Semiconductor Temperature Transducers

Chapter 10

Low-cost semiconductor transducers are useful within the range, -55°C to +150°C. The types to be discussed here, as in Chapter 1, are *diodes, direct temperature-to-frequency converters* (the AD537), and *absolute-temperature-to-current converters* (the AD590).

T-TO-F CONVERSION USING DIODES

In Figure 10-1, the –2.2mV/°C change of voltage across the 1N4148 sensing diode modulates the frequency generated by a relaxation oscillator. The oscillator consists of an integrator and unijunction transistor, which periodically resets the charge across the 4300pF capacitor. The current through the capacitor, hence the rate at

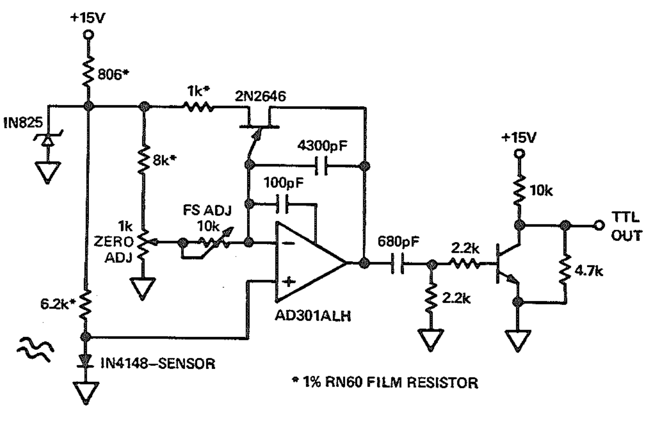


Figure 10-1. Diode temperature-to-frequency converter

which it charges (and the frequency), is determined by the difference between the voltage at the wiper of the zero-adjust pot and the voltage at the diode.

At the lowest temperature in the range, the zero-adjust pot is set as closely as possible for zero frequency. Then, as temperature increases, the voltage at the amplifier's + input decreases, and current flows through the 10kΩ pot and the integrating capacitor. The pot is set for full-scale frequency (about 1kHz) at full-scale temperature. For the range 0° to 100°F, accuracy is to within 1°F.

This approach is economical, in a sense; the concept and circuit are simple (but not the simplest), and the components are not expensive. However, each individual diode must be calibrated, and if a new diode sensor is installed, the circuit will require recalibration.

DIRECT T-TO-F CONVERSION WITH THE AD537

The AD537 (described in some detail in connection with the application shown in Figure 7-6) is an IC V/f converter, which requires a single capacitor to determine the frequency range. Either voltage or current can be used as an input. A unique device among VFC's, the AD537 has square-wave output (constant 50% duty cycle, irrespective of frequency), a 1.00V reference terminal (V_R), and a 1mV/K absolute-temperature-reference terminal (V_T).

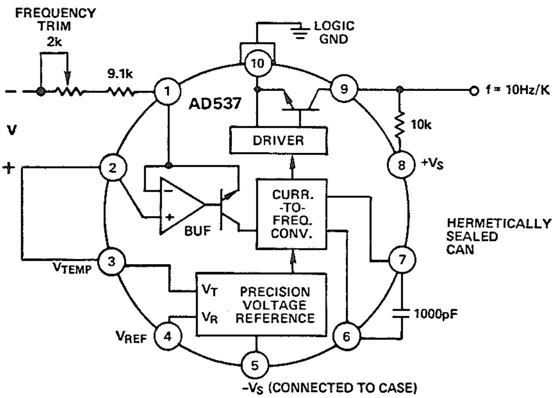
The V_T output can be used as shown in Figure 10-2 to perform direct temperature-to-frequency conversion. It can also be used with other external connections in temperature-sensing or compensation.[1]

An absolute-temperature(kelvin)-to-frequency converter is easily implemented (a). The 1mV/K output is connected as the input to the buffer amplifier, which then scales the oscillator-drive current to a nominal 298μA at +25°C (298K). If a 1000pF capacitor is used, the corresponding frequency will be 2.98kHz. Adjustment of the 2kΩ trim resistor for the correct frequency at a well-defined temperature near +25°C will normally result in an accuracy to within ±2°C from –55°C to +125°C (using an AD537S*). An NPO ceramic capacitor is recommended to minimize nonlinearity due to capacitance drift.

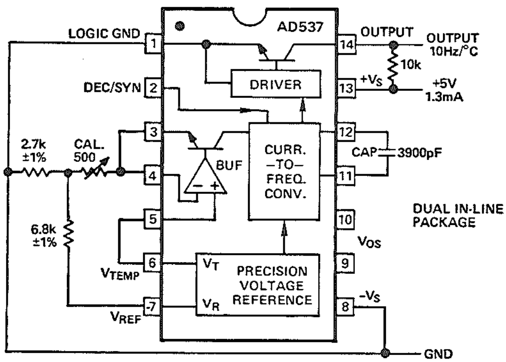
[1] Many interesting applications of the AD537 can be found in the Application Note, "Applications of the AD537 IC Voltage-to-Frequency Converter", by Doug Grant. It is available at no charge from Analog Devices.

*Only the AD537S will perform to +125°C. For applications requiring maximum temperature of +70°C (+158°F), the J or K grades can be used with the same circuit values.

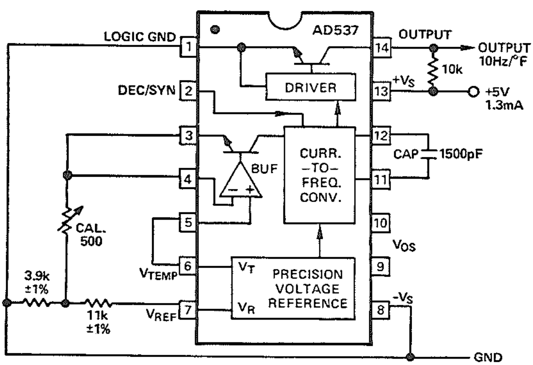
Other temperature scales are available by scaling and offsetting. (b) shows connections for Celsius, and (c) shows the connections for Fahrenheit.



a. Absolute temperature to frequency



b. Celsius temperature to frequency



c. Fahrenheit temperature to frequency

Figure 10-2. Direct temperature-to-frequency conversion

For the Celsius scale, the lower end of the timing resistor is offset by +273.2mV, using the reference-voltage output. The component values take into account the required corrections for the loading of the 1.00V output (it is not zero-impedance). The frequency range in this application is 0 to 1250Hz, corresponding to 0° to +125°C.

The Fahrenheit scale requires an offset of +255.37mV, and increased gain (x9/5), produced by the component values shown. The output frequency range is 0 to 2570Hz for a temperature range of 0° to +257°F (–17.78° to +125°C), using the AD537S*. For variety, (a) shows connections for the hermetically sealed can version, (b) & (c) for the DIP version.

ABSOLUTE-TEMPERATURE-TO-CURRENT CONVERSION

The AD590, described in detail in Chapter 1, produces a current in microamperes that is numerically equal to the absolute temperature on the Kelvin scale (0°C = 273.2K), for temperatures from -55°C (218K or -67°F) to +150°C (423K or 302°F), independently of applied voltage over the specified +4V to +30V range. A two-terminal device, it is optionally available in a hermetically sealed TO-52 transistor package, a miniature flat-pack, a variety of probe hardware (AC2626), and in chip form (for user packaging or for measuring temperatures on circuit substrates).

