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Precision resistor arrays stabilize and enable miniaturization of electronic circuits

By Vishay Draloric/Beyschlag
Resistors Division, Dr. Carsten
Bronskowski

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Thin-film chip resistor arrays can accommodate this demand for reduced size, higher precision, and increased electric stability through their integration of multiple resistors on a single ceramic substrate. By integrating these components, resistor arrays require less space than the same number of discrete resistors. This permits a higher package density of the electronic circuit and thus a higher number of electronic functions per area unit. In addition, thin-film chip resistor arrays are used in applications where the relative behavior of the resistors is critical, such as voltage dividers and feedback circuits in environments where operational amplifiers or dc-to-dc converters are used.

This article shows how thin-film chip resistor arrays can positively affect a circuit's electric stability while at the same time minimizing the area required. Using the example of a voltage divider, the relative parameters "tolerance matching" and "TCR tracking" are explained and the temperature behavior of resistor arrays is discussed. In addition, it is shown how the tolerance and temperature coefficient of resistors can be controlled during the production process.

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Precision resistor arrays stabilize and enable miniaturization of electronic circuits

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Relative tolerance (Tolerance matching) using the example of a voltage divider

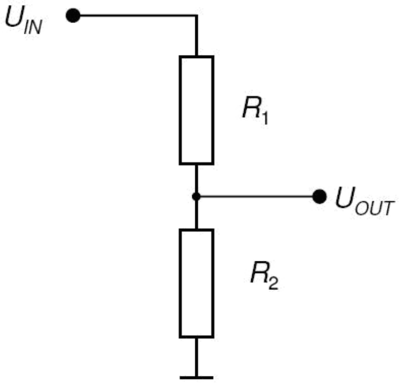


Image 1: Voltage divider composed of R_1 and R_2.

Image 1 depicts an unloaded voltage divider composed of the resistors R_1 and R_2. At the voltage divider's output pin, the output voltage V_{OUT} – which is determined by the value of R_1 and R_2 and their deviation against the nominal resistance value Δ - can be measured.

$$V_{OUT} = \frac{1}{1+\frac{R_1}{R_2}\cdot\frac{1+\Delta_1}{1+\Delta_2}} V_{IN} \qquad (1)$$

The deviation against the nominal resistance is described as absolute tolerance. The error term $(1+\Delta_1)/(1+\Delta_2)$ is equal to 1 if both absolute tolerances Δ_1 and Δ_2 are equal. Approximately equal tolerances are achieved in resistor arrays. ***Image 2*** shows an example for the tolerances of a thin film chip resistor array with four integrated resistors.

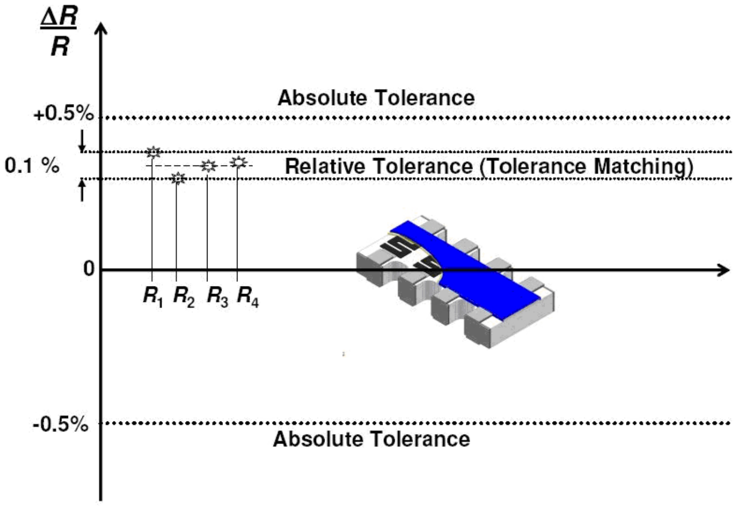


Image 2: Tolerance of a resistor array

In this example, all four resistor values of the array lie within the absolute tolerance limit of ± 0.5 percent. In addition, for precision resistor arrays the tolerance matching is also specified. This is defined as the spread between minimum and maximum resistance deviation; it is an unsigned value. In the example above, the tolerance matching amounts to 0.1 percent. When compared to single resistors used in a voltage divider this equals a deviation of ± 0.05 percent.

