Advantages of Precision Resistance Networks for Use in Sensitive Applications

Abstract

Modern electronics can be produced with improved performance and reliability by integrating resistance dividers and networks into common packages in place of discrete components. This paper discusses several of the advantages of selecting specialized dividers and networks, including performance specifications, lot uniformity, physical constraints, and cost and procurement logistics. An analysis of an amplifier and voltage divider circuit has been done to highlight some of the advantages in practical applications.

Introduction

Analog circuit designers may improve circuit performance and reliability by specifying resistor networks and dividers within schematics that call for stability over time, under varying power levels, and despite environmental changes. Without specialized network specifications, engineers may not be able to achieve target performance specifications with their designs. Figure 1 displays some common schematics whose performance relies on identical operation of multiple resistors. Various MIL specifications and available QPL data may be considered to show that resistance networks offer several advantages as compared to discrete components, and are available using commonly available technology.

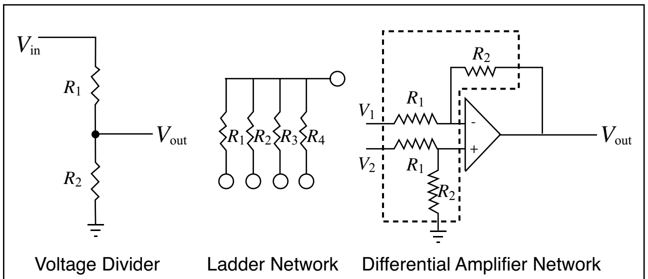
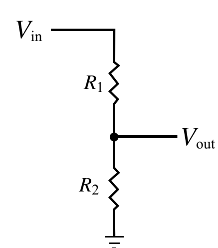


Figure 1. Typical precision resistor schematics

Mounting Considerations and Real Estate

Designers may save board space when they specify resistor networks by optimizing the available layout geometries. Mounting configurations include but are not limited to surface-mount, through-hole, and wire bonding methods. Discrete components require that each resistor have two terminals, unlike dividers or networks where common output pins may connect two or more resistors. Consider the voltage divider in Figure 1, which uses three terminals instead of four as separate resistors would. Dividers and networks also can benefit from positioning multiple resistors on a single substrate. It is not uncommon to reduce footprint area by 25% or more by utilizing multi-resistor substrates in both PCB mount and hybrid wire bonding applications by combining bond pads and terminations.

Temperature Coefficient of Resistance (TCR) Tracking – The Reference Voltage Divider



$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Figure 2. Voltage divider

The TCR tracking parameter becomes important in the case of a voltage divider generating a reference voltage. The resistance drift with temperature contributes to errors in circuits that experience significant ambient temperature changes. The ratio can only be maintained if two resistors maintain a fixed value as the temperature is varied (have a TCR of zero) or else both shift in the same direction and magnitude (as a percentage). The worst case analysis of temperature drift of a voltage reference can be theoretically calculated to show the advantage of using precision networks as compared to very low TCR discrete resistors. One exception to the matching TCR rule for high TC resistors however, applies when the resistors because of their locations are operating at different temperatures, in which case only the lowest absolute TCR will result in a stable ratio. Reviewing a very low TCR resistor with the specification of 5 ppm/°C, the maximum drift can be calculated both in worst case conditions from +25°C to +125°C. In worst case analysis, the ratio of two seemingly

Advantages of Precision Resistance Networks for Use in Sensitive Applications

Table 1 - Worst Case Analysis — Discrete M55342 char E Resistors TCR Tracking

Resistor	Value at 25°C	TCR –55°C / 25°C / +125°C	TCR Tracking	V_{in}	V_{out} at 25°C	V_{out} at 125°C	Temperature Drift
R1	1000 Ω	+25 ppm/°C	50 ppm/°C	5V	2.500V	2.50625V	**5000 ppm (6.25 mV)**
R2	1000 Ω	–25 ppm/°C					

Table 2 - Worse Case Analysis — Precision Foil Resistor Network Optimized for 0.5 ppm/C TCR Tracking

Resistor	Value at 25°C	TCR –55°C / 25°C / +125°C	TCR Tracking	V_{in}	V_{out} at 25°C	V_{out} at 125°C	Temperature Drift
R1	1000 Ω	+5 ppm/°C	0.5 ppm/°C	5V	2.500V	2.500062V	**50 ppm (0.062 mV)**
R2	1000 Ω	+4.5 ppm/°C					

identical resistors may be as mismatched as much as twice their TCR. This can be seen when one considers resistors specified as ±5 ppm/°C, which may be as far as 10 ppm/°C apart should one resistor be +5 ppm/°C and the other resistor –5 ppm/°C. Some networks using ultra stable resistive elements such as Bulk Metal® Foil resistors, which have both low absolute TCR as well as extremely low TCR tracking, may allow circuit designers to design a 2.5V reference circuit with an error budget of less than 50 ppm across a ±100°C temperature variation once calibrated.

Careful attention to TCR tracking and specifying tightly matched resistor ratios, such as those found in precision foil resistor networks, can reduce the circuits error budget by an order of magnitude or greater.

Lot Uniformity

Resistor networks and single-substrate resistors guarantee users that each resistor involved has been manufactured using the same processes, under like conditions, and at the same time. The use of various discrete components runs the risk that each component may have a different date code, manufacturer, and even technology type. A MIL-PRF-55342 chip, for example, can be either thin film or thick film technology since both are qualified to meet the same characteristics. Resistance ratios which use two different values and, by default, separate part numbers will have a high likelihood that a divider network will use two chips produced at different times and under different conditions. Networks are able to be built using only elements from a common ceramic plate production, and even then improved performances are realized further when chips are located on a common substrate to ensure uniformity between components.

