Microvolt Comparator

National Semiconductor
Linear Brief 32

INTRODUCTION

Comparison of dc signal levels within microvolts of each other can be made by using an LM121A pre-amp and an LM111 comparator IC. Implementing this with two separate IC's decreases noise, eliminates troublesome thermal effects, and achieves a maximum offset drift of 0.22 μV/°C *(Figure 1).*

Designing a practical comparator with a voltage gain of 10 million involves protecting the *input* stage from temperature changes or gradients, and avoiding problems of including the noise filter within the positive feedback loop. The circuit as shown has a 5 μV hysteresis which can be trimmed to 1 μV under certain conditions. Further, delays *decrease* with increasing overdrive (see chart) due to elimination of input stage thermal effects, saturating stages, and dielectric soak or polarization effects on signal filter capacitors (Table I).

DESIGNING WITH A PRE-AMP

With the bias network shown, the LM121A input stage has an open-loop temperature stable voltage gain of close to 100. The 100k output impedance of the LM121A is shunted by C_S to filter out pickup and internally generated noise. No feedback to the inputs of the pre-amp is employed to avoid degrading common-mode rejection of the system.

The separate pre-amp with a gain of 100 provides two major advantages over single comparator designs. First, V_{OS} and other small errors attributed to the LM111 are reduced by the 100 gain factor. More important, temperature gradient changes which occur within the LM111 when switching any output load, are completely isolated by the separate packages and do not affect the pre-amp. If the entire microvolt comparator were on a single silicon chip, a temperature variation of as little as 1/1000°C across the input stage could have a significant effect.

TABLE 1. Typical Overdrive Delays

Hyst. Set	R_H	R_S	C_S	Delays with Various Overdrives			
				25%	100%	1000%	100 mV
5 μV	75 kΩ	10 kΩ Max.	6800 pF	2 ms	1.8 ms	600 μs	560 μs

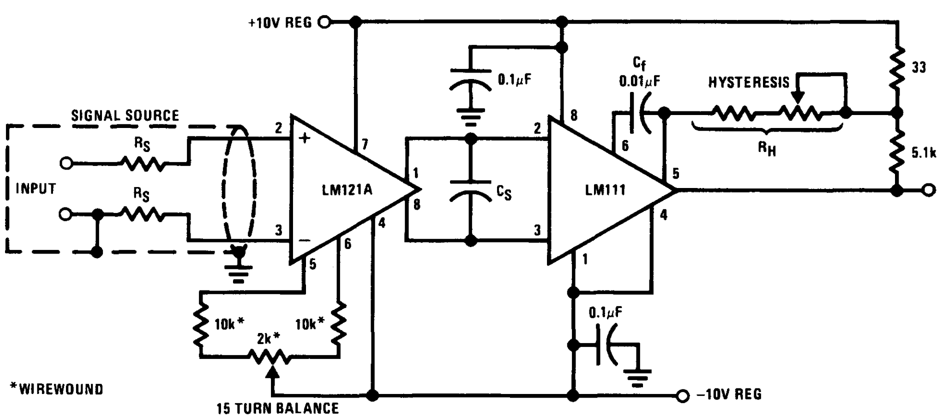

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FIGURE 1. Schematic Diagram

This effect is a major reason for designing circuits sensitive and stable to microvolt dc signals with a *separate* pre-amplifier. Further, the special 4-transistor input stage, when adjusted to zero offset with the "balance" control between pins 5 and 6, automatically reduces V_{OS} change with temperature to almost zero.

FILTERING

The pre-amp/comparator system generates a continuous stream of very fast pulses if assembled without a filter, even with positive feedback for hysteresis. This is caused by both stray output-input feedback, and noise. The noise is both thermal and pickup from the environment, including power switching transients and fluorescent light hash. To cure this, shunt filter capacitor C_S is used.

Placing this capacitor outside the positive feedback loop has two advantages. It eliminates a tendency for the comparator to oscillate during slow transitions. Also, response time to small signals is halved since the positive hysteresis feedback signal is not stored on the filter capacitor.

A higher frequency filter (C_f) is needed to provide a low impedance shunt to any high frequency noise and stray feedback that may be picked up between LM111 terminals 5 and 6. These two terminals have almost the same voltage sensitivity as the normal input terminals. The positive feedback to terminal 5, as described below, is only delayed slightly by this filter.

FEEDBACK

The positive feedback provided by the 5.1k/33Ω voltage divider with R_H is needed to insure clean, rapid changes of state. It is applied to one of the "balance" terminals (pin 5) of the LM111 to simplify the circuit over a balanced feedback network, and to minimize signal stored on C_S as previously described. The current fed back to terminal 5 is single ended with respect to the balance adjust network between these terminals, and hence injects a dc offset of the desired polarity and amplitude for a few microvolts of latching.

PERFORMANCE

A tabulation is shown for one of the many possible combinations of input circuits, filters, etc. For large amplitude signals, C_S can be decreased and hysteresis increased for greater speed. Conversely, to obtain hysteresis as low as 1 μV, trim R_H (to about 300k) use a C_S of 0.01 μF to 0.1 μF and have a low impedance source of signals.

For reduced ambient range and drift specifications, an LM321 can be paired with the LM311 for a cost saving while maintaining the same comparison sensitivity.

DESIGN TIPS FOR MICROVOLT SIGNALS

Even with high performance devices such as the LM121, microvolts of error can occur from thermocouple effects, common-mode signals, "microphonics," or unbalances in the input or nulling circuits. As pointed out in Application Note AN-79, Kovar lead to copper circuit board thermocouple effects can cause a 3.5 μV offset voltage for only 0.1°C difference across the input leads. A compact layout of input connections and shielding from air currents will minimize this problem.

Although the LM121A has excellent common-mode rejection (> 120 dB), a 1V change in common-mode voltage can induce up to 1 μV of error voltage. For this reason common-mode voltage changes should be kept to a minimum. Also, common-mode voltages allow mechanical vibrations in the probe cable to induce "microphonic" noise signals. Short, stiff, low capacitance and symmetrical input shielded wires are recommended.

If it is possible to have a signal source balanced with regard to ground, it will help decrease errors due to bias currents, and noise due to common-mode and microphonic effects. Matched, low temperature coefficient parts should be used in the balance network, and care should be exercised in shielding input circuits and eliminating ground-loops.

APPLICATIONS

The microvolt comparator is particularly well suited to controllers or test equipment having thermocouples or strain gauges as inputs. This includes wind speed indicators, RMS to dc converters, vacuum gauges, gas analysis equipment, conductivity gauges, and hot wire controls. The strain gauges can be used in materials testing, electronic weighing, pressure transducers, and load limiting sensors for cranes, hoists, and rolling mills.

As a temperature controller, ⅛ degree or less on-off differential can be obtained using thermocouple types E, J, T or K. Other microvolt signals used for control may come from Hall effect sensors, Bolometers, slide-wires, and heat-flow thermopiles. A microvolt comparator will be useful in "Go/No-Go" testing of low resistances such as switch and relay contacts, RTDs, coil and fuse resistances, and pressure-sensitive-plastic conductors.