The AD590 is available in several accuracy grades, as Table 1 indicates. The specifications of interest depend on whether the device is used uncalibrated or with calibration at a single value.

TABLE ONE. AD590 ACCURACY SPECIFICATIONS (MAX ERROR)

Conditions	Max Error (±°C)				
Grade	I	J	K	L	M
Error at 25°C, as delivered	10.0	5.0	2.5	1.0	0.5
Errors over the -55°C to +150°C range:					
Without external calibration	20.0	10.0	5.5	3.0	1.7
With error nulled at 25°C only	5.8	3.0	2.0	1.6	1.0
Nonlinearity	3.0	1.5	0.8	0.4	0.3

For greater accuracy (in any grade), the device may be calibrated at two points. Since accuracy is a function of calibration error, linearity error, and operating range, there is a wide variety of

*Only the AD537S will perform to +125°C. For applications requiring maximum temperature of +70°C (+158°F), the J or K grades can be used with the same circuit values.

possible worst-case accuracy specifications, many considerably better than 0.05°C, based on the above. They are tabulated in the Appendix, "Accuracies of the AD590."

SIMPLEST READOUT, AN ANALOG METER

In Figure 10-3, the circuit consists simply of an AD590, a 0 to 500μA zero-adjustable analog meter, and a source of voltage (say, a 6V lantern battery). The meter will read temperature directly, to the accuracy determined by the meter and the device grade specification, with the error nulled at 25°C (298.2K). As long as sufficient voltage is available to supply voltage drops due to line resistance and maintain adequate excitation voltage at the device, the meter reading will be independent of the distance between the device and the readout.

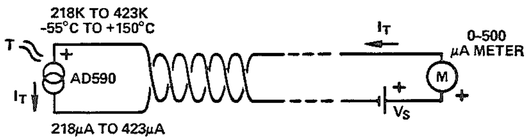


Figure 10-3. Simplest measurement system using the AD590 or the AC2626 probe

The AD590's breakdown voltage rating of ±200V, TO-52 case or stainless-steel probe to either lead, means that the AD590, or its probe version, the AC2626, may be placed in intimate contact to measure the temperature of conducting surfaces operating at common-mode voltages substantially higher than the AD590's supply.

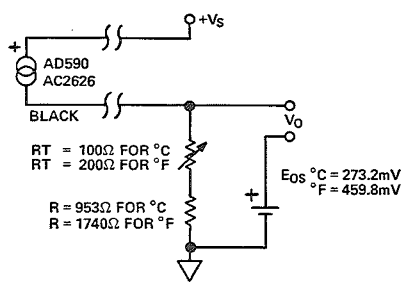
Where the degree of resolution available is appropriate, the meter may be caused to read out in °C or °F, instead of K—without additional circuitry—by using an appropriately calibrated meter scale. If remote readout at several locations is desired, additional meters may be connected in a series loop.

VOLTAGE READOUT

In most applications, the AD590 will be interfaced to a system that requires a voltage input. In principle, all that is needed is a series resistance. A 1kΩ resistance (for example) in series with the AD590 will develop a 1mV/K voltage drop. This voltage may be applied at the input of an inverting or non-inverting op amp, a digital panel meter, or any other circuit capable of working with an accurately fixed resistive source. If readout of the same temperature is required at several remote locations, a current loop may be used with a (e.g.,) 1kΩ resistance (and either an instrumentation amplifier or a floating measurement system) at each location.

If the system that the AD590 feeds has offset and gain adjustments, a two-point calibration may be performed; calibrate the offset adjustment near the lowest temperature in the range, and set the gain (span) adjustment for null in the vicinity of the highest temperature to be measured. Single-point calibration for each AD590 used in a system is easily accomplished by trimming the load resistance at the specified temperature.

For readout in °C or °F, instead of kelvin, an appropriate amount of offset must be introduced, as Figure 10-4 shows. Also, for temperatures based on Fahrenheit, the nominal value of load resistance is 9/5 that required for temperatures based on Celsius.



FOR MOST APPLICATIONS, A SINGLE POINT CALIBRATION IS SUFFICIENT. WITH THE PROBE AT A KNOWN TEMPERATURE, ADJUST R_T SO THAT V_O CORRESPONDS TO THE KNOWN TEMPERATURE.

Figure 10-4. Voltage readout using the AD590 or the AC2626 probe

The AD2040 is a digital panel meter designed specifically for low-cost single-channel digital-thermometer measurements employing the AD590 or the AC2626 probe. Available for either +5V system power or ac mains power (for isolated measurements), it provides all required offset and span calibrations for readout in K, °C, °F, or °R with ±1°C resolution.

Figure 10-5 is a block diagram of the AD2040, showing the AD2026 basic digital panel meter, the current-to-voltage span conversion resistors (R1, R2, R3), the offsetting resistor network (R4, R5, R6, R7), and the connections to the terminal strip. Attenuated voltage from the AD580 2.5-V reference provides the offsets for reading out the °F and °C scales. Jumpers are connected

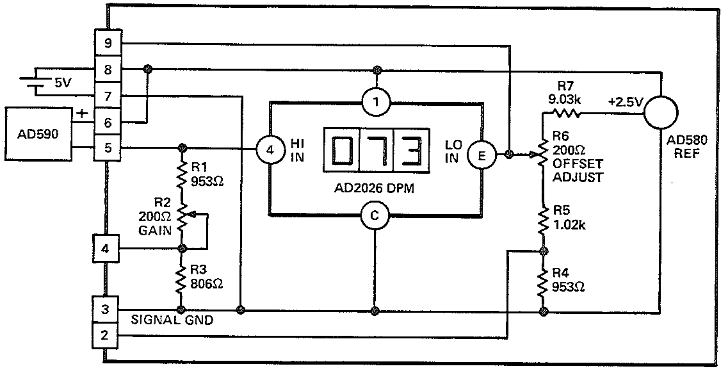


Figure 10-5. Connection diagram of the AD2040, showing internal connections and external connection to read Fahrenheit temperatures from -67° F to +302° F

by the user at the terminal strip, and the device is trimmed to read out in the appropriate units of temperature for display, according to this scheme:

Units	Connect These Terminals Together
Celsius	2, 3, 4
Fahrenheit	None
Kelvin	3, 4, 9
Rankine	3, 9

MEASURING DIFFERENTIAL TEMPERATURE

It is often necessary to measure, record, and control the temperature *difference* between two physically close—or widely separated—entities. A few examples of such temperature differences include the temperature rise above ambient inside a piece of equipment, temperature rise of a power transistor above ambient, the temperature difference between the inside and outside of an air-conditioning duct or plenum, and temperature gradients inside an oven or a refrigerator.

Depending on the application, the measurement of temperature differences may require resolutions as fine as a few millidegrees with full-scale ranges as great as several hundred degrees. For such applications, in the range from −55°C to +150°C, it is easy to implement ΔT measurements using the AD590 sensor or the AC2626 probe.

