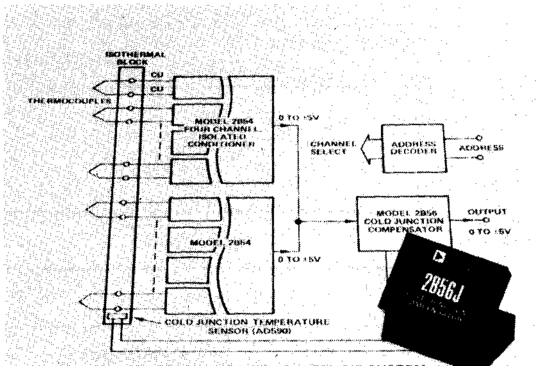
ANALOG DEVICES

High Accuracy, Thermocouple Cold Junction Compensator

MODEL 2B56

FEATURES
Universal Thermocouple Compensation:
Internally Provided: Types J, K, T
User Configurable: Types E, R, S, B
Digitally Programmable Type Select
High Accuracy: ±0.8°C max over +5°C to +45°C
High Ambient Rejection: 50 to 1 min
Low Cost:
Small Size: 1.5" X 2" X 0.4"

APPLICATIONS
Thermocouple Signal Conditioning
Temperature Measurement and Control Systems
Temperature Data Acquisition and Logging
Temperature Controllers



TEMPERATURE MEASUREMENT SYSTEM

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GENERAL DESCRIPTION

Model 2B56 is a high accuracy, universal thermocouple cold junction compensator. Designed to operate with an external temperature sensor in thermal contact with the cold junction, the 2B56 provides an automatic compensation for amplified thermocouple signals over wide ambient temperature variations. The 2B56 is calibrated to compensate the cold junction to a reference temperature of 0°C. The total compensation error is ±0.8°C max over +5°C to +45°C.

Designed to compensate seven different thermocouple types, the 2B56 may be digitally programmed to select compensation for types J, K and T, and one user programmed type (E, R, S, B or none). This feature makes the 2B56 especially suitable for multichannel applications involving several thermocouple types.

COLD JUNCTION COMPENSATION PRINCIPLES

In thermocouple measurements, temperature is determined by measuring the potential difference between the measurement (hot) junction of two dissimilar metals and the reference (cold) junction which is formed when thermocouple leads are connected to a measuring circuit. Since this potential difference is proportional to the temperature difference between the measurement temperature and the temperature at the reference junction, the reference junction temperature must be known. Changes in reference junction temperature influence the output voltage and, therefore, cold junction compensation is required to eliminate measurement errors.

Two methods may be used to reduce errors introduced at the thermocouple connections: keep the reference junction at a known constant temperature, or measure the reference junction temperature and cancel the changes by the appropriate correction to the thermocouple output signal. The first method, accomplished by immersing the reference junction in an ice bath maintained at 0°C is not very practical. The 2B56 employs the second method and has been specifically designed to eliminate the need for ice baths by electronically simulating the desired reference point. Digital programmability, high accuracy and low cost make the 2B56 ideal for single or multichannel thermocouple temperature measurement, indication or control systems.

FUNCTIONAL DESCRIPTION

The 2B56 compensates for cold junction temperature by adding a correction signal at the output of the user's thermocouple amplifier, as shown in Figure 1. The value of the correction signal is determined by the cold junction temperature, as measured by a sensor, and the thermocouple type in use, as specified by two digital TYPE SELECT inputs. Since compensation is done at the output of the thermocouple amplifier it is also necessary to scale the correction signal for the gain of the amplifier. This is done by a scaling circuit which has provision for a user-supplied gain-setting resistor for each thermocouple type in use.

Compensating networks for thermocouple types J, K, and T are built into the 2B56. A fourth compensation (X) can be programmed with two external resistors for any other thermocouple type. The X compensation can also be used without programming resistors to obtain an uncompensated output when sensors other than thermocouples are in use.

