

Application Note



Spacecraft Health Monitoring

Using

Analog Multiplexers and Temperature Sensors

Aeroflex Plainview Application Note

Spacecraft Health Monitoring using Analog Multiplexers and Temperature Sensors

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Overview:

One method of monitoring the health of a satellite is to measure the temperature of critical systems. For example there are often hundreds of areas to measure within: solar array panels, power systems / batteries and motors.

An effective way to retrieve and organize temperature measurements from various satellite bays or sensitive systems is to utilize circuits (See Figure 1) containing analog multiplexers, a precision current source, and temperature sensors such as Thermistors or Resistance Temperature Detectors (RTD).

The sensors' resistance changes predictably with temperature, and is characterized on the manufacturer's datasheets. (Table 1 is an example.) By exciting a sensor via a known current source, we are able to use Ohm's Law to correlate the sensor's analog voltage level into a temperature measurement.

Analog Multiplexers offer a convenient way of organizing and processing multiple analog voltage signals. As shown in Figure 1, the Analog Multiplexer (MUX) channels voltage signals from multiple sensors into a single channel of an analog to digital converter (ADC), which then passes digital information for system processing.

This application note will expand on the basic diagram below while highlighting the benefits of using Aeroflex's MUX85xx in common temperature monitoring solutions.

Benefits of following this application note's design recommendations are:

- Better signal organization
- Higher measurement accuracy with system error reduction techniques
- Typical 5:1 reduction in PC Board space (80% reduction)
- Improved reliability with Aeroflex's MUX85xx module that includes:
 - Input transient protection with built-in Transorbs
 - Single Event Upset (SEU) mitigation through the use of current limiting resistors
 - Improved EMI conducted emissions and susceptibility through decoupling capacitors

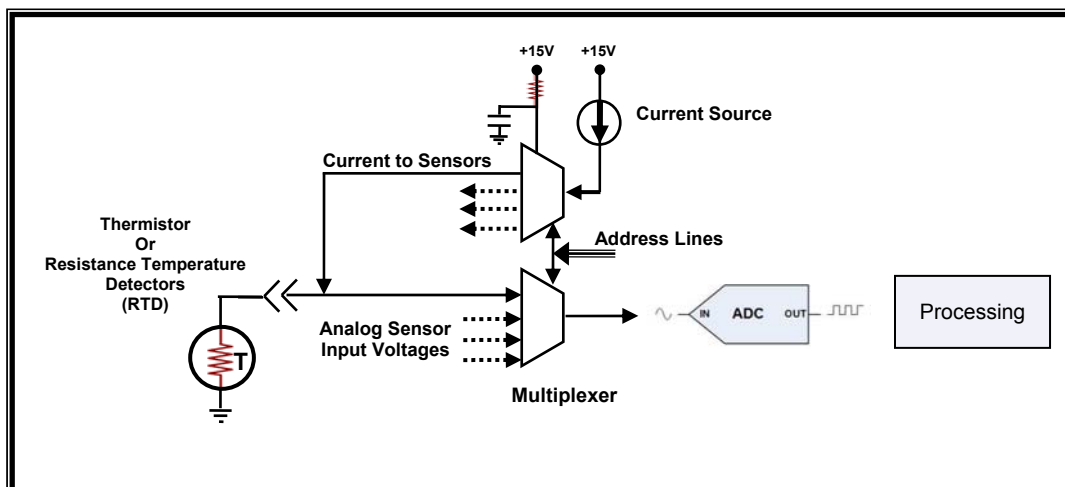


Figure 1

MUX85xx Advantage

Often satellites require hundreds of temperature measurements, which equates to hundreds of channels to monitor. When considering that most space grade multiplexers only come in 8 or 16-channel packages, an engineer will require a great number of MUX packages and PC board real estate.