Figure 10-6 shows how simple the basic circuitry can be: two AD590's, two 9V transistor-radio batteries, and a microammeter. Currents I_1 and I_2 are generated independently in response to the temperatures of the two sensors. The currents flow in opposite directions through the meter, which reads their difference. For example, for temperatures of 35°C and 25°C, the current through the meter will be +10μA, corresponding to a difference of 10 kelvin, or +10°C. If I_1 is less than I_2, the reading will be negative. For perfectly matched IC's at the same temperature, the reading will be zero. If they aren't perfectly matched, zero can be trimmed by adjusting the mechanical zero of the analog meter. The meter can be protected by shunt diodes and an empirically determined value of series resistance (as shown in Figure 10-6) and/or by a shunting switch.

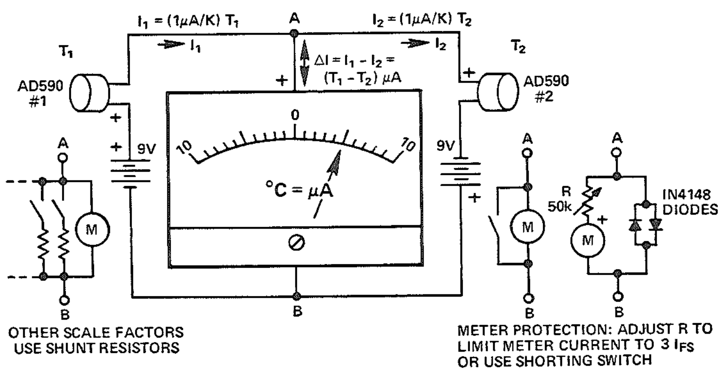
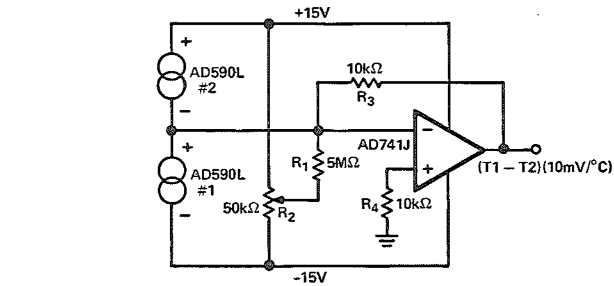


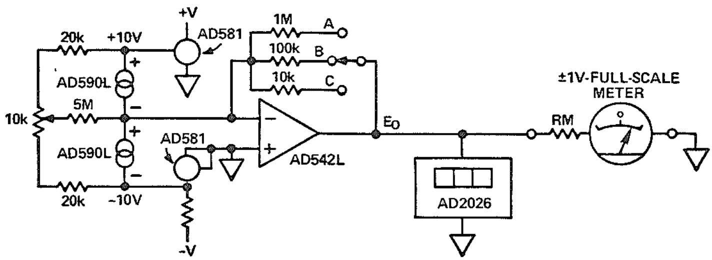
Figure 10-6. Differential temperature meter

If the meter has a 5″ scale, it can resolve changes of 0.1°C in a distance of 0.025″. For wider ranges of temperature change, a less-sensitive meter can be used, or range switching can be obtained by using resistive shunts across the sensitive meter. If greater sensitivity/resolution is desired, and one AD590 is always warmer than the other, a 10μA meter with 8″ scale length (e.g., Triplett 820 series) provides 0.025° resolution. Note that resolution is limited by the meter scale, not the errors of the AD590's.

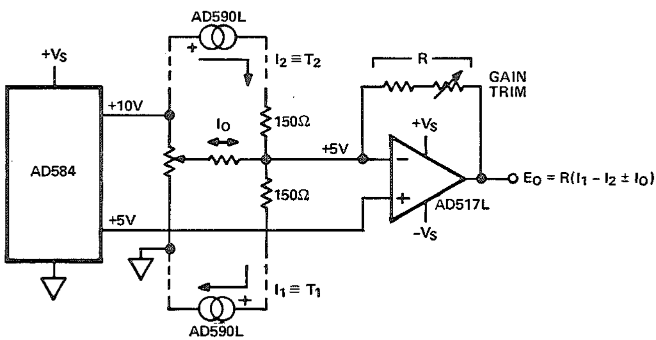
For applications calling for voltage readout, the circuit of Figure 10-7a may be used. It demonstrates one way differential measurements can be made, using two AD590's and a single op amp. Resistors R1 and R2 allow offsets, due to either mismatches between the AD590's or to small temperature differences, to be trimmed out.



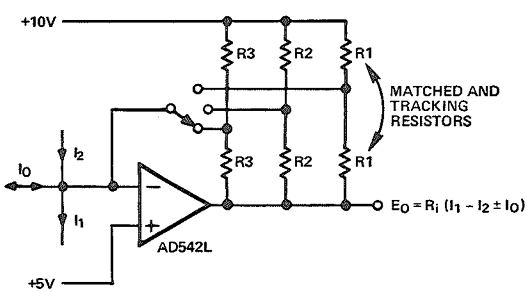
a. ΔT measurement with the AD590



b. High-resolution ΔT measurement with AD590's or AC2626 probes.



c. High-resolution ΔT measurement using the AD584 multi-reference to establish ±5V of excitation for the AD590's



d. Gain-switching for (c)

Figure 10-7. Differential temperature measurement using the AD590

For even finer resolution, circuit b may be used. It adds range switching, the higher-performance parts required for 100X greater sensitivity, and readout devices.

Here's how it works: the AD542L TRI-FET* op amp, acting as a current-to-voltage converter, sums the opposing currents and converts them to voltage at a level determined by the feedback resistance. The 10kΩ potentiometer is used to zero the output when the AD590's are at equal temperature.

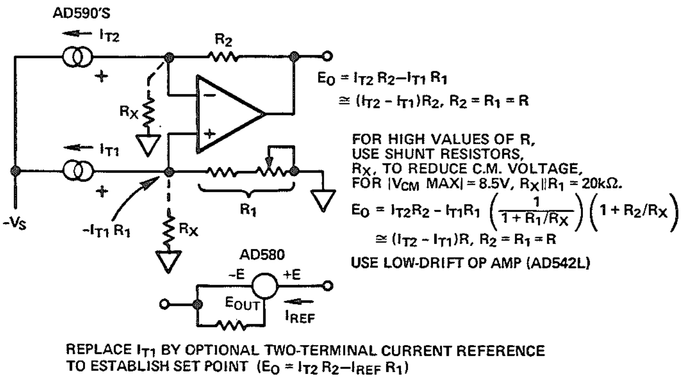
In switch position A (1MΩ feedback resistance), the scale factor is 1V/°C. The least-significant digit of the 999mV-full-scale AD2026 panel meter permits a resolution of one millidegree Celsius over the range from –0.1°C to +0.1°C. Or, an analog meter can resolve 10 millidegrees over a ±1°C range. Resolution and scale factor for all switch positions:

	AD2026 DPM		Zero-Center Analog Meter	
Position	Resolution	Full Scale	Resolution	Full Scale
A	0.001°C	-0.099°C to +0.999°C	0.01°C	±1°C
B	0.01°C	-0.99°C to +9.99°C	0.1°C	±10°C
C	0.1°C	-9.9°C to +99.9°C	1.0°C	±100°C

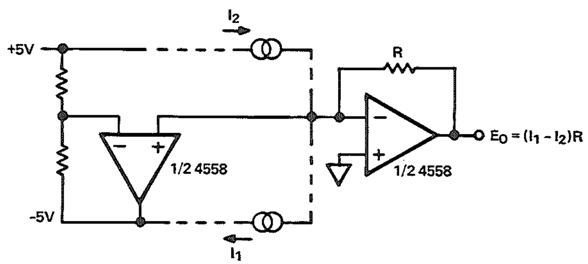
The following precautions should be taken to insure good electrical performance at high sensitivities: use well-matched AD590's (L or M suffixes); excite them from stable dc voltage (AD581 precision references), and use a low-bias current op amp with low voltage drift (e.g., AD542L). The AD584 multireference permits simpler reference circuitry (c and d).

