7% solution

Completing a task that requires closely matched carbon-composition resistors with values accurate to within ±1/2% produces a valuable lesson.

Howard Johnson, PhD -- EDN, June 10, 2010

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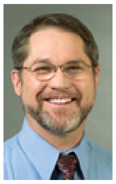

In 1983, my mentor, Martin Graham, PhD, had me build a Wheatstone bridge for measuring the common-mode impedance of certain twisted-pair cables, now known generically as Category 3 UTP (unshielded twisted pair). My setup required some closely matched carbon-composition resistors with values accurate to within ±½%.

The measurements would be taken at fairly high frequencies covering the 10- to 100-MHz range. At such frequencies, even the parasitic series inductances and shunt capacitances of the resistors must match. That requirement rules out the use of trimming potentiometers to meet the stringent accuracy requirement.

I needed a few bull's eye, hit-the-spot, on-the-money, perfect resistors. Looking at the lab stock available on that day, I found no high-precision carbon-composition resistors. There were some 2% metal-film resistors in stock, but I knew that the manufacturers of those parts sometimes etched serpentine patterns in the metal film to elongate the resistor, thus increasing the parasitic series inductance to levels unacceptable for my application. Carbon-composition resistors are made in a simple cylindrical shape that is ideal for high-frequency use.

The only carbon-composition resistors I found had a 10% tolerance. I decided that they might work if I hand-selected values good enough for my purpose. I reasoned that out of 100 parts rated at 10% tolerance, about 10 should fall within 1% of the advertised value and that even more would do so if the distribution were centrally clumped. From those 10 parts, I hoped to select a couple of pairs suitable for my setup.

Imagine my surprise when, after an hour of labor and after checking 300 resistors, I found that none-absolutely none-fell within my 1% initial selection window.

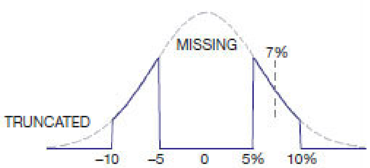

Figure 1 This histogram of 10%-resistor values reveals how 5% resistors are "made."

Mathematically, if the component values were distributed evenly across the whole tolerance band of ±10%, the probability of any one resistor's falling within a ±1% selection window should be one out of 10, or 0.1. The probability of any one resistor's falling outside the selection window then equals the complement of that value, 0.9. If you repeat the experiment 300 times, the probability of all the resistors' falling outside the selection window equals (0.9)300=1.8×10-14. It seemed to me inconceivable that such a low-probability event could ever actually occur in my sample of 300 parts. Monkeys striking random keys on a typewriter could more likely compose a sonnet in the mean time between experimental failures of that magnitude.

Perplexed, I sought guidance from Martin. I found him in the company cafeteria enjoying a meatloaf sandwich. On a ketchup-stained napkin, he patiently drew an odd-looking curve (**Figure 1**).

The drawing complete, Martin said, "A 10% carbon-composition resistor is made in a somewhat slipshod manner. The manufacturer tries to get it right, but some of the variables are just too difficult to control. They make up a batch, test them all, and then throw away the bad ones. What's left is a distribution of values truncated on either side at the ±10% limits. The other main feature of the distribution is the big gap-toothed section in the middle. That's where they pulled out all the good parts and sold them at a higher price with a ±5% tolerance. How else do you think they make 5% resistors?"

My jaw hit the floor when I grasped how perfectly his explanation matched my results. He paused and then passed along another point of wisdom: "Design your circuit to use values that lie 7% away from the nominal standard values, either higher or lower, and you'll find plenty of those in the bins when you do your hand selection."

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TALKBACK

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L I believe it. Pharmaceutical companies do the same thing. US is 1%, other countries (Canada, France, other parts of Europe) are somewhere in the 2-5% range and so on. By the time you get to Asia it's usually 20% or so. Which means your blackmarket pills will either barely work (80%) or they'll be borderline overdose (120%) with nothing in between.

AM Anderson - 2010-6-7 11:23:35 PDT

I found the same bi-modal distribution when I was testing 1% zeners. Makes perfect sense. That is why I caution younger engineers not to assume a uniform or gaussian distribution on components unless they have data.

M Walter

Mark Walter - 2010-23-6 09:21:36 PDT

Yes indeed. That is how they made the resistors, and how they were sorted. What I find most amazing is that he did not find a bunch of resistors that were close in value, but not close to the marked value.
It brings to mind an instance where an individual thought that they would be helpful, and marked all of my resistor bins with the values that they read with a DMM. So none of the bin markings corresponded to the resistor markings. That was a real pain, with matters made worse by the fact that the markings were done with a permanent marker.

William Ketel - 2010-11-6 13:23:30 PDT

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