Known Good Die

Engineers often seek out parts which they are familiar with, and often those which have an established history of performing reliably in sensitive applications. Improved performance from resistor networks cannot be utilized at the expense of reliability. If higher levels of performance are required than can be obtained using existing MIL specs, designers can specify custom networks using the exact same Bulk Metal® Foil processes and technology as qualified to MIL-PRF-83401, char C. Designers may specify various schematics, resistance values, tighter TCRs, tighter tolerances, better long-term stability, and critical ratios with the same technology qualified to the existing MIL-PRF-83401 and many other military and space specifications. Networks like this can be built with very fast lead times as well since the initial process R&D has already been developed. Additionally, manufacturers of precision foil resistor specification MIL-PRF-55182/9 have the capability of adding a third lead to the same package forming a resistance divider, while maintaining the same materials and processes of the very stable standard RNC90 resistors that are qualified to R level failure rates. Specifying resistor networks in this way does not require costly qualifications or experimenting with untested technologies.

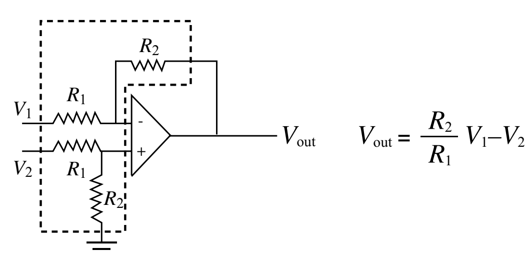


Figure 3. Differential amplifier

Long-Term Drift – The Differential Amplifier

Once calibrated and installed, equipment must operate on its own until the specified recalibration period, otherwise the designer cannot be confident in the stability of the ratiometric resistors in the circuit. In high reliability

Advantages of Precision Resistance Networks for Use in Sensitive Applications

applications, such as undersea telecommunications, space applications, and downhole drilling, resistor networks must behave reliably and stable for long periods of time without any means of adjustment or recalibration. The load life specification provides a good indicator of how well components will maintain their ratios after applied power, temperature, and time. Since the tendency of resistors in a set to drift together is the primary measure of ratio stability, a comparison of each lot's standard deviation after 1000 hours of life testing is an easy and effective estimation of long-term ratio drift. So that the comparison is accurate and relevant, the most stable QPL resistors, both discrete and networks, with the tightest load life specification, MIL-PRF-55182/9 discretes and MIL-PRF-83401 char C networks, have been selected for comparison below. The following test summary data was accumulated from Vishay Foil Resistors' QPL maintenance program at facility S8016 for MIL-PRF-55182/9 and MIL-PRF-83401/01 testing requirements.

From Figure 3 and Tables 3 and 4, we can see that the gain ratio, R_2/R_1, would benefit from four tracking resistors in a network package deviating from the average trend of the lot by a typical 7.7 ppm from each other as compared to a discrete component 29.2668. In this data set, there was not one case in which the discrete resistors used in a differential amplifier outperformed network resistors in the 1000 hour load life test.

Table 3 - Load Life Test

Results After 1,000 Hours		Network Resistors MIL-PRF-83401 Style
Date Code	**Qty of Resistors**	**Average 1σ Lot Deviation (ppm)**
0714	10 networks of 7 isolated resistors	4.50745
0741	10 networks of 7 isolated resistors	12.193
0814	10 networks of 7 isolated resistors	9.3634
1014	10 networks of 7 isolated resistors	4.9174
	280	**7.745313**
	Total Qty	**Weighted Average Standard Deviation**

Table 4 - Load Life Test

Results After 1,000 Hours		Discrete Resistors MIL-PRF-55182 Style
Date Code	**Qty of Resistors**	**1σ Lot Deviation (ppm)**
0606	48	35.09
0736	48	34.419
0828	48	29.921
0910	48	28.684
0937	24	24.571
1001	24	11.869
	240	**29.2668**
	Total Qty	**Weighted Average Standard Deviation**

Cost Savings

Resistive networks may in many cases provide a lower overall solution cost than discrete components. It may be much more cost effective to qualify a single network than procuring various different resistance values in different quantities from different suppliers. Networks also allow customers to specify only a single part number, which they may stock accordingly for their program. Finally, during the assembly process, there is only one component to mount, inspect, and test as compared to isolated parts.

Conclusions

Resistor networks allow designers to achieve higher levels of precision measurement and signal conditioning than with discrete components. They can achieve their goal of ratiometric stability reliably, and by using known MIL qualified designs. There may be cases where cost savings are realized through logistics purposes and decreased board space requirements. In circuits requiring stable operation under extreme environmental variances, precision resistor networks will meet higher performance specifications than discrete resistors of the same resistor technology.

References

MIL-PRF-55182: Resistors, Fixed, Film, Non-Established Reliability, Established Reliability, and Space Level, General Specification for (w/Amendment 4) FSC: 5905, Revision: H, Dated: 13 January 2012

http://www.landandmaritime.dla.mil/Programs/MilSpec/ListDocs.aspx?BasicDoc=MIL-PRF-55182

MIL-PRF-83401: Resistor Networks, Fixed, Film, and Capacitor-Resistor Networks, Ceramic Capacitor and Fixed Film Resistors, General Specification for (w/Amendment 1) FSC: 5905, Revision: H, Dated: 03 February 2011

http://www.landandmaritime.dla.mil/Programs/MilSpec/ListDocs.aspx?BasicDoc=MIL-PRF-83401