Figure 10-8a shows a simple circuit for differential temperature measurement employing a differential operational amplifier in a balanced-bridge single-excitation-source configuration. Output sensitivity is determined by the choice of R2 and R1; for example, 1kΩ corresponds to 1mV/°C, 1MΩ corresponds to 1V/°C.† R1 provides an adjustment for zero when both AD590's are at equal temperatures. If high gain accuracy is necessary, the differential measurement may be calibrated by a gain adjustment elsewhere in the signal path. The op amp may be an AD542 FET-input device for resolving small current changes or high accuracy at low cost, and an AD741 for non-critical measurements.

*Trimmed-Resistor Implanted-FET low-drift FET-input op amp
†Use shunt resistors, R_X, to reduce the common-mode voltage



a. Single op amp



b. Dual op amp—CMV problem eliminated. A zero adjustment may be implemented in the same way as in 10-7c

Figure 10-8. Single excitation-source ΔT-to-voltage circuits

If one of the AD590's is replaced by a current source (e.g., an AD580 reference connected as a 1 to 11mA current source), then the output of the amplifier provides the difference between the measured temperature and a temperature set point, determined by the reference current and the value of its associated resistance.

AVERAGE AND MINIMUM TEMPERATURES

Since the AD590 is a current source, if a number of devices are connected in parallel, the total current flowing will be equal to the sum of the individual currents. Thus, a number of AD590's (n) may be used as a single composite sensor to measure the average of their temperatures. The load resistance will be R_L/n, where R_L is the resistance value used with a single AD590 (Figure 10-9a).

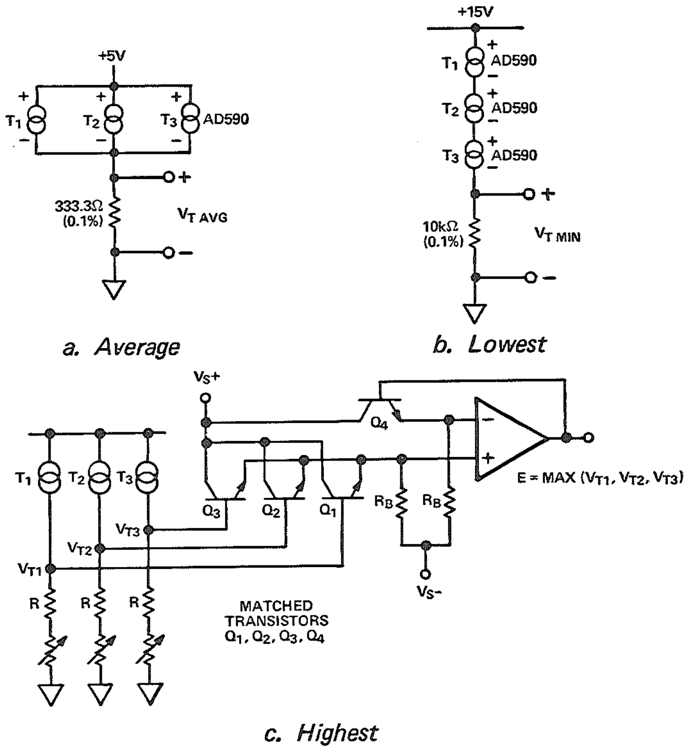


Figure 10-9. Combined measurements

If AD590's are connected in series, the current conducted will be limited to that of the device at the lowest temperature. Therefore, by the simple connection of Figure 10-9b, the lowest temperature in an ensemble can be measured. The *highest* temperature can't be measured quite as simply; the currents must be converted to voltage, and the voltages applied to an "auctioneer", or *upper selector*, an analog circuit that responds only to the highest voltage (c). The highest or lowest temperature at one point over a time interval can be computed by a peak- or a valley-follower (*Nonlinear Circuits Handbook*).

TEMPERATURE-CONTROL CIRCUITS

Figure 10-10 is an example of a variable on-off temperature-control circuit (thermostat) using an AD590. When the temperature at the AD590 is less than the set point, the output of the AD311 comparator swings to its upper limit, turning on the heating element. When the AD590's temperature is above the setpoint, the AD311 will turn the heater off.

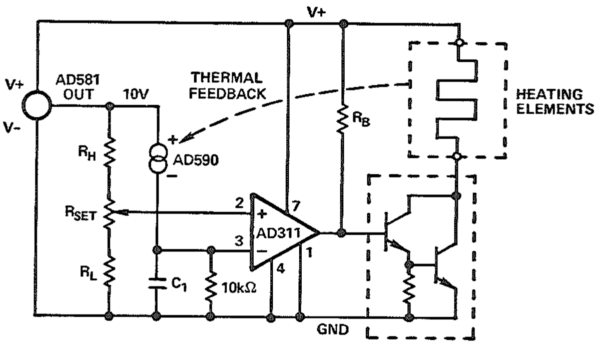


Figure 10-10. Simple temperature control circuit

R_H and R_L are selected to set the high and low extremes for the set point. Depending on the desired sensitivity and mode of adjustment, R_{SET} could be a simple pot, a calibrated multiturn pot, or a switched resistive divider.

The AD590 is insulated from power-supply variations by the 10V reference, for approximately constant dissipation, yet a reasonable voltage (about 6V) is maintained across it. C1 may be needed to filter out extraneous noise if the sensor is remotely located. R_B is determined by the β of the power transistor and the current requirements of the load.

Figure 10-11 is a schematic diagram of a continuously responding temperature-control servo that uses an AD590 as the sensor. The components to the right of A1 (similar to those in Figure 8-5) form a variable-pulsewidth modulator-oscillator to obtain smooth response despite the on-off nature of the heater excitation.

