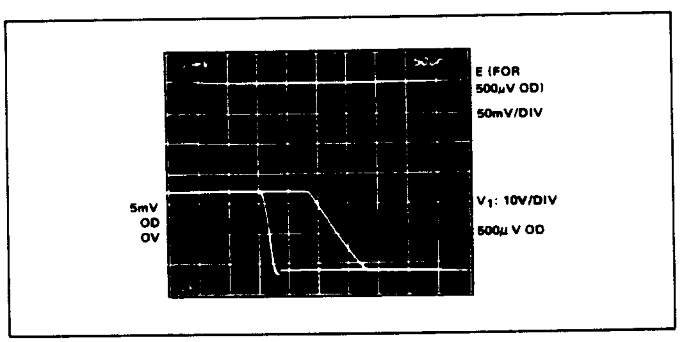


Figure 6. Negative Going Op Amp Response Time vs Overdrive

OP06 DYNAMIC PERFORMANCE CHARACTERISTICS

There is another factor which has a significant effect on slew rates — the way in which the AC gain is rolled off versus frequency. If we refer to Figure 7 we see gain compensation curves for closed loop gains from 1 to 10,000. Figure 8 relates the slew rate to these frequency response curves. These curves point out one of the tradeoffs between good op amp performance and good comparator performance. For example, if an OP06 has a gain compensation for $A_V = 10$, then its slew rate would be 0.08V/μs. This would result in a rise time (20 volt swing) of 250μs. The fact that a designer needs no compensation with the OP06 — when operated as a comparator — allows the rise times observed in Figures 5 and 6.

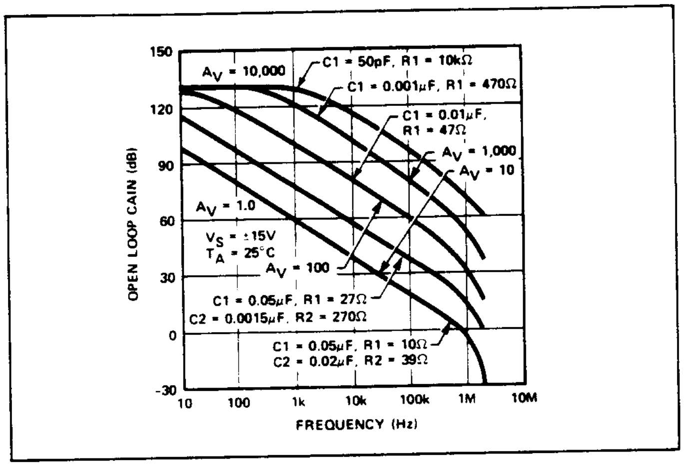


Figure 7. Open Loop Response for Values of Compensation

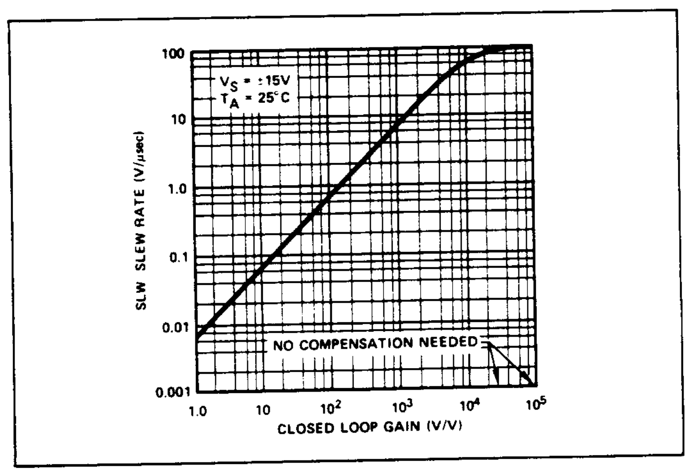


Figure 8. Slew Rate Using Recommended Compensation Networks

COMPARATOR, OP AMP SIMILARITIES

In an op amp, the offset voltage is that voltage which must be applied to the input to drive the output to zero volts. In a comparator this definition is modified to a *specified voltage range* at the output. In ths way the required voltage "window" includes the normal offset voltage of op amps and the signal voltage needed to move the output by some ΔV. Since most op amps operate in ±15 volt systems, an output voltage range of ±15 volts (or a ΔV of 30 volts) has been chosen. Using this range assures saturation at both the positive and negative extremes (−14 volts and +12 volts for the OP06). Low offset voltage and high gain combine to produce the comparator "detector window."

OTHER FACTORS AFFECTING SPEED

To gain further insight into the relation between overdrive and the various switching times, the graph in Figure 9 was generated from measurements on the OP06 "comparator." To further characterize the OP06 performance, delay times were measured versus source resistance (R_S) with a fixed 5mV overdrive. This curve is shown in Figure 10. Since the rise and fall times were essentially constant with R_S variations, they were not plotted. The delay times are the main contributors to total comparator response time. Since the OP06 was not designed as a comparator, individual gain stages will go into saturation when the output voltage is driven to one of its limits. One of the differences between designing op amps and comparators is the addition of clamp diodes to prevent the above mentioned saturation.