Aeroflex's MUX85xx series solves this space challenge with a reliable, well tested MIL-PRF-38534 Class K device. Within the MUX85xx series there are products specifically configured for sensor applications. Below in Figure 2 is an example of MUX8502/12, where:

- (3) 16:1 Multiplexers (identified as B) provide 48 sensor input channels
- (3) 16:1 Multiplexers (identified as A) are paired with above for demultiplexing a single current source into the 48 sensor channels

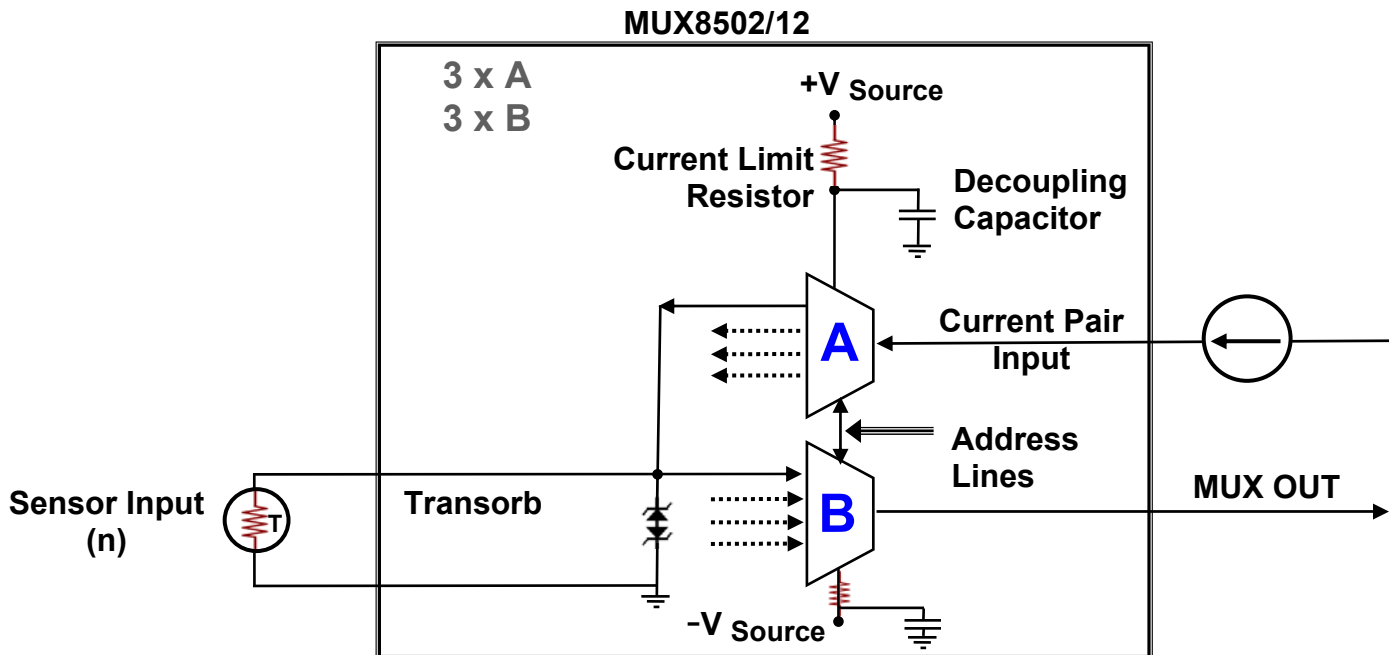


Figure 2

Aeroflex's MUX85xx solution offers:

- Greatest amount of channel flexibility
 - 16, 32, or 48 sensor input channels with each set of 16 paired with a second MUX for a current input. As shown in Figure 2
 - Visit www.aeroflex.com/MUXplainview for more combinations of multiplexers.
- Higher Reliability with
 - Input transient protection with built-in Transorbs
 - Single Event Upset (SEU) mitigation through the use of current limiting resistors
 - Improved EMI conducted emissions and susceptibility through decoupling capacitors
- Typical 5:1 PC board saving (80% reduction of space)
 - See Figure 3
- Save NRE with MUX85xx Multichip Module
 - Lower solution cost when compared to separately sourcing protection circuitry
 - A single module saves layout time and trouble shooting when compared to separately using 116 parts. An example is in Figure 3.