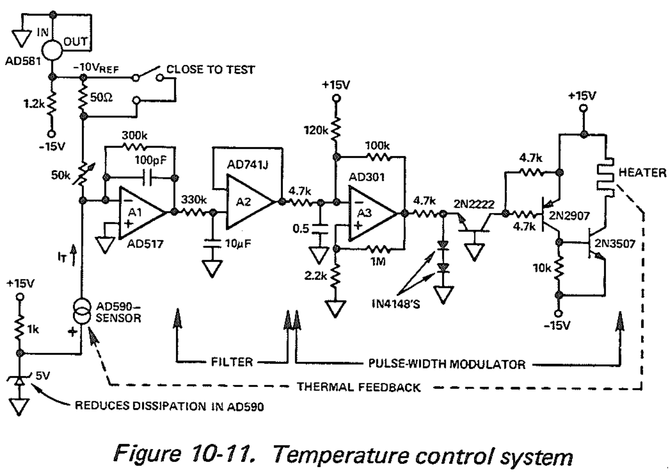
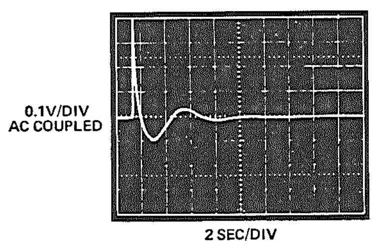


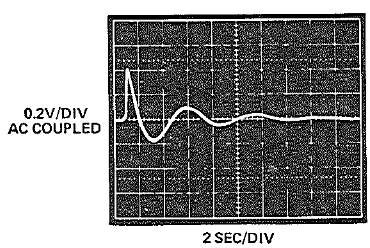
Figure 10-11. Temperature control system

The AD590's output current is compared—at the summing point of inverting amplifier, A1—with a reference current, generated by an AD581 voltage reference, connected as a high-performance -10V "zener diode". The AD517 sums the currents and amplifies the difference (error signal) to drive the servo.

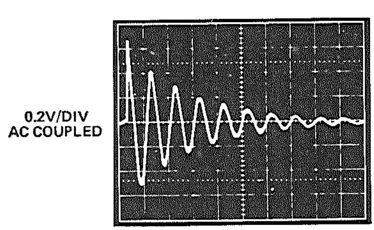
The system for which this circuit was originally designed maintains the temperature inside a small cylindrical oven one inch in diameter, three inches long, and one-quarter inch thick. In order to obtain the most stable dynamic response in a configuration with tightly controlled mechanical parameters and simple dynamics, the AD590 is attached to the wall in close proximity to the heater winding via a film of silicone grease. The response of the error signal to a transient-response test (shorting out the 50Ω resistor in the reference circuit) is stable, as Figure 10-12a shows, b is the



a. AD590 on heater coil with silicone grease



b. AD590 on heater coil



c. AD590 on wall near—but not on— heater coil

Figure 10-12. Response of temperature-control system response to the same stimulus without silicone grease, and c is the response with the AD590 located a short distance away from the heater winding (lengthened time scale to permit more cycles of oscillation to be shown).

While it could be argued that this scheme does not actually control the temperature at the device inside the oven, thermal gradient measurements show that the temperature within the thick-walled, well-insulated oven is sufficiently uniform for low-dissipation loads to make the question moot. The lengthened thermal time constants that would be obtained by locating the AD590 within the oven would increase the problem of reliably obtaining and maintaining dynamic stability (and response speed) without substantially improving the accuracy with which temperature is maintained.

The setpoint of the control circuit in Figure 10-10 can be set digitally, using (for example) an 8-bit d/a converter. In the circuit of Figure 10-13, the desired temperature can be set to any value from 0°C (all inputs high) to +51°C (all inputs low) in 0.2°C steps. The comparator is fed back for a hysteresis band of 1°C, for reduced sensitivity to extraneous noise. The hysteresis can be avoided by removing the 5.1MΩ resistor.

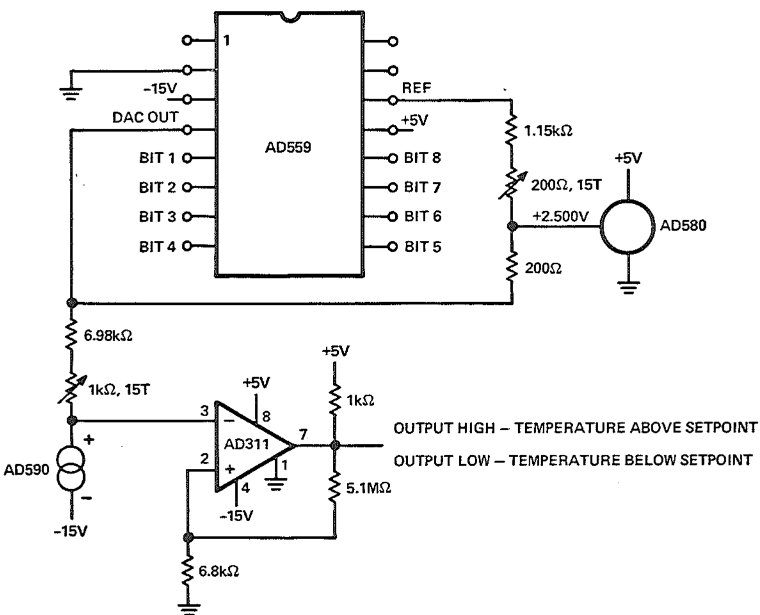


Figure 10-13. Digitally controlled setpoint

Figure 10-14 is an example of temperature control in which a system with a large amount of thermal lag is maintained at near-constant temperature with a high-capacity gas-fired heater by the use of carefully measured pulses of heat.

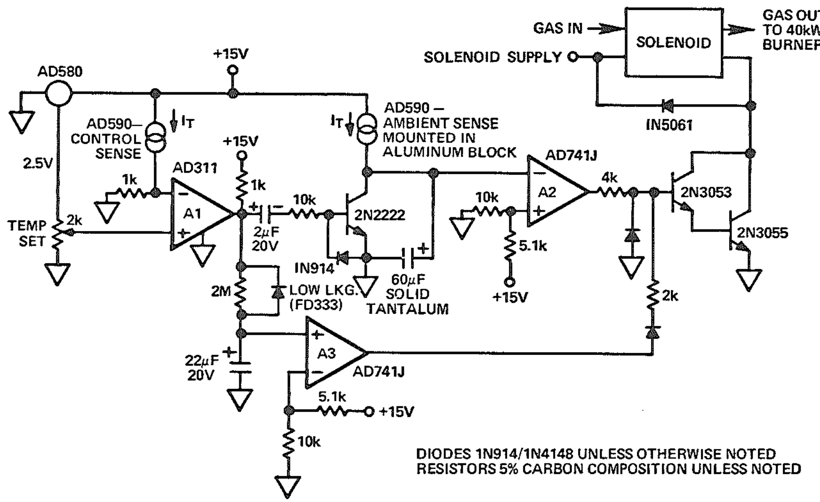


Figure 10-14. Temperature control system

If one assumes that the temperature has decreased sufficiently for the *control-sense* AD590's load resistor's voltage to drop below the reference voltage, the output of the AD311 comparator will swing positive, and the resulting pulse will turn on the transistor, discharging the 60μF capacitor. That negative swing will be inverted by the open-loop AD741, turning on the power transistors and the solenoid that turns on the burner.