Relative temperature coefficient (TCR tracking)

The absolute temperature coefficient α describes the change of the resistance against temperature increase or decrease:

$$\frac{\Delta R}{R_{20}} = \frac{R_{\vartheta} - R_{20}}{R_{20}} = \alpha\left(\vartheta - 20°C\right) \qquad (2)$$

In this context, ϑ represents the layer temperature in degrees Celsius (°C), R_ϑ is the resistance value at layer temperature, and R_{20} is the resistance at 20°C (reference temperature). At a temperature of $\vartheta = 20°C$, $\Delta R/R_{20} = 0$. As per ***equation (2)***, the resistance variation ΔR decreases with lower temperature coefficient α. For this reason, a low temperature coefficient (TCR) is indispensable in order to guarantee a low resistance deviation through temperature variation. The TCR is specified in ppm/K. If the ambient temperature ϑ increases as a consequence of thermal conduction, thermal radiation, or convective flow through near-by components to 120°C, for example, a 50-ppm/K resistor will change its value by ± 0.5 percent. The temperature coefficient always refers to a defined temperature range. Typical temperature ranges are – 55°C to + 125°C. For automotive applications in harsh environments like engine control units or gear box controls, the temperature range goes up to +155°C. ***Image 3*** shows the TCR for a thin film chip resistor array.

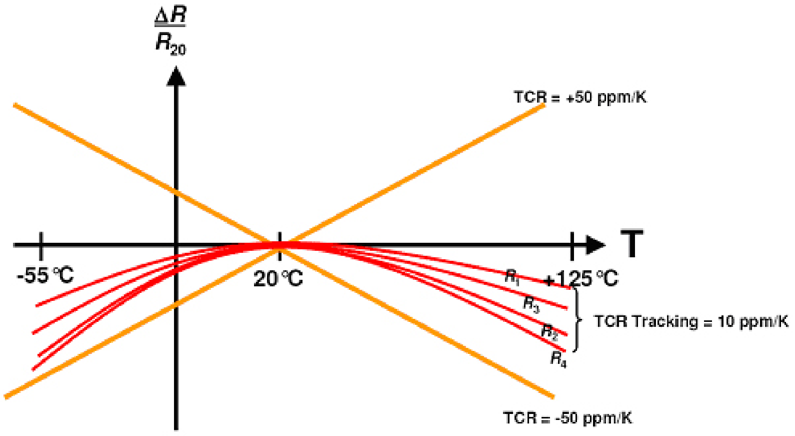


Image 3: TCR tracking

The limit for the absolute TCR in this case amounts to ± 50 ppm/K. The TCR curves for the four integrated resistors R_1, R_2, R_3, and R_4 are within these limits. In a precision resistor array, the relative temperature coefficient is specified in addition to the absolute one. The relative TCR (TCR tracking) is defined as the difference between the highest and the lowest TCR of the four integrated resistors. In this example, TCR tracking amounts to 10 ppm/K. This corresponds to a TCR of ± 5 ppm/K in a temperature range of – 55°C to + 125°C with respect to discrete resistors incorporated in a voltage divider. Like in the discussion of the relative tolerance, the four resistors exhibit a uniform behavior with respect to TCR tracking, which yields a desirably low value.

Temperature behavior of a voltage divider

Across a printed circuit board, in most cases the local ambient temperatures differ from region to region. This is a consequence of thermal conduction, thermal radiation, and the convective flow of heat among adjacent components. If discrete resistors are used, different ambient temperatures result in diverging resistance variation. This effect is illustrated in the ***Image 4***.

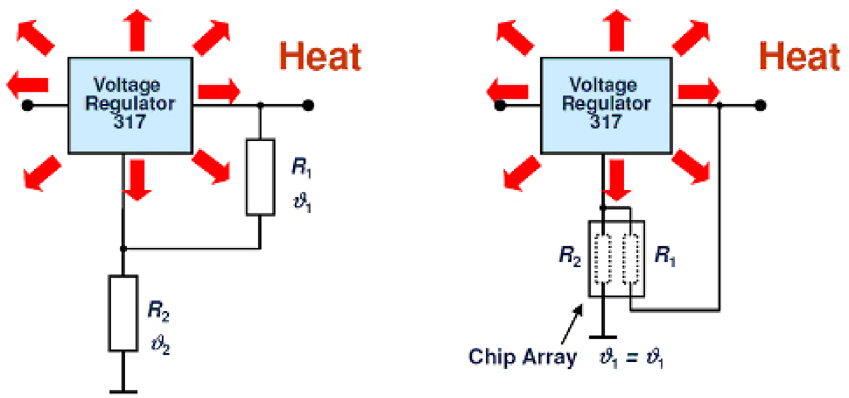


Image 4:
Left - different local ambient temperatures if discrete resistors are used.
Right - equal local ambient temperature if integrated resistors (resistor array) are used.

The output voltage of a fixed voltage regulator is adjusted by means of a voltage divider (***Image 4***, left). The two discrete resistors have a value of $R_1 = R_2 = 1$ kΩ and a TCR of ± 50 ppm/K. They are located one below the other on a PCB. The fixed voltage regulator which is placed next to R_1 causes an ambient temperature increase as a consequence of thermal radiation and convection. This causes the temperature of R_1 to rise to + 120°C. The local ambient temperature of R_2 remains almost unchanged at + 20°C. The different temperature levels of R_1 and R_2 produce a voltage divider mismatch that can be computed using equation 2. The impact of the mismatch to the adjacent circuit which contains the voltage regulator can be significant. In the worst case the fixed voltage regulator fails to provide the voltage stability required which in turn can cause the entire circuit to fail.