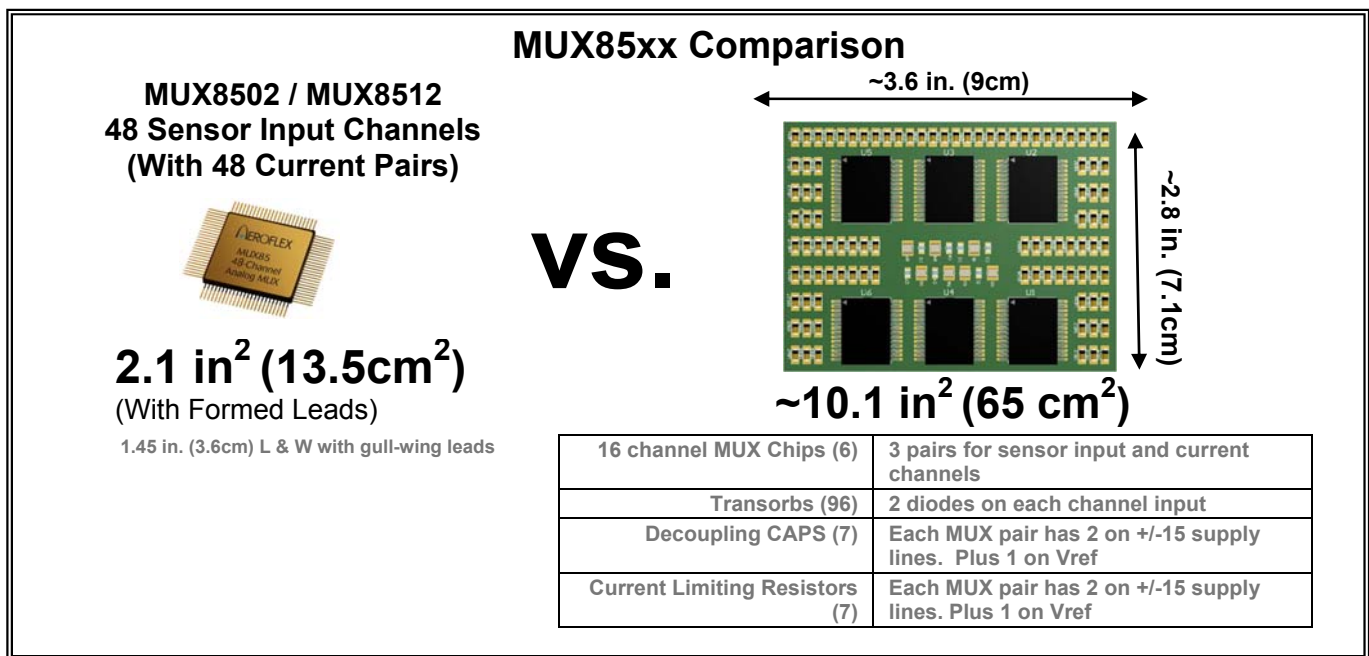


Figure 3

Picking the Right Temperature Sensor

Deciding on whether to use a Thermistor or a Resistance Temperature Detector (RTD) is based on the application. Below are some guidelines to help you determine the right solution for your design.

Thermistors are classified into two types: the resistance of positive temperature coefficient (PTC) thermistors increases with increasing temperature, and the resistance of negative temperature coefficient (NTC) thermistors decreases with increasing temperature (See Chart 1). NTC thermistors are more commonly used. Thermistors are generally made of ceramics or polymers and are suitable for temperature ranges between -90°C and 130°C . They are non-linear devices with respect to resistance and temperature. A common value at 0°C is $5\text{K}\Omega$.

More information may be found on: <http://en.wikipedia.org/wiki/Thermistor>

Resistance Temperature Detectors (RTD) are commonly made with platinum wire and a variety of manufacturing techniques that enables them to cover a wide temperature range of -200°C to 600°C . They are more linear than thermistors. A common value at 0°C is 100Ω .

More information may be found on: http://en.wikipedia.org/wiki/Resistance_thermometer

	Advantages	Disadvantages
Thermistor	<ul style="list-style-type: none"> Response Time (Typically their small size responds quickly to temp. changes) Less Expensive 	<ul style="list-style-type: none"> Limited Temperature Range (-90°C to 130°C) Less linear
RTD	<ul style="list-style-type: none"> Very Accurate Reasonably Linear Wide Temperature Range (-200°C to 600°C) 	<ul style="list-style-type: none"> Expensive Slower Response Time

Temperature Sensor Insight from GOES I-M Databook (Revision 1 Aug. 31 1996)

Source: <http://goes.gsfc.nasa.gov/text/goes.databook.html>

Forward note: Platinum resistors refers to an RTD

“Two types of temperature sensors are used: thermistors and platinum resistors. Thermistors are calibrated over two ranges: -40 to $+70^{\circ}\text{C}$ with a resolution of $\pm 1^{\circ}\text{C}$, or -18 to $+175^{\circ}\text{C}$ with a $\pm 2^{\circ}\text{C}$ resolution. Thermistors are generally applied to electronic units whose typical operating range is -10 to $+45^{\circ}\text{C}$, with a non-operating range of -25 to $+51^{\circ}\text{C}$. They are also used extensively on propulsion components whose typical operating range is -3 to $+165^{\circ}\text{C}$. The platinum resistors have a range of -200 to $+125^{\circ}\text{C}$ with a resolution of $\pm 2^{\circ}\text{C}$. These are used on components with wide temperature ranges such as the solar array, which has a range of -165 to $+70^{\circ}\text{C}$.”