The *ambient-sense* AD590, considered as a current source, will charge the 60μF timing capacitor positively at a rate of about 5V/s, faster at high ambients, slower at low ambients, until the threshold of A2 has been exceeded. Its output changes state and turns the burner off. A short time thereafter, the *control-sense* AD590's temperature-increase resulting from the burn will cause the output of A1 to go negative, clearing the ac-coupling capacitor and readying it for the next time the temperature has dropped below the set-point.

The function of A3 is to keep the burner on during startup, and to back up A2 during operation, if it should fail to switch. However, the long time-constant at the input of A3 keeps it out of action during the normally fast operation of the timer-A2 incremental-temperature-adjusting circuitry.

Circuits of this kind, carefully implemented, have been used to control a 5000-gallon vat to 100°C ± 0.1° and to provide 0.001°C control resolution for an oven used to keep a quartz delay-line at constant temperature in a retrofit operation where heater and power-supply parameters could not be altered.

HIGH-LOW TEMPERATURE MONITORING

It is often desirable to have an indication when the temperature is higher or lower than a desired normal value by a given amount. The circuit of Figure 10-15 provides a pair of adjustable thresholds and LED indication of when they have been exceeded. This circuit can be used in conjunction with the digital readout provided by an AD2040 digital thermometer (Figure 10-5). The analog voltage developed across the (nominally) 1kΩ resistance (for kelvin and Celsius), and appearing at terminal 5, is compared, in a CA3290E dual comparator, with the voltages set by the *hi limit* and *lo limit* pots, which derive their reference voltage from an AD580 2.5V reference.

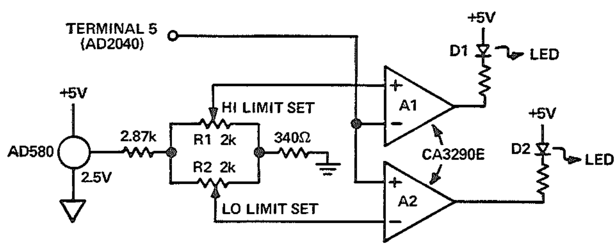


Figure 10-15. Limit detector and readout circuitry

When the voltage at terminal 5 goes higher than the *hi limit set* voltage, the output of A1 goes low and D1 is turned on. Similarly, when terminal 5 is at a lower voltage than the *lo limit set* voltage, the output of A2 goes low and turns on D2.

To set the high limit, using a meter that has already been calibrated, replace the AD590 with a variable resistor. Adjust the resistance until the reading of the meter is numerically equal to the desired high-temperature set point. Adjust R1 until D1 just turns on. Repeat the procedure to adjust R2 for the lower limit.

MULTIPLEXED APPLICATIONS

The high compliance voltage and high-impedance reverse blocking capability of the AD590 allow it to be powered directly from +5V CMOS logic, to permit easy multiplexing or switching, as well as pulsed measurements for minimum internal heat dissipation (or drain from the excitation/switching supply). In Figure 10-16, an AD590 connected to logic high (with a low gate input) will pass a signal current through the current-measuring circuitry, while the AD590's connected to logic zero (gates high) will pass insignificant current. The switch outputs used to drive the AD590's may be employed for other purposes, but the additional capacitance due to the AD590 should be taken into account, since it will cause some degradation of rise and fall times. The 1kΩ load resistance converts the absolute-temperature-proportional current to a voltage of 1mV/K.

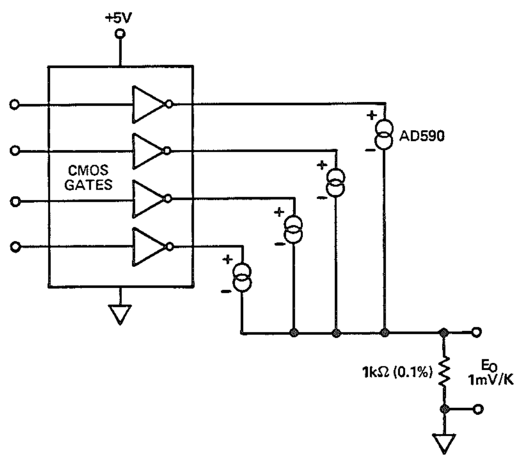


Figure 10-16. AD590 driven from CMOS logic

Figure 10-17 shows a method of multiplexing AD590's connected for high accuracy in the two-trim mode. As many as eight different temperatures can be multiplexed and measured to within ±0.5°C absolute accuracy over the temperature range −55°C to +125°C. Since the output of the op amp is limited with ±15V supply, to obtain accurate output over the full −55°C to +150°C temperature range, a +20V supply should be used for the op amp.

With a matrix approach, a large number of points can be monitored at a remote location using a small number of switches. Because the AD590's output is a current, switch resistance and line drop

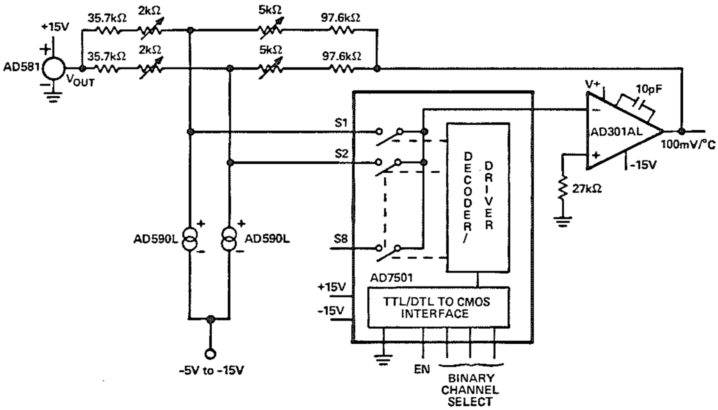


Figure 10-17. 8-channel multiplexer

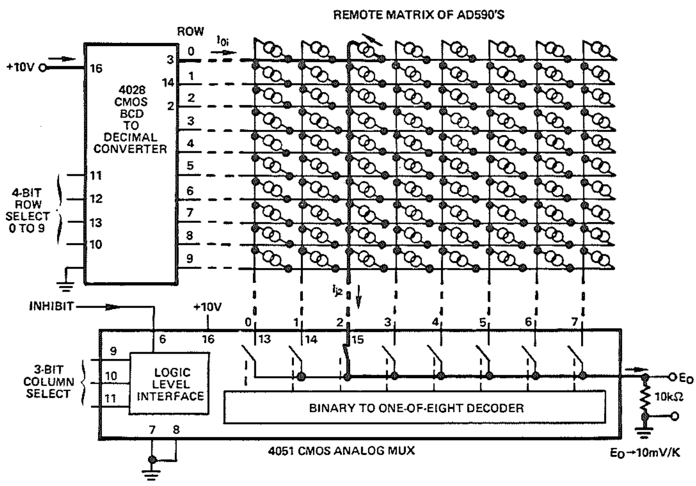


Figure 10-18. Matrix multiplexing scheme for temperature readout. Heavy line shows path for I_{02}

are unimportant. The scheme shown in Figure 10-18 is a form of multiplexing uniquely applicable to the AD590. Here, the temperature of any one of 80 remote sensors can be read, independently of CMOS switch resistance, via only 18 wires, as addressed by a 7-bit word. The eighth bit can be an *inhibit* line that turns all sensors off for minimum dissipation while idling.

