Versatile IC Preamplifier Makes Thermocouple Amplifier with Cold Junction Compensation

National Semiconductor
Linear Brief 24

INTRODUCTION

Accurate electronic temperature measurements are not simple. There exists a large array of temperature sensors; each with its own peculiarities. The major sensors are thermistors, resistance sensors, and thermocouples. (Diodes and transistors have been used but they are not normally sold for this purpose.) Thermistors are highly non-linear, making wide range measurements difficult. Resistance sensors are large, require a bridge, and tend to be relatively costly. Thermocouples are small, relatively linear, inexpensive, but require reference junction temperature compensation.

Thermocouples are made when wires of different metals are joined. A voltage is produced proportional to the temperature *difference* between the junction and the output ends of the wire. This voltage is the Seebeck coefficient and is usually specified in volts (or microvolts) per degree. Depending on the material, it can range from nearly zero to volts—for some semiconductors. Commercially available thermocouples produce an output of between 10 μV/°C and 50 μV/°C.

Since the output voltage of thermocouples is proportional to temperature difference, the ambient temperature or measurement end of the thermocouple must be known. Alternatively, compensation can be applied for temperature changes. This is done either by terminating the thermocouple in a temperature controlled environment or with electrical compensation circuitry. The amplifier shown here provides a direct reading output of 10 mV/°C and automatically compensates for reference junction temperature changes. Further, calibration is relatively simple.

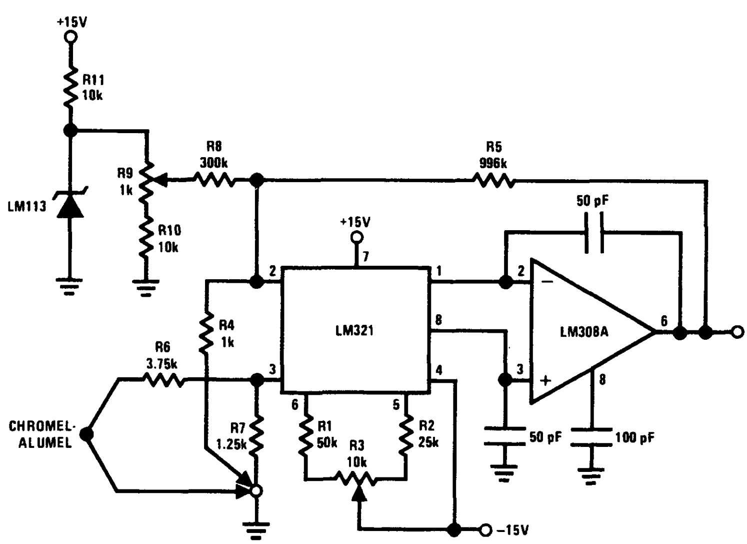
CIRCUIT DESCRIPTION

An LM321 preamp is used in conjunction with an LM308A op amp to form a precision, low-drift, operational amplifier. The LM321 is specifically designed for use with general purpose op amps to obtain drifts of 1 μV/°C. When the offset voltage is nulled, the drift is also nulled. There is a theoretical relationship between the offset voltage and drift when the offset is not nulled to zero. The drift of the amplifier is then used to compensate the thermocouple for ambient temperature variations. Drift given by:

$$\frac{d\,V_{OS}}{dT} = \frac{V_{OS}}{T}$$

where T is in degrees Kelvin.

Resistors R1, R2, and R3 set the operating current of the preamp, and R3 is used to adjust the offset. The offset and drift are amplified by the ratio of the feedback resistors R4 and R5 and appear at the output. R6 and R7 attenuate the thermocouple's output to 10 μV/°C to match the amplifier drift and set the scale factor at 10 mV/°C. The LM113 provides a temperature stable reference for offsetting the output to read directly in degrees centigrade.



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CALIBRATION

Calibration is independent of thermocouple type; however, circuit values are for chromel alumel. R6 and R7 must be changed for different thermocouples. First, the thermocouple is replaced by a short of copper wire and the LM113 is shorted to ground. Then the offset is adjusted so the output reads the ambient temperature at 10 mV/°k—for 25°C this is 2.98V. The short across the LM113 is removed and R9 is adjusted for the correct output in degrees centigrade. Connect the thermocouple, and it's ready to go.

PERFORMANCE

It should be mentioned that for stable performance, good construction techniques are necessary. Resistors R4, R6, and R7 should be wirewound so they contribute a minimum of error due to thermocouple effects from temperature gradients across the circuit. The entire circuit should be enclosed in a box with the end of the thermocouple terminated in the box near the LM321. This will minimize temperature gradients across the circuit and insure close thermal coupling between the LM321 and the reference end of the thermocouple.

Typically, the LM321 will track temperature changes with less then 0.03°C error per degree change. Self-heating of the LM321 will change its temperature by about 2°C; this is calibrated out initially. Reference and resistor drift can be expected to contribute about 0.02°C/°C. Of course, no compensation is made for nonlinearities of the thermocouple output voltage as a function of temperature. Over a wide measurement range with relatively stable ambient temperature, thermocouple error will be the major inaccuracy.