SPECIFICATIONS (typical @ +25°C, V_S = ±15V unless otherwise noted)

MODEL	2B56A
COLD JUNCTION COMPENSATION	
Thermocouple Types:	
Internally Compensated	J, K, T
Externally Programmable	B, E, R, S, None
Reference Temperature	0°C
Compensation Accuracy	
Total Output Error @ +25°C[1]	±0.2°C
vs. Ambient Temperature (+5°C to +45°C)[1]	±0.8°C max
Compensation Error	
vs. Sensor Temperature (+5°C to +45°C)[2]	±0.4°C max (±0.15°C typ)
vs. Compensator Module Temperature (0 to +70°C)[3]	±0.02°C/°C max (0.01°C/°C typ)
Cold Junction Temperature Sensing Element	AD590 or 2N2222
INPUT SPECIFICATIONS	
Voltage Signal Range	±10V
Input Impedance	100kΩ
Signal Gain[4]	+1V/V
vs. Temperature	±10ppm/°C
Input Offset Voltage	±1mV max
vs. Temperature	±15μV/°C max
OUTPUT SPECIFICATIONS[5]	
Output Voltage	±10V @ ±5mA
Output Impedance	0.1Ω
DYNAMIC RESPONSE	
Selection Settling Time	0.5ms
Signal Settling Time, to ±0.01%	50μs
DIGITAL INPUTS	
Select Inputs A & B	TTL, CMOS Compatible
POWER SUPPLY	
Analog, Rated Performance	±15V dc ±10% @ ±5mA
Operating	±12V to ±18V dc
Digital, V_{DD}	+5V to +15V dc @ 2mA max
TEMPERATURE RANGE	
Rated Performance	0 to +70°C
Operating	-25°C to +85°C
Storage	-55°C to +125°C
CASE SIZE	1.5" X 2" X 0.4"

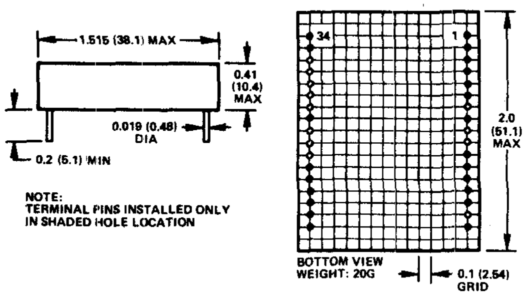
NOTES

[1] Total compensation error composed of errors of temperature sensor and module at the same ambient temperature.
[2] Compensation error contributed by ambient temperature changes at temperature sensor.
[3] Compensation error contributed by ambient temperature changes at the module.
[4] Signal gain of 2 is also available by jumper selection.
[5] Protected for shorts to ground or either supply voltage.

Specifications subject to change without notice.

OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).



PIN DESIGNATIONS

PIN	FUNCTION	PIN	FUNCTION
1	SIGNAL INPUT	18	ANALOG COMMON
2	SENSOR SELECT	19	T TYPE SELECT
3	SENSOR SELECT	20	T TYPE SELECT
4	SENSOR INPUT	21	$+V_{DD}$
5	SENSOR SELECT	22	DIGITAL COMMON
6	SENSOR SELECT	23	$+V_S$
7		24	
8	V_{REF}	25	
9		26	
10		27	$-V_S$
11	"X" COMPENSATION	28	
12	TYPE J } GAIN SELECT	29	
13	TYPE K } GAIN SELECT	30	
14	TYPE T } GAIN SELECT	31	
15	TYPE "X" } GAIN SELECT	32	
16		33	OUTPUT
17	ANALOG COMMON	34	SCALE

MATING SOCKET: AC1217

T Type	Max Gain for Sensor Temp to +45°C	to +70°C
J	1000	650
K, T	1300	820
E	870	550
R, S	9000	5500
B	Any	Any

Table I. Maximum Gain vs. Sensor Temperature and Thermocouple Type

T Type	RX1	RX2
E	412kΩ	1.43kΩ
R, S	412kΩ	121Ω

Table II. Resistor for Compensating Types E, R and S

Type Sel. Logic B	A	Compensation
0	0	J
0	1	K
1	0	T
1	1	X

Table III. Digital Selection of Compensation Type

Sensor Temp (°C)	V_{CAL} (mV) 2N2222	AD590
5	616.5	634.5
10	604.9	645.9
15	593.3	657.3
20	581.6	668.7
25	570.0	680.1
30	558.4	691.5
35	546.8	702.9
40	535.1	714.3
45	523.5	725.7

Values may be interpolated

Table IV. Calibration Voltage vs. Sensor Temperature

A buffer amplifier is provided at the output of the 2B56 to preserve accuracy when driving heavy loads. The gain from V_{IN} to V_{OUT} will be +1 when SCALE is connected to V_{OUT} (see Figure 1). Input and output signal swings of up to ±10V can be accommodated with this connection. When the SCALE pin is left open, the gain from V_{IN} to V_{OUT} is +2. This is useful when interfacing a thermocouple amplifier with a ±5V output swing (such as the 2B54) to an A to D converter with a ±10V input range.