Figure 10-19 shows how an AD2040 low-cost digital thermometer may be used with a CMOS multiplexer to provide selective excitation and readout for eight AD590 sensors, according to the binary code applied to the address lines. The 10V Zener diode reduces the drop across the AD590's from 15V to 5V to reduce self-heating. Note that the sensors are shown schematically as current sources in this and other figures.

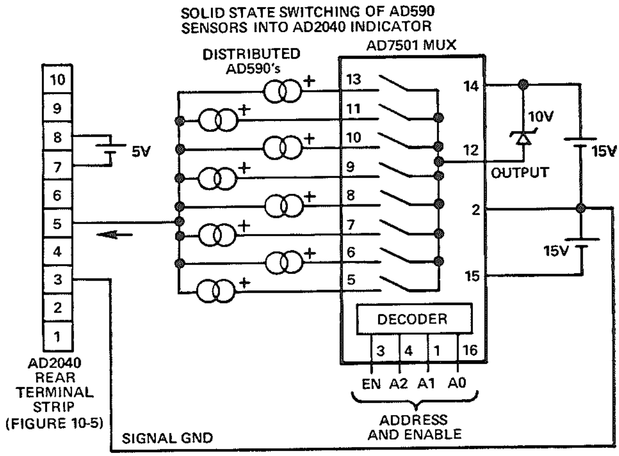


Figure 10-19. Selective excitation and readout among eight channels of temperature-sensing using a CMOS multiplexer

Multiplexing is not always electronic. Figure 10-20 shows a manual switching scheme for reading a variety of sources applied to an AD2040 digital thermometer. This figure also demonstrates the flexibility of powering the AD590. Here, it is shown powered (a) from the meter's supply, (b) from a remote lantern battery and a transistor battery. The meter itself is also shown being powered (in field applications) by a 6V lantern battery. Battery-excited AD590's should operate for a month on the 9V transistor battery

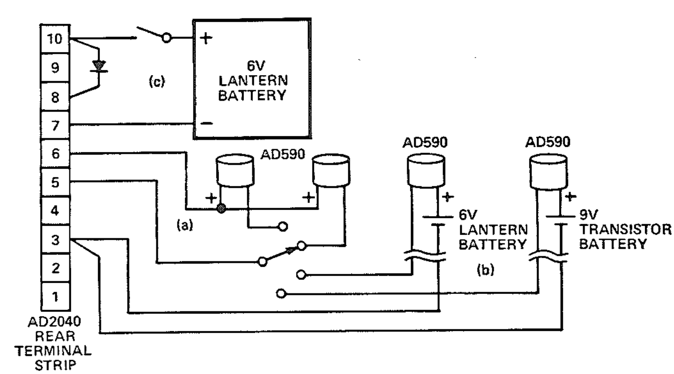


Figure 10-20. Typical modes of excitation for field applications, showing switch circuitry to select among sensors

or for one year on a 6V lantern battery; in intermittent operation, the meter should operate for 20 hours on the lantern battery.

The scanning digital thermometers, AD2036 and AD2037, have been mentioned earlier in association with thermocouple and RTD interfacing (see Figures 7-10, 8-6, and 9-7). A scanning thermometer dedicated to AD590 applications, the AD2038, is also available. In simplest terms, a single AD2038 provides the user with a tool to measure six temperatures in the range –55°C to +150°C (–67°F to +200°F) at six different remote points scattered over an area 5 kilometers (3 miles) square. Resolution is 0.1°C or 0.1°F. A twisted pair of insulated wire is all that is required to connect the measurement locations and the AD2038. Since the measurement is transmitted as a current, accuracy is independent of voltage drops, as long as the minimum voltage required for excitation appears across the sensor. The AD2038 provides the excitation, offset (for °C and °F), and readout.

Figure 10-21 shows the circuitry that provides the excitation for the reads the output of the AD590's. Each of the remote sensors must have at least 4V across it to function properly. The AD2038 can provide 7.5V of excitation, as shown for Channel 0. A remote battery (or a source of higher voltage) may also be used, as shown for Channel 5. Because there is no need to consider line- or contact-resistance at any point, the user may connect a variety of relays, switches, connectors, or even isolation resistors in series with the AD590 and AD2038 inputs, as long as sufficient excitation voltage is available.

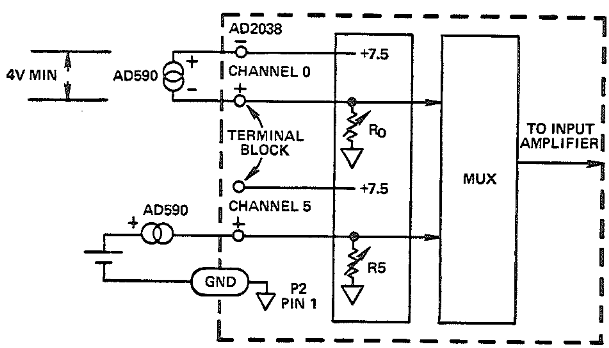


Figure 10-21. Applying the AD2038 six-channel scanning thermometer with AD590 two-terminal electronic temperature sensors

At the AD2038, the current from each AD590 is passed through an adjustable resistor (available to the user for trim) to converter to voltage for input to the AD2038's a/d converter and display.

ISOLATION

Temperature measurements are often performed in harsh environments where offground potentials, such as line voltage, may be accidentally impressed on the temperature sensor. In such cases, it is important to protect the sensor, the input circuitry, and (most important) the system electronics that the output communicates with. Two widely used forms of solution to this problem are isolation amplifiers (Chapter 4) and V/f conversion.

In Figure 10-22, showing one of perhaps several channels, an AD590 in a probe performs the current-output temperature measurement. A model 288 isolator and its associated 947 isolated supply provide isolated power for the AD590 and input/output isolation. A two-point calibration may be performed: calibrate 0°C by placing the probe in a zero-temperature bath and adjusting R_O for E_O = 0V; calibrate full scale by placing the probe in boiling water (100°C) and adjusting R_S for 1.000V output.

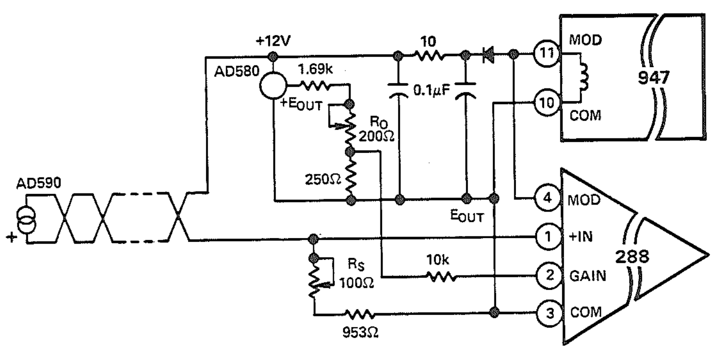


Figure 10-22. Isolated temperature measurements

Model 288 is a synchronized isolation amplifier, designed for multi-channel applications. For single-channel applications, Model 284 or 277 might be more suitable.

Figure 10-23a is an application where the simplicity of application and low power requirements of the AD590 combine with a monolithic V/f converter and an unorthodox power-transmission technique* to accomplish a difficult interfacing task.

