ANALOG DEVICES

AN-273 APPLICATION NOTE

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Use of the AD590 Temperature Transducer in a Remote Sensing Application

by Paul Klonowski

INTRODUCTION

The AD590 is a two-terminal integrated circuit temperature transducer that produces an output proportional to absolute temperature. For supply voltages between +4 V and +30 V the device acts as a high impedance, constant current source supplying 1 μA/K. Laser trimming of the chip's thin-film resistors is used to calibrate the device to an output of 298.2 μA at 298.2K (+25°C).

A typical application for the AD590 is a remote temperature-to-current transducer. Figure 1 shows a thermometer circuit that measures temperature from –55°C to +100°C and whose output voltage is 100 mV/°C. Since the AD590 measures absolute temperature (its nominal output is 1 μA/K), the output must be offset by 273.2 μA in order to read out in degrees Celsius. The output current of the AD590 flows through a 1 kΩ resistance, developing a voltage of 1 mV/K. The output of the AD580 2.5 V reference is divided down by resistors to provide a 273.2 mV offset, which is subtracted from the voltage across the 1 kΩ resistor by an AD524 instrumentation amplifier. The amplifier provides a gain of 100, so that the output range corresponding to –55°C to +100°C is –5.5 V to +10 V (100 mV/°C). An operational amplifier can substitute for the instrumentation amplifier, although care must be taken when designing with the op amp since the gain at the two input terminals will be different.

THE PROBLEM

A question often asked of Analog Devices Applications Engineers by customers using the AD590 in a remote temperature-to-current application is, "How long can I make the cable and how can I eliminate any noise that the cable picks up?" Experiments were performed in an effort to provide some guidelines for answering this question using the circuit of Figure 1 with a 1000' shielded, though initially ungrounded, twisted pair cable (Belden 9461, style 2092). In order to duplicate actual conditions the experiments were performed in an industrial environment.

TYPES OF NOISE

There are three basic types of noise inherent in a data-acquisition system. The first type is *transmitted noise*: noise received with the original signal and indistinguishable from it. The second type is *intrinsic noise:* noise generated within the devices used in a circuit, e.g., resistors, op amps, etc. Included in this category are Johnson, shot and popcorn noise. The third type is *induced noise*: noise picked up from the outside world and coupled into the circuit. This application note discusses methods of reducing induced noise, which is the only form of noise that can be influenced by choices of wiring and shielding.

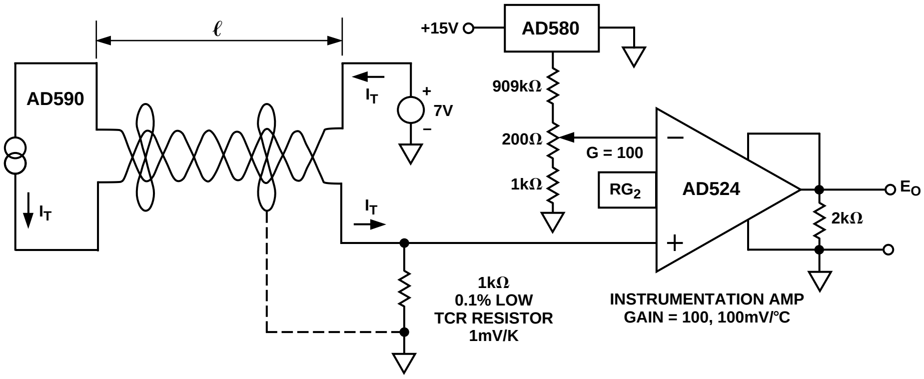

Figure 1. Thermometer Circuit

NOISE FACTORS

Three elements are involved in any noise problem. The first is the source of the noise. Possible noise sources include AM radio signals, logic signals, magnetic fields and power line transients. The second element is the coupling medium. That is, how is the noise source entering the circuit? Possible coupling mediums include a common circuit impedance (Figure 2), stray capacitance (Figure 3) and mutual inductance (Figure 4). A brief description of each follows.

Common impedance noise is developed by an impedance common to several circuits. This might occur, as shown in Figure 2, when a pulse output source and an op amp's reference terminal are both connected to a "ground" point having tangible impedance to the power supply terminal. The noisy return current of Circuit 1 develops a voltage, V_{NOISE}, across the common impedance Z which will appear as a noise signal to Circuit 2. Possible solutions to this problem include proper circuits for distributing power and the use of isolation transformers and optical isolators.