Recommendations for your Circuit

This application note uses NTC thermistors with the following characteristics:

Thermistor Sample Values

Temp °C	Resistance (KΩ)
-55	482.2
-32	100.3
-20	48.56
-15	36.49
-10	27.67
0	16.33
15	7.857
25	5.000
50	1.801
75	0.740

Table 1

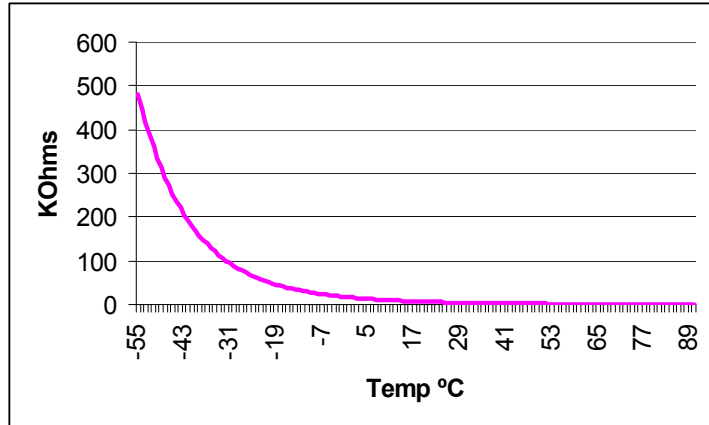


Chart 1

Reading Temperature from the Thermistor Sensor

A precision current source is the preferred method for exciting a voltage out of the thermistor. With a constant current source, a change in the sensor's resistance is directly proportional to the voltage.

A designer must be aware that the constant current source may drift over time due to radiation affects. This error can be compensated for. Later this application note will discuss a calibration process, which will allow the designer to monitor and compensate for any changes in the current source.

Instead of a constant current source an alternate method would use a precision voltage supply (typically +5.000 V) to make a voltage divider with a separate precision resistor (typically 5 KΩ) for each sensor. Each component may drift over time resulting in a reduction in measurement accuracy on each sensor. This application note will utilize the precision current source. Overall, either approach is valid. The preferred implementation depends on your required accuracy, cost and board space.

Reading Temperature from the Thermistor Sensor (Continued)

Figure 4 demonstrates the constant current source method.

As shown in Figure 4 we have placed a resistor (R_1) in parallel with the thermistor. The value of R_1 was chosen based on the following considerations:

1. Desired range of temperature measurements. This application note assumes -32°C to 75°C .
2. Choose a value for R_1 that prevents saturation of the current source driver. For example, clipping (V_{OUT} without R_1) is shown in Table 2 on temperatures less than 0°C ., where the resistance would drive the current source into saturation and not able it to drive the current. (The current source is not able to generate a higher voltage than its 15V source.)
3. Compatibility with an Analog to Digital (ADC) device's input voltage range. This application note assumes that the ADC device has a 0 – 5V input range. With $R_1 = 5.23\text{K}$, we see in Table 2 that the column (V_{OUT} with R_1) maintains V_{OUT} below 5V over the entire range of temperatures.

Temp $^{\circ}\text{C}$	R_T ($\text{K}\Omega$)	V_{OUT} With Out R1	V_{OUT} With R1
-32	100.3	~ 14.9	4.97
-20	48.56	~ 14.9	4.72
-15	36.49	~ 14.9	4.57
-10	27.67	~ 14.9	4.40
0	16.33	~ 14.9	3.96
15	7.857	7.86	3.14
25	5.000	5.00	2.56
50	1.801	1.80	1.34
75	0.740	0.74	0.65

Table 2

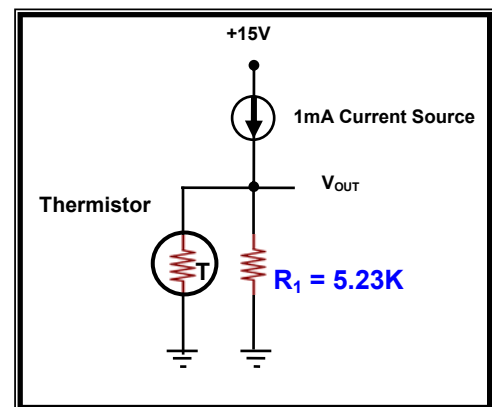


Figure 4

Sample Temperature Circuit 1 (Figure 5)

