What's your (single) point, youngster?

I was asked to help a young colleague with a product that was close to production. The circuit had a detector that connected to the virtual ground of an op-amp setup to convert detector current to voltage. The detector impedance was only about 1 kΩ; the feedback resistor's value was 100 MΩ. So, even though the op-amp circuit functioned as a transimpedance amplifier, it was also a voltage amplifier with a gain of 100,000. The unit was supposed to work with either batteries or a battery eliminator. We had tested it over the full input-voltage range, from an almost-dead battery to the highest possible eliminator voltage, but we didn't try a battery eliminator until late in the project. When we connected the eliminator, we saw a shift of approximately 100 mV.

Many theories existed regarding the cause. One engineer blamed it on breakdown phenomena involving the conductive coating on the inside of the case; others suggested strange current-leakage paths involving the same coating. Another posited RF rectification and was sure a few ferrite beads and some "good" capacitors would solve the problem.

I worked backward from the error and calculated that it would require only a 1-μV difference in the ground voltage between the op amp and the detector. I asked my younger colleague involved in the design whether he had used a true single-point ground, and he assured me that he had, sending me a copy of the artwork to prove it. I came back to him with the artwork and asked where the ADC, the detector, and the op amp's noninverting input connected to ground; he said each connected in a different place.

"That's not exactly a single-point ground," I said.

Rolling his eyes, the youngster said he'd done better than a single-point ground: He'd implemented a solid-copper ground plane for the analog section and a separate ground plane for the digital section. The common point was at the ADC. The whole analog ground plane carried only 100 μA and could not possibly develop 1 μV. The analog ground plane was, in fact, equivalent to a single-point ground.

"Have you got a unit that has the problem that I can play around with?" I asked.

"I've got about a hundred, and I've got to get them fixed. I'm looking into eliminating the error in software," he said. "You can have one, but please don't break it."

"Show me how to get the effect," I said, fetching a 4.5-digit digital voltmeter that was nearby and putting it on the 100-mV scale.

The youngster smirked. "You'll never see anything with that. It has only 10-μV resolution."

It was worth enduring all of his eye rolling when I found two points on the supposedly single-point analog ground that differed by 30 μV; this went away when I disconnected the battery eliminator.

The fix was simple. The ADC had differential inputs, so we tied its inverting input to the op amp's noninverting input. We moved the detector's ground connection to the op amp's noninverting input. The unit behaved flawlessly, even though its ground wasn't ground.

It turns out the youngster had inadvertently connected the return for the battery eliminator to the analog ground plane instead of the digital ground plane. When the eliminator was powering the unit, the entire load current flowed through the analog ground plane, causing a difference of approximately 1 μV between the old detector ground and the op amp's ground.

Two effects had ganged up on my colleague: a measly 1 μV of ground voltage and a low detector impedance that turned his transimpedance amplifier into a high-gain voltage amp. EDN

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