Capacitively-coupled noise is produced by stray capacitance which couples the voltage changing noise source into high impedance circuits, as shown in Figure 3. The nature of the impedance Z determines the shape of the response. Methods of reducing capacitively-coupled noise include reducing the noise source, properly implementing shields and reducing the stray capacitance.

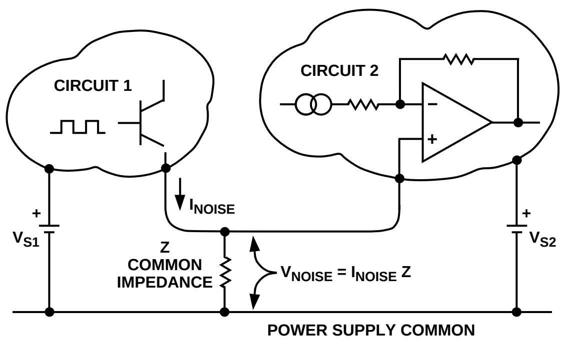

Figure 2. Common Impedance Noise

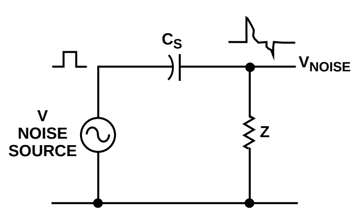

Figure 3. Stray Capacitance Noise

Magnetically coupled noise is produced by mutual inductance and can occur, for example, in an incorrectly shielded cable as shown in Figure 7. Figure 4 is a simple, model of this incorrectly shielded cable, where L_S represents the inductance of the shield, L_C represents the inductance of one of the center conductors, and L_M represents the mutual inductance between the two. The noise current I(t) flows through L_S and establishes a magnetic flux; this time-varying flux also surrounds L_C and produces a voltage $V_{NOISE(t)}$ proportional to the time rate of change of the current I(t) flowing through L_S. This voltage can be expressed as

$$V_{NOISE(t)} = LM \frac{dI(t)}{dt}$$

The third element involved in any noise problem is the receiver, or the circuit susceptible to the noise. It is important to understand the role of each of the three elements (the noise source, the coupling medium, and the receiver) in order to solve the noise problem*. In this experiment it was determined that the noise sources were 60 Hz pickup and AM radio signals, the coupling medium was stray capacitance and the receiver was the AD524.

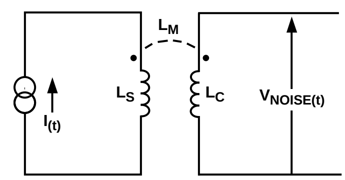

Figure 4. Mutual Inductance Noise

INITIAL NOISE EFFECT

The photograph in Figure 5 shows the output of the circuit in Figure 1 with the shield ungrounded and with the remote AD590 at 30°C. Ideally, the output should be a 3 V (100 mV/°C) dc signal. However, a 60 Hz signal resulting from an electric field has been capacitively coupled into the circuit via the stray capacitance of the cable and then amplified by a gain of 100. Note, however, that the 60 Hz signal is offset by a dc signal; when the output voltage of the AD524 was measured with a dc voltmeter the value read was 3.0 V. This is because the voltmeter read the value of the dc signal due to the AD590 along with the average value of the 60 Hz sine wave noise signal. The average value of a sine wave is zero. In essence, notwithstanding the interfering signal the average value was correct. The accuracy of all the measurements were verified through the use of an RTD measurement system; the AD590 under test was physically attached to the RTD.

*An excellent article dealing with this subject is "Understanding Interference-Type Noise" by Alan Rich, found in Section 20 of the Analog Devices Databook.

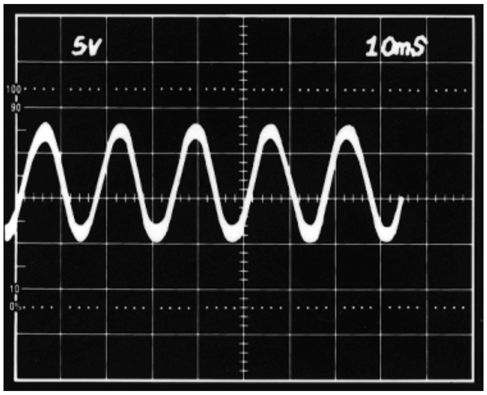

Figure 5. E_O (Figure 1) with Shield Ungrounded

SHIELDING

One effective way to eliminate electrostatic noise is to use shielding. A charge resulting from an external potential cannot exist on the interior of a closed conducting surface. A shield is, in effect, a closed conducting surface that surrounds the twisted pair of wires within the cable.