Figure 5 shows a sample circuit with N thermistors creating N analog voltage signals. Each analog voltage signal channeled through the multiplexer corresponds to one temperature measurement. However, when examining this circuit, one would predict variances in accuracy due to using a specific current source for each thermistor, because the multiple current sources are not perfectly matched. We are able to mitigate the error induced by current source matching by adding an additional multiplexer to allow a single current source to be used for all of the thermistor input channels.

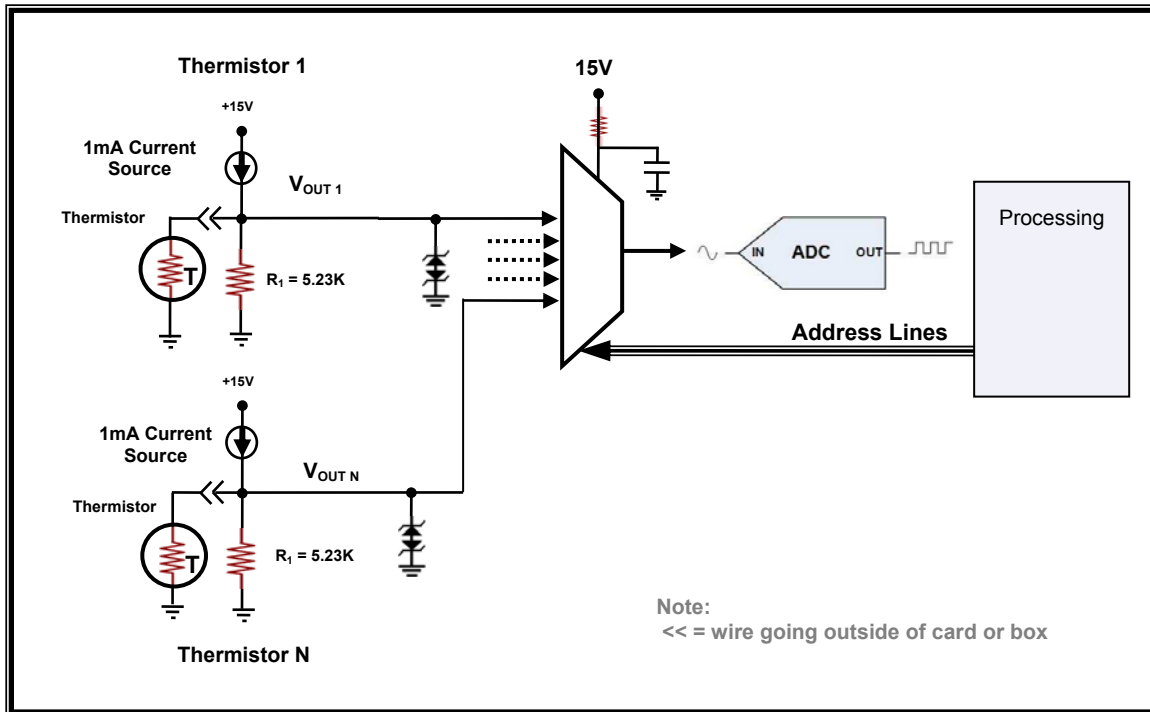


Figure 5

Sample Temperature Circuit 2 (Figure 6)

The prior Figure 5 is further optimized by adding a multiplexer to channel a single current source into each thermistor input. This allows all thermistors connected to the current source to have consistent measurements, because the variation due to mismatched current sources is eliminated. In Figure 6 we denote this multiplexer as MUX (Current). The MUX (Current) is used as a demultiplexer (DEMUX). Both the MUX (Sensor Input Voltage) and MUX (Current) have their address lines tied together, since both MUXes have the same input channel selected under all conditions.