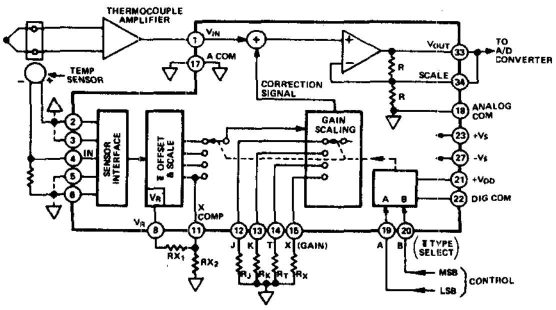


Figure 1. 2B56 Functional Block Diagram

It should be noted that the 2B56 is designed for use with noninverting thermocouple amplifiers. Thus a positive voltage change at the input of the 2B56 must indicate increasing temperature.

OPERATING INSTRUCTIONS

Temperature Sensors: The temperature sensor used with the 2B56 can be either the Analog Devices AD590 temperature transducer or the popular 2N2222 transistor. Either sensor type can be used without loss of accuracy, but each has advantages in different applications. The 2N2222 (the metal can version must be used) is widely available at very low cost. However, an adjustment must be made whenever the sensor is replaced. The AD590 is available in several precalibrated accuracy grades, but at somewhat higher cost.

Connections are shown for both sensor types in Figure 2. Resistor R_{CAL} is the calibration adjustment point. It is used only to adjust for unit-to-unit variations in the sensors. All other adjustments have been made internal to the 2B56.

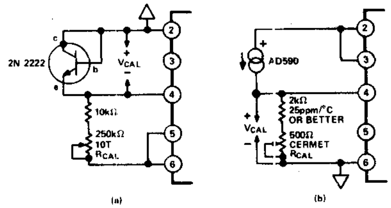


Figure 2. Sensor Connections and Calibration

With either sensor type, proper placement of the sensor is important. Close thermal contact of the sensor and the thermocouple termination point (reference junction) is necessary, particularly when nearby heat sources are present, since these could cause the sensor temperature to differ from the reference junction temperature. In multichannel applications, care should be taken to keep all input terminals at the same temperature to avoid channel-to-channel errors. The sensor may be placed at any distance from the 2B56. When the sensor leads are more than ten feet long, or where strong noise sources are present, shielded cable should be used with the 2N2222 sensor. The AD590 will operate properly with twisted-pair leads at distances up to a few hundred feet.

Gain Selection: Since the 2B56 performs cold junction compensation at the output of the user's thermocouple amplifier, it must take the gain of that amplifier into account. For this purpose, four gain-programming pins are provided: one each for the J, K, and T compensations and one for the X (user-selected) compensation. Thus the user's thermocouple amplifiers can have different gains for each thermocouple type in use, and the 2B56 gain will be selected automatically when the thermocouple type is selected at the digital TYPE SELECT inputs. Gain-programming resistors are connected as shown in Figure 1. The value of each resistor is $R = 10k\Omega/(G-1)$ where G is the gain of the user's thermocouple amplifier from the thermocouple terminals to the input of the 2B56. As an example, if the thermocouple amplifiers in use have a gain of 110 for type J, 90 for type K, and 220 for type T, then $R_J = 91.7\Omega$, $R_K = 112\Omega$, and $R_T = 45.7\Omega$. Gain resistor pins for unused thermocouple types must be grounded. The resistors used to set gain should have a tolerance of 1% or better. A 1% error in setting gain will result in a 0.01°C/°C slope error.