This effect can be reduced by placing R_1 and R_2 on an isothermal line as much as possible. By doing this, the ambient temperature of R_2 is brought closer to the temperature level of R_1. However, since discrete resistors can only be placed at certain minimum distances to each other, even the smallest possible distance will involve a different temperature level. The situation becomes even worse if different resistor values are involved ($R_1 \neq R_2$). Due to their unequal values they will dissipate different amounts of power ($P_1 \neq P_2$), leading to an unequal temperature level of the resistors.

Resistor arrays offer a good alternative for guaranteeing equal ambient temperatures for all integrated resistors. Due to the integration of the resistors, such arrays feature a uniform temperature behavior. The ceramic substrate offers a high heat conductance; thus all integrated resistors are approximately on the same thermal level. Consequently, the fixed voltage regulator provides an output voltage which does not depend on temperature influences in a first approximation.

Implementation

Tolerance

The tolerance of a thin film chip resistor or a thin film chip resistor array is adjusted by means of a laser conditioning process. The laser beam cuts a meander structure for example into the resistive layer, as is illustrated in ***Image 5***. During the adjustment process the resistance is constantly monitored, ensuring that the final resistance value is within the desired tolerance limits.

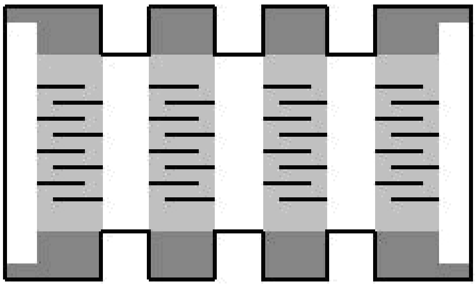


Image 5: Meander structure in a thin-film chip resistor array

Temperature coefficient

A thin-film resistor’s temperature coefficient depends on multiple process parameters, including the alloy composition, the coating process (sputtering process), and the subsequent temperature conditioning. In order to achieve low temperature coefficients, each one of these process parameters needs to be done with high exactness. The subsequent heat treatment adjusts the temperature coefficient of the thin metal layer. Depending on the duration and temperature of this heat treatment, the temperature coefficient - which initially is negative - becomes increasingly positive, that is the electric behavior of the thin layers becomes increasingly metallic.

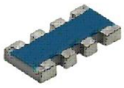
Products

Thin-film chip resistor arrays consist of multiple resistors integrated on one substrate and permit the definition of a relative tolerance and of a relative temperature coefficient. The manufacturing process permits implementation of uniform or different resistance values on the ceramic carrier. Thus, voltage dividers or feedback circuits can be easily implemented, which feature resistance ratios ≥ 1. Another advantage of arrays is that the board space is minimized. This is especially advantageous in complex electronic systems where PCB area is limited. In addition, placement costs are lower compared to discrete resistors since only one component has to be placed onto the PCB.

Automotive applications such as engine control units or gear box controls require robustly designed chip arrays that can handle the power, temperature, and humidity levels and thermo-cycling involved in this harsh environment. The standards of the Automotive Electronics Council, such as AEC-Q200, have acquired great importance for resistors and other passive components intended for use in the automotive industry. AEC-Q200 invokes various electrical and climatic tests and the level of test severity. The high number of test methods and the nature of the tests ensure that the quality of a component is tested in many different respects. Humidity tests in particular provide a high level of test severity. Since tests invoked by AEC-Q200 are requested to be done only once without any repetition, some manufactures fulfill these tests in regular intervals to maintain the high quality of their products.

These properties of resistor arrays translate into an advantage when used to implement voltage dividers, feedback, and analog signal conditioning circuits where high long-term stability for the divider ratio even in harsh environments of automotive applications is required.

Summary and trends



Miniaturization poses increased requirements to passive components, in particular to resistors. Thin-film resistor arrays reduce the area required on the PCB without sacrificing the electric stability of its resistance value. By integrating four resistors on a ceramic substrate, area requirements are reduced by more than 25 percent. In addition, placement costs are reduced since only one component needs to be handled instead of four discrete ones. Relative factors such as relative tolerance and relative temperature coefficient significantly affect the electric stability of the resistor network or divider circuit. These relative dimensions are particularly beneficial in applications such as voltage dividers or feedback networks in operational amplifier circuits. Automotive applications require chip arrays in a very robust design. An AEC-Q200 qualification is most desirable to ensure the quality of the component which is tested in many different respects.

The push for ever-smaller technological solutions, in particular in automotive and industry electronics, calls for smaller designs even for passive components. For this reason, resistor arrays will be scaled down to smaller standard packages. Furthermore, solutions offering high divider ratios will permit flexible solutions for many analog circuits.