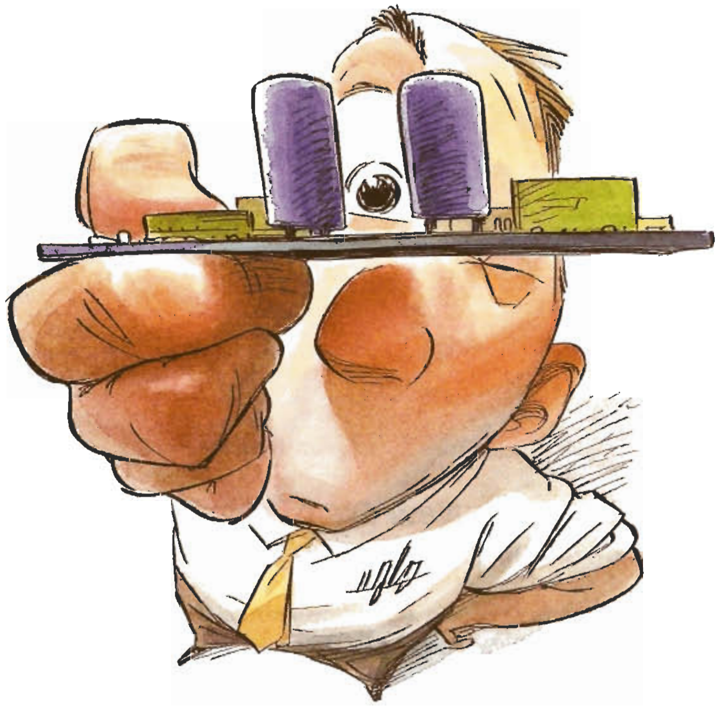
Mind the gap!



I recently had to revamp one of my company's more-than-30-year-old designs. Like any project these days, the new design needed to be smaller, cheaper, include many more functions, and see completion in a relatively short time. To decrease risk, I chose to reuse much of the physical interface from the previous design, including a transformer-isolated interface to the outside world. However, the constraints of a smaller design, coupled with the new functions I was adding, did not allow for 100% reuse of the existing components for this interface.

Scratching for PCB (printed-circuit-board) space, I decided to modify the six transformers that provided the isolation to the outside world from a square-shaped, double-E-core design to a more volumetric-efficient, circular pot-core design. The company developed the previous design when design documentation was not mandatory, so I did not have a set of requirements on which to base the new transformer. However, as long as I kept the turns ratio the same, the wire gauge appropriate, and the flux density similar, I thought the risk should be low. I exactly followed this method and also ran a worst-case calculation to verify plenty of margin due to saturation. I used the voltage-based flux-density equation for transformer saturation ($B=[V\times10^8]/[4\times N\times A_C\times f]$), where B is flux density, V is applied voltage, N is the number of turns, A_C is the cross-sectional area, and f is the applied frequency. It turns out that my design had more than 50% saturation margin.

To further reduce risk, we ordered several prototypes from an overseas vendor that our supply chain recommended because of its low overall cost. Due to low volumes of the prototype run, a US factory rather than the regular overseas production facility produced the samples. The prototypes performed flawlessly, and we released the new design on time, under budget, and within scope.

A few months after fielding several units, we received a report that the new design was failing intermittently in the field. After visiting the field several times and running multiple tests in the lab, we attributed the failures to interactions with another piece of equipment at the outside-world interface. The puzzling thing was that we had tested compatibility with this equipment many times before release. Even more frustrating was that it appeared that the root cause was saturation of the new transformer design! How could this be? We had plenty of design margin and tested multiple samples. We found the old modules with the sample transformers with which we had initially qualified the design. When we applied this hardware to our test setup, we could not reproduce the failure. Using the hardware from the field, however, the failure was reproducible. Now we had to determine the difference between the two versions of hardware.

The new transformer design used an ungapped pot core that was less costly and easier to obtain than a gapped pot core. And it appeared to meet the saturation requirements with plenty of margin. However, we did not consider transient saturation due to current rather than voltage in our design calculations. It turns out that, in the prototype samples we tested, the two pot-core halves were not completely pressed together, thus creating an unwanted air gap. Because the pot core was dipped in polyurethane, the unwanted gap was permanently fixed. This unintended air gap was enough to keep the sample transformers from saturating. Once we moved production of the transformers to the overseas factory, that facility correctly built the transformers without an air gap. These transformers saturated in the field, and we had to change the modules. The good news was we didn't have many units in the field. EDN

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