The gain of the thermocouple amplifier will normally be determined by the thermocouple type, temperature measurement range, and A to D converter input range, but there are some practical limits imposed by the 2B56. The minimum allowable gain for proper operation is 40. The maximum gain which can be used is limited by the dynamic range of the compensation circuits in the 2B56, and is a function of thermocouple type and the temperature range (at the sensor) over which compensation is to be effective. Table I lists the maximum gain for each thermocouple type both for the specified +5°C to +45°C sensor temperature range and for a wider (reduced accuracy) 0 to +70°C range.

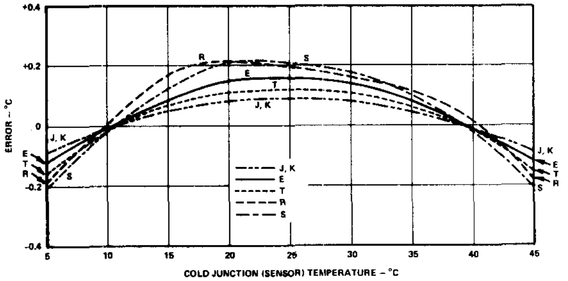


Figure 3. Error Due to Thermocouple Nonlinearity

Compensation of Other Thermocouple Types: Compensation for type J, K, and T thermocouples is built into the 2B56. A fourth compensation can be added by installing two resistors (R_{X1} and R_{X2}) as shown in Figure 1. Table II gives the values needed for proper compensation of type E, R, and S thermocouples. Type B thermocouples are a special case, in that they have almost no output in the +5°C to +45°C range, and therefore, do not need cold junction compensation at all. To accommodate a type B thermocouple, select No Compensation (described in the next section). Errors due to cold junction temperature will be less than ±1°C for any measurement temperature above 260°C. In the measurement range beyond 1000°C (where type B thermocouples are normally used) the error will be less than ±0.3°C.

No Compensation Operation: In some instances it may be desirable to disable the compensation function of the 2B56, so that it functions as a straight-through amplifier with a gain of one (or two, if the output scaling feature is used). This might be done, for example, in a multichannel system with a mixture of thermocouples and strain gage signals or other sources requiring no compensation. It is also necessary when using the type B thermocouple, as described above. The X compensation can be programmed to provide no compensation by grounding pin 11 (X COMP), Figure 1. A 200Ω resistor should be used for R_X (at any gain). Selecting X compensation with this connection will give an uncompensated output.

Digital Inputs: The TYPE SELECT inputs are compatible with TTL or CMOS logic, or may be used with jumpers or switches. Table III shows the truth table for these inputs. Each input has an internal 22kΩ pullup resistor to V_{DD} and drives a single CMOS gate. For use with TTL signals, V_{DD} should be connected to the +5V logic supply. When CMOS logic is used, connect V_{DD} to the CMOS logic power supply (which must be in the +5V to +15V range). If jumpers or switches are used, connect V_{DD} to the +15V analog power supply. Grounding a SELECT input will give a logic "0"; an open input will be at logic "1" due to the action of the internal pullups.

A separate pin is provided for logic ground to minimize ground loop problems. However, for proper operation logic ground at the module must be within ±0.3V of analog common. Failure to observe this restriction may result in damage to the module.

Calibration: Only one adjustment is necessary to get proper operation of the 2B56. This is shown in Figure 2 for both sensor types. R_{CAL} is adjusted to obtain the correct voltage at V_{CAL} for the appropriate sensor type and temperature, as listed in Table IV. Use a high-impedance voltmeter to measure V_{CAL} to prevent loading errors.

The tolerance to which the calibration adjustment must be made depends on the requirements of the application. For either sensor type, and for all thermocouple types, each millivolt of calibration error will result in a temperature offset error at the 2B56 output of 0.44°C, accompanied by a slope error of 0.0015°C/°C.

Curvature Error: The voltage output of thermocouples is a nonlinear function of temperature, so the reference junction output which is compensated by the 2B56 is also nonlinear. The correction signal generated by the 2B56, however, is approximately linear. The 2B56 is adjusted internally to give the best fit of its linear correction to the nonlinear reference junction output over the +5°C to +45°C range. The remaining error, which is included in the specifications given on page 2, is shown for each thermocouple type in Figure 3. Note that as a result of thermocouple nonlinearity the error at +25°C will not be zero after calibration is done. The error for a particular thermocouple type could be adjusted to zero at +25°C by appropriate adjustment of the thermocouple amplifier offset, but the improvement will be at the expense of increased errors over the +5°C to +45°C range.