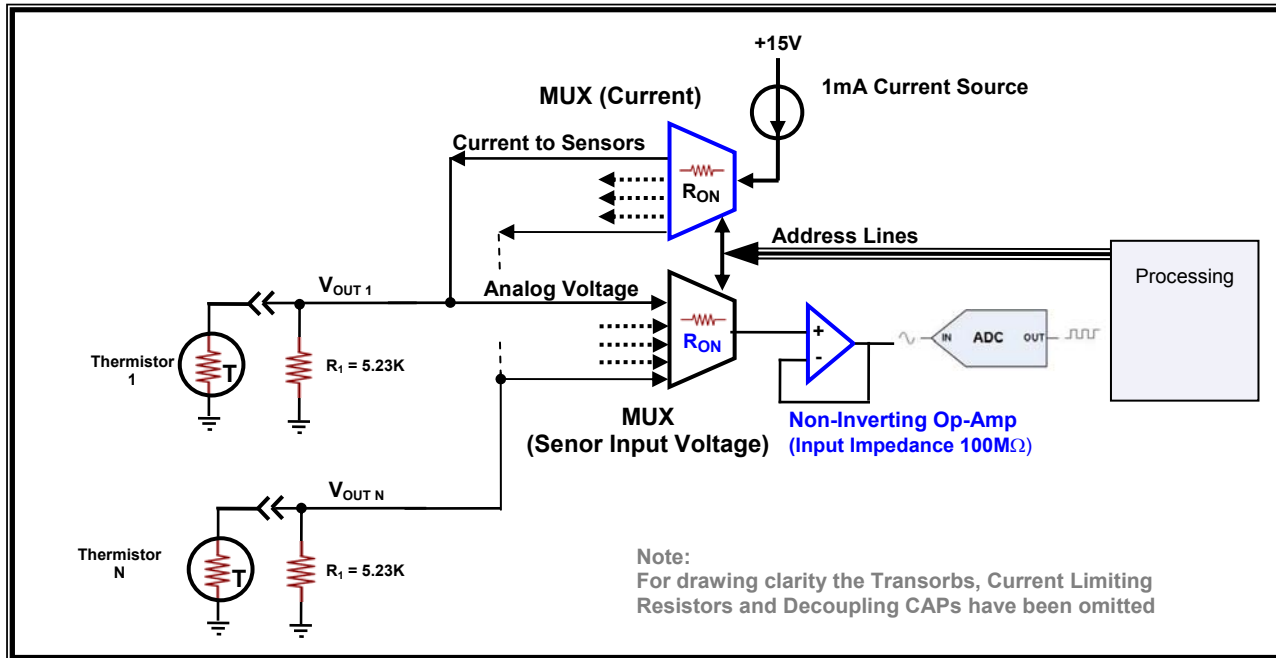
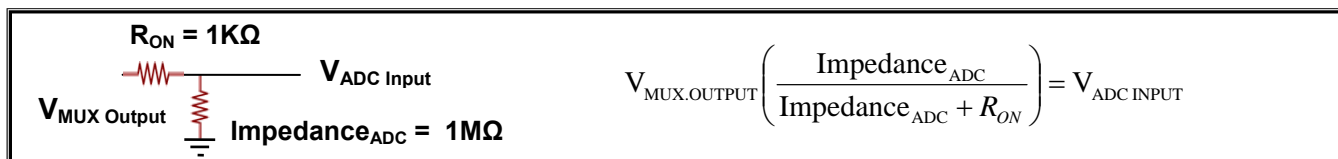


Figure 6

Another possible source of error is from the inherent R_{ON} of the MUX (Sensor Input Voltage). A typical value is around 1000Ω , but this may vary over temperature, thereby adding an additional error component. Measurement error (Error_ R_{ON} below) is related to the voltage divider formed by R_{ON} resistance and the input impedance of the ADC.



Regardless of the R_{ON} value we are able to reduce its affect. In Figure 6 we added a non-inverting unity-gain Op-Amp between the MUX (Sensor Input Voltage) and the ADC. The calculation below shows an R_{ON} error reduction from 0.1% to 0.001% with an Op-Amp that has an input impedance of $100M\Omega$.

Without Op-AMP
$$\text{Error}_{R_{ON}} = 1 - \left(\frac{\text{Impedance}_{ADC}}{\text{Impedance}_{ADC} + R_{ON}} \right) = \frac{R_{ON}}{\text{Impedance}_{ADC} + R_{ON}} = \frac{1K\Omega}{1.001M\Omega} = 0.1\%$$

With Op-AMP
$$\text{Error}_{R_{ON}} = \frac{R_{ON}}{\text{Impedance}_{Op-AMP} + R_{ON}} = \frac{1K\Omega}{100M\Omega + 1K\Omega} = 0.001\%$$

Optimized Temperature Circuit 3 (Figure 7)

Further refinements are possible with the addition of a Calibration Resistor and EMI Filtering Capacitors.