In order for a shield to be effective it should be connected to the reference potential of any circuitry contained within the shield. If the signal is connected to earth ground, then the shield should be connected to earth ground (see Figure 6). No voltage should exist between the reference potential and the shield conductor.

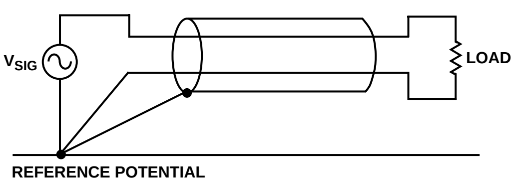

Figure 6. Correctly Shielded Cable

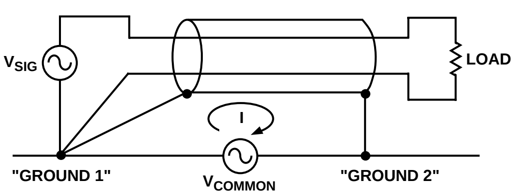

Figure 7. Incorrectly Shielded Cable

Only one end of the shield should be tied to "ground." Tying both ends of the shield to "ground" will produce a shield current equal to the difference in the potential of the two "grounds" divided by the series resistance of the shield (see Figure 7). As previously discussed, the mutual inductance between the shield and conductors will couple this noise current into the conductors in the form of a series voltage, V_{NOISE}.

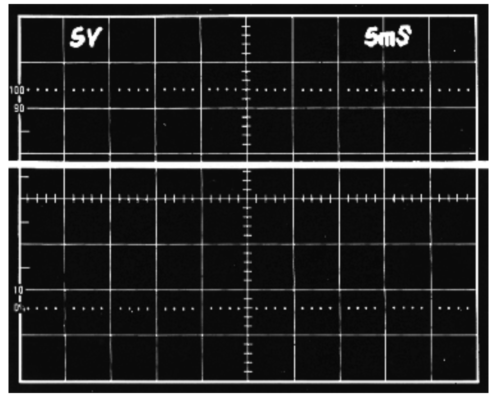

Figure 8. E_O with Shielded Grounded

Although the 60 Hz signal noise has been eliminated, voltage spikes are still visible in Figure 8. Figure 9, which is another view of the AD524 output with the scope ac coupled and the scale magnitude increased, shows the high frequency noise still being picked up by the cable. A look at Figure 10, which is a view of the signal being fed into the noninverting terminal of the AD524, shows that the noise being picked up is actually an AM radio signal.

RF NOISE

RF noise is a combination of an electric field and a magnetic field, or an electromagnetic field. This electromagnetic field extends into and beyond the space between conductors. That is, the electromagnetic field and hence the RF energy is "steered" by the conductors.

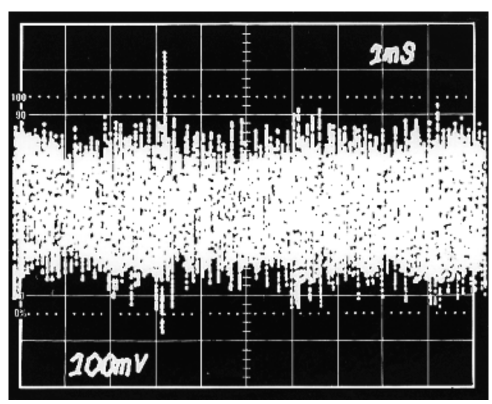

Figure 9. RF Noise at E_O

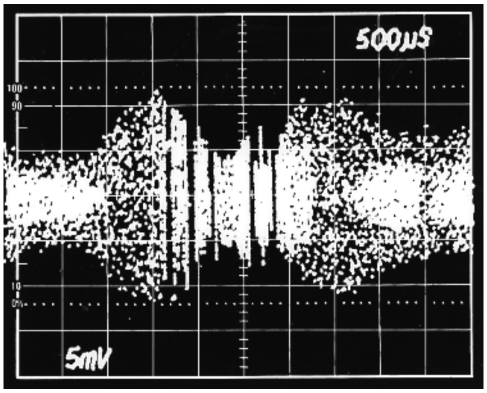

Figure 10. RF Noise at AD524 +Input

RF energy both enters and is reflected in a system wherever there is an impedance mismatch or discontinuity in the system. This includes discontinuities at the end of the signal run; at the AD590 end and the AD524 end of the cable. In order to eliminate these discontinuities it would be necessary to RF shield the entire circuit system, perhaps using conduit and metal boxes. In most cases however, this is rather impractical.