APPLICATIONS

The application of the 2B56 to a single-channel system is shown in Figure 1. Because the 2B56 compensates at the output of the thermocouple amplifier, it is also very attractive for use in multiplexed multichannel systems. Three typical applications are shown in Figure 4. The amplifier-per-channel structure shown in Figure 4a is one example of a system which could have a different gain for each thermocouple type in use, with channels preassigned or switchable for thermocouple type. The model 2B30 may be used as an amplifier for applications not requiring isolation.

In systems of this type, it is important that the ON resistance of the multiplex switches be less than 100 ohms, since larger values can create slope errors in the 2B56. If switches with higher resistance are used, a unity-gain buffer should be placed between the multiplexer and the 2B56. An AD741 or AD301-type amplifier will suffice unless the system is very fast.

Figure 4b shows an input-multiplexed system. Different gains for different channels in this type of system are sometimes provided by software control of the amplifier gain. The 2B56 can also accommodate this situation, since it can accept a different gain for each thermocouple type.

Figure 4c shows a somewhat different application of the 2B56. Here the signal input is grounded, so that the output is simply the correction signal rather than a corrected version of the input. In this case the actual summation is done elsewhere, usually in the processor following the A to D converter. The advantage of such a structure is that it allows somewhat simpler calibration of the individual channels because the compensator can be bypassed.

There is no electrical limit to the number of channels that can be served by a single 2B56 in these applications or the many others that are possible. There is, however, a thermal limit in that a single temperature sensor must accurately monitor the temperature of a number of sets of input terminals. The actual channel limit will thus be determined by the allowable error and the degree to which all the inputs can be held at the same temperature.

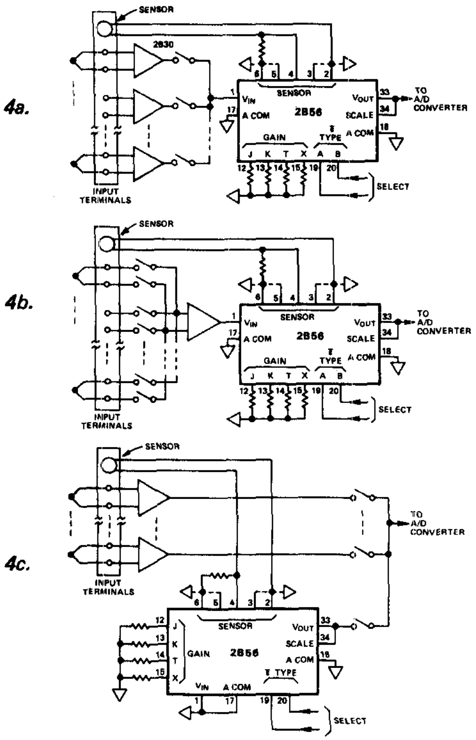


Figure 4. Model 2B56 in Various Multichannel Applications

Figure 5 shows the application of the 2B56 to the output of the 2B54 Four-Channel Isolator. More than one 2B54 can be served by the same 2B56 by using the built-in output switches of the 2B54 to connect several isolators to one output line. Note that the values of the gain-setting resistors for the 2B54 and 2B56 are the same, since both have the same gain formula. This permits very simple reconfiguration when the system must be tailored for new applications.

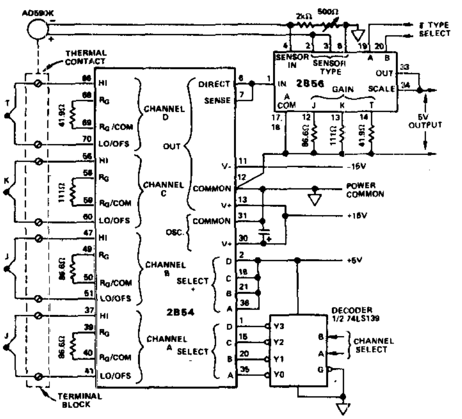


Figure 5. Four-Channel Thermocouple Temperature Measurement with Cold Junction Compensation