Calibration Resistor

A high precision calibration resistor was added to compensate for variations of the 1mA current source from the effects of temperature, radiation and aging. The calibration resistor acts as a reference point mitigating any variations that may happen during the mission. To achieve the benefit of on-line calibration one must first select and measure the calibration resistor. Since we know the precision resistor's value (1 K Ω) we are able to determine the currents source's value ($I_{\text{current source}} = V_{\text{measured}} / 1 \text{ K}\Omega$). If variances occur to the current source its new value would be available to update the temperature algorithm that converts the thermistor's voltage level into temperature.

EMI Filtering Capacitors

Temperature sensing thermistors are usually spread out across the satellite making their wires susceptible to pick up EMI. The addition of the 0.1 μF capacitors (typically ceramic) compensates for EMI, but this may affect system timing. A delay is added due to the time required for the constant current source to charge the capacitor to its final voltage value.

Engineers need to be mindful of this additional time variable and switch the MUX slow enough to allow for a stable voltage to be read by the ADC. For faster switching MUX time a smaller capacitor may be used, but this will reduce EMI filtering. The next section details more on EMI.

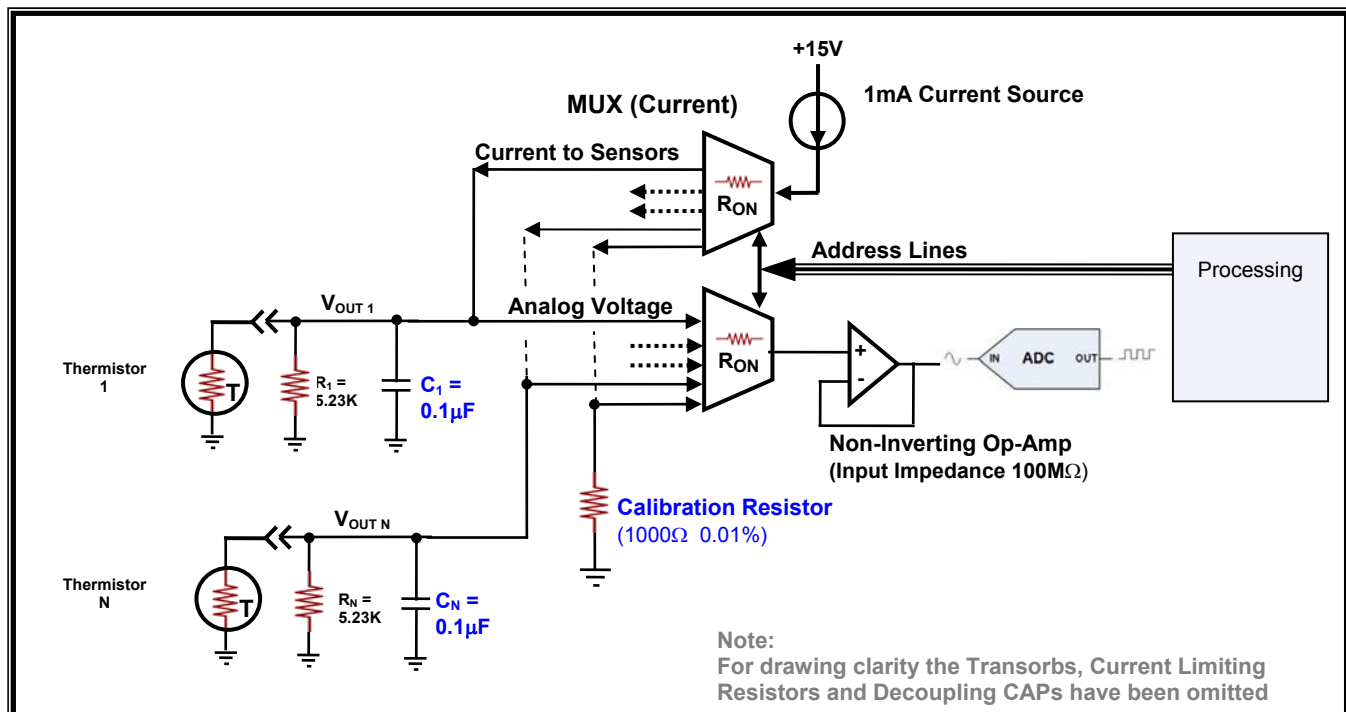


Figure 7

Filtering for Electromagnetic Interference (EMI)

In spacecraft applications, the temperature sensors are often located at some distance from the data acquisition unit, which contains the MUX, excitation source and processor, and are connected by cables. As a result, designing to meet EMI requirements is critical, particularly with respect to Radiated Susceptibility (RS) and Radiated Emissions (RE). Test requirements and techniques are often identical or similar to those specified in MIL-STD-462.