What is usually sufficient for most systems is to provide RF filtering using passive components at the critical point of interest. It is important to note that this filter may not eliminate the RF energy but it may just reflect the energy and redistribute the problem. A circuit topology which ensures that none of the external circuitry is affected by the RF noise is discussed later.

BYPASS CAPACITORS

A bypass capacitor can be used to divert some of the high frequency noise current to ground. Figure 11 is a simple schematic that shows the effect of the bypass capacitor. Recalling that the reactance of a capacitor $X_C = 1/2\,\pi\,fC$ and assuming that we have the minimum radio carrier frequency of 550 kHz, using a 0.33 µF capacitor the impedance seen by the noise current is:

$$X_C = 1/2\,\pi\,(550 \times 10^3)(0.33 \times 10^{-6}) = 0.88\ \Omega$$

Of course the direct current supplied by the AD590 will be unaffected by the bypass cap and will continue to flow into the 1 kΩ resistor. Only the high frequency noise current will be affected. Figure 12, which is a view of the signal at the AD524 noninverting terminal, shows the result of tying a 0.33 µF capacitor across the 1 kΩ "load" resistor with the shield still grounded. Figure 13 is a look at the output signal of the AD524 with the 0.33 µF capacitor. Compare Figures 10 and 12, and Figures 9 and 13. The bypass capacitor reduces the noise magnitude by a factor greater than 5.

In this instance the radio carrier frequency was 550 kHz. It is important not to ignore RF noise, even if the bandwidth of the external circuitry is smaller than the bandwidth of the RF noise. A large RF component will overload the inputs of the external circuitry and be detected, causing an apparent dc shift in the component's output signal.

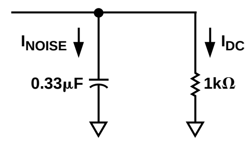

Figure 11. Bypass Capacitors Reduce RF Noise Effect

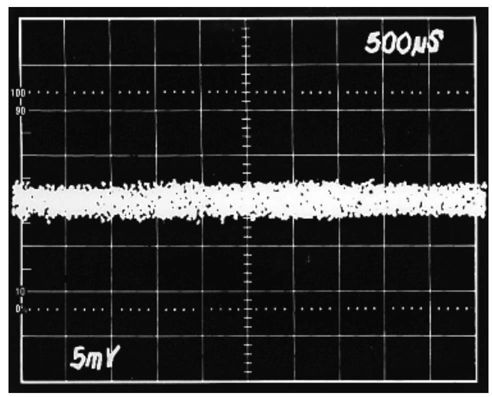

Figure 12. AD524 +Input with Bypass Capacitor

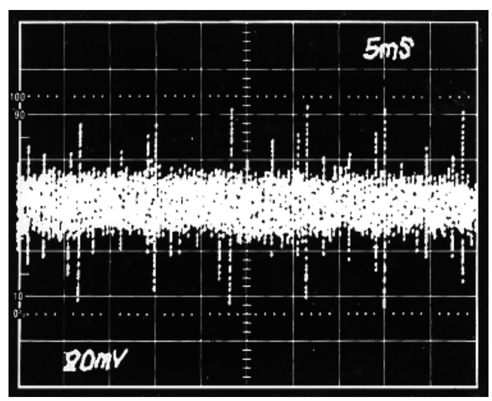

Figure 13. E_O with Bypass Capacitor

SERIES RESISTORS

Although an improvement, Figure 13 shows that noise is still entering the circuit. Another method of reducing the amount of noise seen at the noninverting terminal of the op amp is to limit the noise currents through the cable by adding 1 kΩ resistors in series with the AD590.

This in effect forms a noise-voltage divider between the load impedance (the 1 kΩ resistor and the 0.33 μF capacitor) and the series resistors. Figure 14 shows the output of the AD524 with this final circuit configuration. The 10 mV p-p amplitude of the output noise is actually 100 × the amplitude of the noise seen at the input of the AD524, which is 100 μV p-p. Note also that the high frequency spikes in Figure 13 have been eliminated in Figure 14. Figure 15 is the schematic of the final circuit which has reduced the noise by a factor of 2000 over the circuit in Figure 1.