*This circuit was reported to us by J. Williams, who advises us that a patent is pending on aspects of this system.

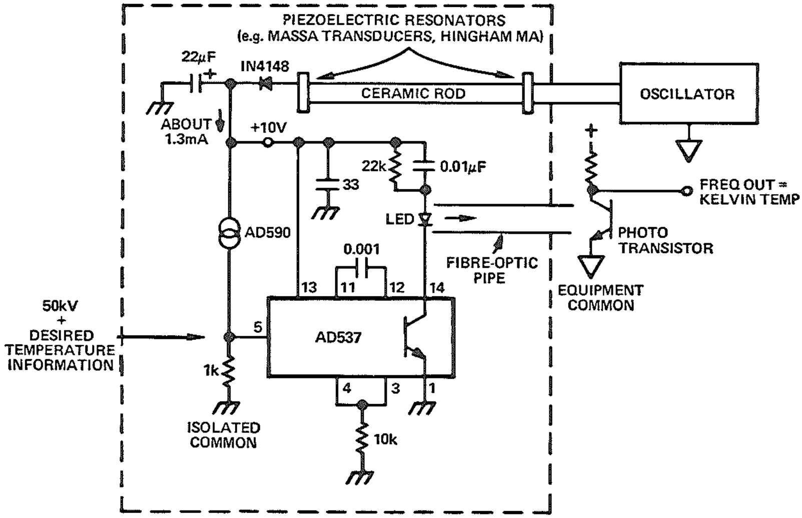


Figure 10-23a. 50kV-Isolated temperature measurement

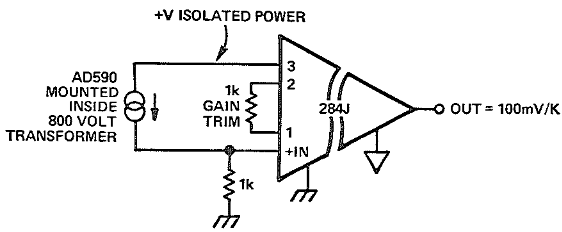


Figure 10-23b. Isolation amplifier in temperature measurement

A nuclear-physics experiment requires temperature monitoring of a 140°C surface (to 0.1°C resolution); the surface is floating electrically at *50kV*! The AD590 is mounted on the surface and its output serves as the input bias voltage for an AD537 IC V/f converter. Each time the open-collector output of the AD537 goes low, a quantity of charge is dumped through the 0.01µF capacitor into the LED, causing it to emit a short spike of light, which is transmitted via fibre optics. The electrical output is a frequency proportional to the temperature of the isolated surface.

Power for the AD590 and the AD537 is supplied by an oscillator, which drives one end of a ceramic rod acoustically, via a piezoelectric transducer. At the other end of the rod, another piezoelectric transducer converts the acoustic signal to an electrical signal, which is half-wave rectified to obtain dc power.

The reason for this unusual configuration is the high value of isolation voltage. For more-usual degrees of isolation, a standard isolation amplifier would be a better choice. For example, (b) shows how, in a similar circuit, an AD590 and an isolation amplifier are used to achieve contact temperature measurement in the presence of 800 volts of ac common-mode voltage.

4-20mA CURRENT TRANSMISSION

For some applications, the typical 300-microampere magnitude of current from the AD590 is either insufficient or is non-standard; and quite a few applications call for isolated current. For such applications, conversion to voltage, using an op amp, followed by a 2B20 voltage (0 to +10V) to current (4 to 20mA) converter, is a not-too-difficult solution.* Where isolation is called for, the 2B22 is useful, because it can accept voltage spans as small as 0 to 1V, and provide the appropriate degree of gain and offset, by the choice of external components.

For the designer who is measuring temperatures over a narrow range, the circuit of Figure 10-24 may be of interest. It converts the output of an AD590 to a 4-20mA range, in which 4mA corresponds to 17°C and 20mA corresponds to 33°C, for measurements of 25°C ambient ±8°C (i.e., the output sensitivity is 1mA/°C, a current amplification of 1000:1).

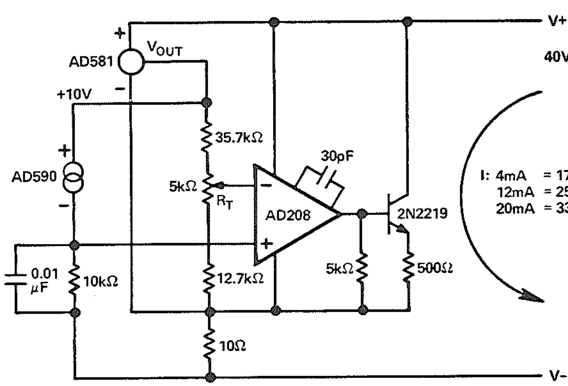


Figure 10-24. 4 to 20mA Current transmitter

SOUND-VELOCITY MONITOR

The thermometer and reference outputs of the AD537 V/f converter (Figures 7-6, 10-2, etc.) can simplify the measurement of

*Model 2B57 is a complete, two-wire, loop-powered, AD590-input, 4-to-20mA output transmitter.

many physical parameters. For example, the velocity of sound in air can be computed from the formula:

$$\begin{aligned} c &= (331.5 + 0.6T_C) \\ &= (167.6 + 0.6T_K) \end{aligned} \tag{10.1}$$

where

c is the velocity of sound in m/s
T_C is the temperature in degrees Celsius
T_K is the temperature in kelvin

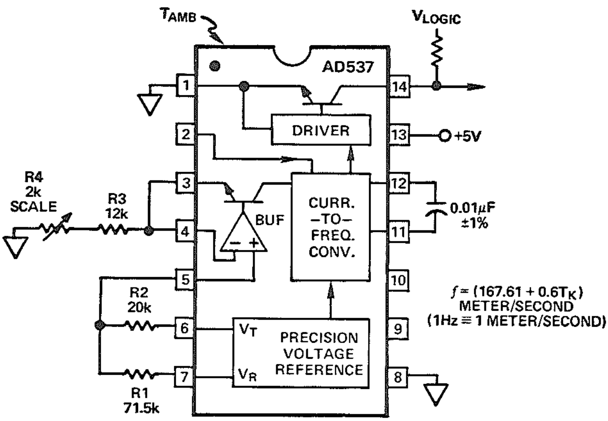


Figure 10-25. Sound-velocity monitor

In the circuit of Figure 10-25, R2 and R1 provide the appropriate weighting of the thermometer and reference outputs as given by:

$$\frac{R_2}{R_1 + R_2} \cdot 1V + \frac{R_2}{R_1 + R_2} \cdot V_T = 167.61 + 0.6T_K \tag{10.2}$$

From this, $R_2/R_1 = 167.61/600$. If R_2 is 20kΩ, then $R_1 = 71.5k\Omega$. With these values, the voltage on pin 5 will be 452.8mV at 300K. This must be scaled to an output frequency of 347.6Hz, corresponding to the speed of sound at 300K. If a 0.01μF timing capacitor is chosen, the value of scaling resistance, R_3, is found to be 13kΩ.