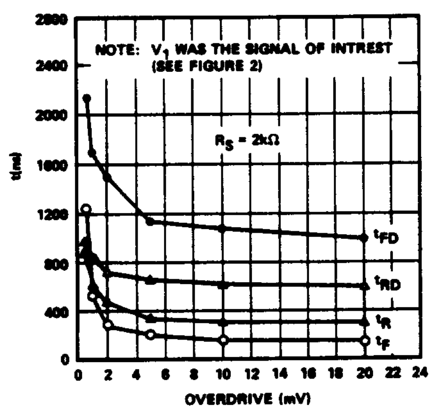


Figure 9. Rise, Fall and Delay Times vs Overdrive Signal

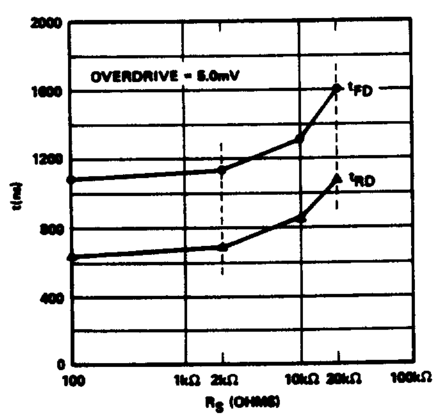


Figure 10. Delay Times vs Source Resistance (R_S)

NOISE AND POWER SUPPLY REJECTION

When dealing with sub-millivolt signals, noise referred to the comparator input becomes an important factor. Basically, the noise comes from two sources:

1) Normal input noise of an op amp;

2) Noise induced by power supply ripple.

Figure 11 shows the wideband noise-on an RMS basis-vs. system bandwidth. What is more important is the RMS to peak conversion factor. Table I shows the crest factors for gaussian noise. Note in particular that the crest factor is less than four 99.99% of the time, and less than five 99.9999% of the time. Thus the RMS noise is 1μV for 10kHz bandwidth and this yields a "worst case" of 5μV peak or 10μV peak-to-peak.

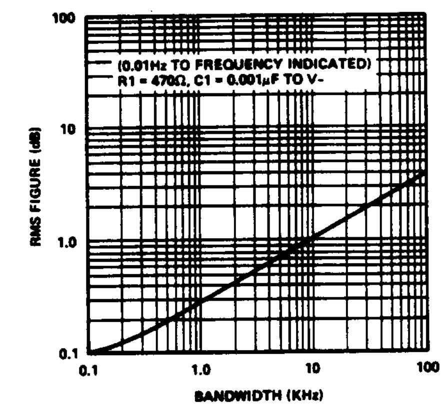


Figure 11. Input Wideband Noise vs Bandwidth

Table 1. Crest Factors for Gaussian Noise (1)

% OF TIME PEAK IS EXCEEDED	PEAK / RMS	PEAK FACTOR IN dB = 20 $\log_{10}$ PEAK/RMS
10.0	1.645	4.32
1.0	2.576	8.22
0.1	3.291	10.35
0.01	3.890	11.80
0.001	4.417	12.90
0.0001	4.892	13.79

The other source of noise comes from the power supplies. Looking at Figure 12 note that the power supply rejection ratio (PSRR) is 115dB (1.8μV/V) out to 300Hz. For example a power supply which had 1 volt (peak-to-peak) ripple would only produce 1.8μV peak-to-peak "noise." Thus it becomes obvious that the total noise performance of the OP06 is indeed outstanding.

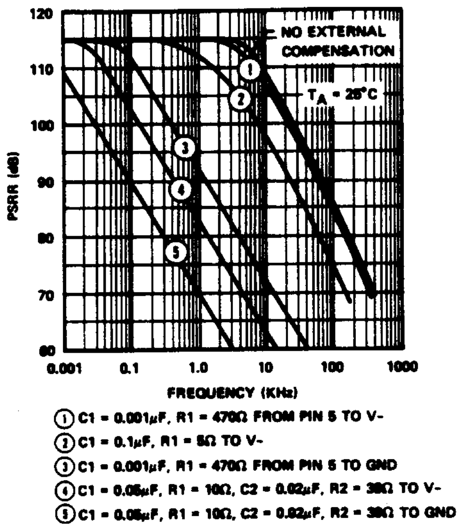


Figure 12. PSRR vs Frequency

CONCLUSION

The combination of ±30V input overvoltage protection, gain of 1 million, low noise, low drift and external compensation allow operation of the OP06 op amp as a low-level comparator. Low-level performance is unsurpassed by any presently available comparator.

BIBLIOGRAPHY

1. Bennett, W. R., "Electrical Noise," McGraw-Hill, New York, 1960, page 44.