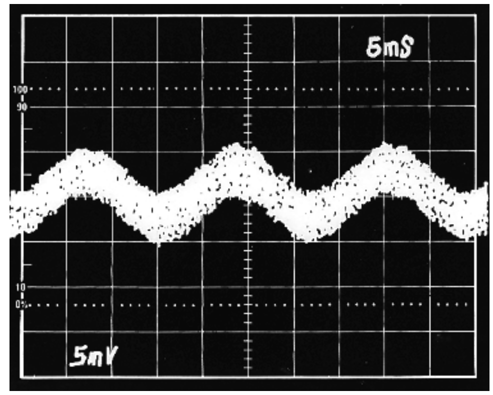

Figure 14. E_O with Bypass Capacitor and Series Resistors

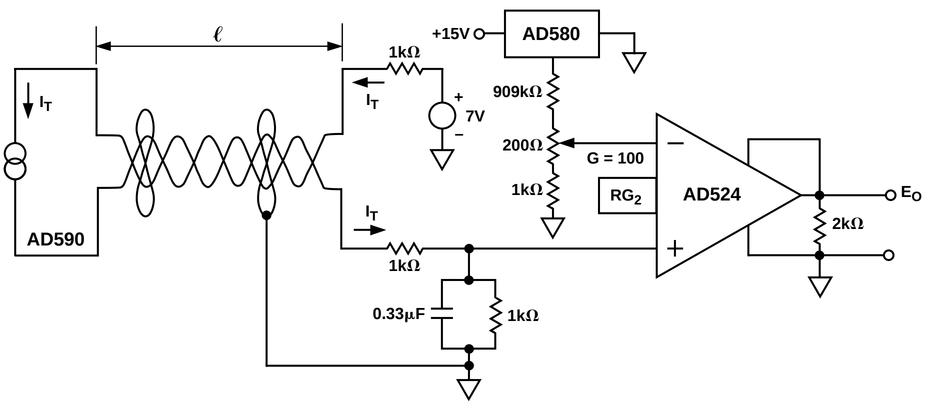

Figure 15.

CONCLUSION

In order to eliminate the effects of RF noise, the circuit of Figure 16 is recommended.

In Figure 16, the resistors and capacitors are placed at both ends of the cable. This ensures that the RF noise remains within the cable and does not affect the external circuitry. Further note that these resistors can be arbitrarily large as long as the voltage potential is large enough to supply the current (V = IR). The use of a bypass capacitor across the AD590 with the series resistors will filter RF signals. Theoretically the RF signal could be rectified by the AD590 and offset the accuracy of the device.

Using the techniques outlined above, noise and interference can be effectively eliminated through the use of shielded twisted pair cable and resistors and capacitors. Thus it is possible to drive the AD590 over 1000 feet of cable without a loss of accuracy.

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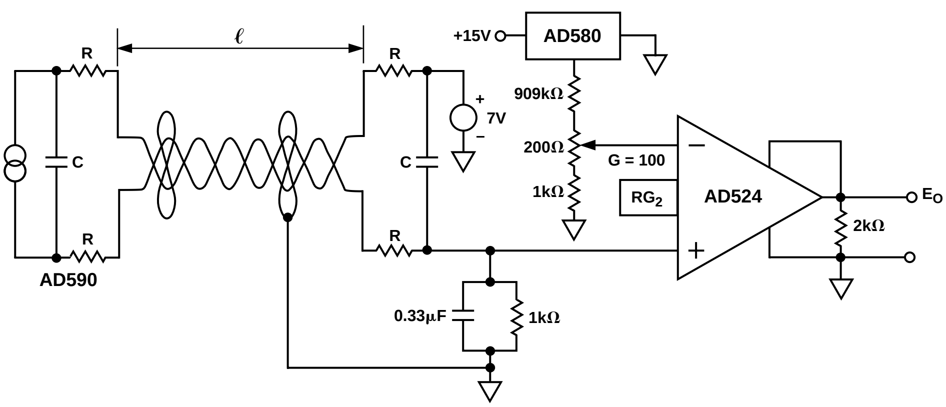

Figure 16.

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