Radiated susceptibility problems are caused by the presence of radiated electromagnetic fields, which may be produced by transmitters on board the satellite, or by other sources. For each application, the applicable frequencies and field strengths are generally specified. These electromagnetic fields can induce voltages and currents in the interconnecting cables, which can be superimposed on the DC voltage from the temperature sensor, thereby causing a measurement error. In general, it is necessary to determine the amplitude of the voltage and current that can be induced on the cable, and, if necessary provide an input filter circuit or other means of attenuating this induced voltage (or “pickup”) so that it will be negligible, relative to the required measurement accuracy. This is equivalent to achieving a desired signal-to-noise (S/N) ratio.

In most cases, RS problems occur when the amplitude of the induced voltage is sufficiently large for detection, or rectification, to occur. “Detection,” in this context, is a carryover from Amplitude Modulation (AM) detection in a radio receiver. The DC component, or the AM component, is extracted from the carrier frequency by the detection process, resulting in an error in the measured voltage, which becomes an error in the measured temperature.

Unlike many integrated circuits, the analog inputs of the Aeroflex MUX85xx series of multiplexers do not contain the usual clamping diodes, which would act as AM detectors. (For this reason, the Absolute Maximum Rating of the analog input voltage can exceed the positive and negative input rail voltages.) However, it is likely that the circuits connected to the outputs of the multiplexers, including the current source, buffer amplifier and A/D converter, do contain clamping diodes, which can cause detection. For this reason, it is necessary to insure that the MUX input EMI voltages are kept below the threshold of detection, which is usually several hundred millivolts. This is usually accomplished by combinations of the following techniques:

- Twisted pairs, with a separate return for each temperature sensor, on the interconnecting cables to provide common mode rejection.
- Shielded cables to provide attenuation of the induced voltage on the cable. For extremely large field strength levels, double-shielding may be required.
- A low-pass filter on each MUX input. This may be a single ceramic capacitor, or a more complex network. Care must be taken to assure that capacitors provide low impedance at the frequencies of interest.
- Filter pins on the mating connector.
- Proper design and layout of the printed circuit card.
- Careful analysis of the system timing, to avoid low-voltage measurements during periods of generation of high field strength.

It should be noted that the capacitance of the analog inputs of the multiplexers is on the order of 70 picofarads. This capacitance can be a helpful component of the input EMI filter, and can provide significant attenuation at high frequencies.

Electrostatic Discharge (ESD) Protection via Transorbs

ESD requirements are often imposed as part of the procurement specification. In many cases, the “human body model” is employed, in which a 100 pf capacitor is charged to 4000 V, either positive or negative polarity, and discharged into every I/O pin of the unit, through a defined series resistance. This test is designed to simulate the situation of a person accumulating charge, such as may happen from walking on a carpeted surface in a room with low humidity, and then discharging the accumulated energy into an exposed pin. Multiplexers being connected to temperature sensors are particularly susceptible to ESD because they may be directly connected to the “outside world.”

The design for ESD protection is somewhat related to EMI protection, but often an input filter does not provide sufficient ESD protection. For this reason, Aeroflex MUX85xx devices include bidirectional transorbs on every analog input. The transorbs are open circuits at low voltages, but act as voltage clamps to protect the MUX inputs at +/- 20 V, which is adequate to provide protection for all commonly specified conditions of ESD.

Conclusion

This temperature monitoring application note has demonstrated an effective methodology for improving accuracy and better organizing temperature signals through the use of analog multiplexers.

Analog multiplexers are paired together with one sending current to the sensors and another retrieving the sensors’ analog voltage reading. Additional circuitry elements were also identified for protection and improved accuracy.

Aeroflex’s analog multiplexers (MUX85xx series) provide designers with compact HiRel solutions that incorporate paired MUX connections with internal protection according to MIL-PRF-38534 Class K manufacturing.

For more information on Aeroflex’s multiplexer offering please visit:

www.aeroflex.com/MUXplainview

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