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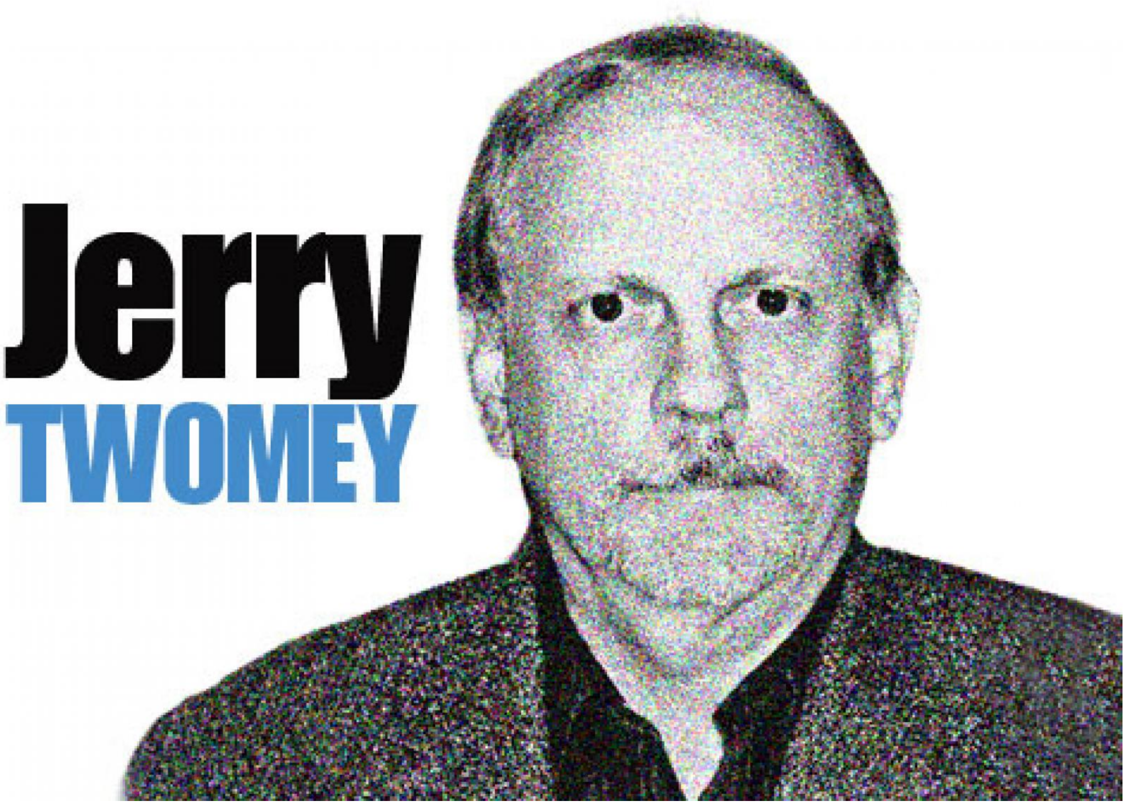

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Simple Grounding Rules Yield Huge Rewards

Jerry Twomey | Apr 27, 2012

JERRYTwomey168x140 Is grounding all that important? Anyone who has seen the Tower of Pisa recognizes the problems of a poor foundation. Lower Manhattan's skyscrapers don't sink into the Atlantic because of the bedrock under them.

The analogy serves well for electronics. You can build a shack on a mud flat. But if you want to build something big and impressive, the ground underneath needs to be rock solid. However, most designers tend to ignore the ground until it becomes a problem.

Will a poor grounding strategy really affect performance? That depends on what's in the design and how the device gets used and abused. Digital devices are pretty forgiving. Grounds can vary by 25% of the power supply, and you can still pass data around.

An RF front end with 80 dB of dynamic range and 1 µV of in-band ground noise, though, is a total showstopper. High-performance audio systems have similar dynamic range, and the slightest amount of ground noise can totally trash a studio recording.

On the abuse side, high-reliability systems need to survive electrostatic discharge (ESD) events and remain functional. A high-voltage ESD zap can cause amps of ground current surge, and the ground responds like a trampoline. Medical electronics not only need to survive these surges, they also must function through the event. Heart attacks don't wait for system reboots.

On The Bench

A few years ago, I was helping some designers get their device ready for medical compliance testing, and they were at a loss. They had ESD crashes and RF emissions failures. The system was entirely ground referenced, nothing differential, with 3 feet of cabling between the sensor circuits and controller system.

That cable was expected to maintain a good ground between boards when it was hit with an ESD pulse. Nope! The data between boards was trashed as the ground bounced with more than 10 V of inductive ringing.

Also, the processor clock was causing current surges in the ground wire between boards, which made a great antenna as the microprocessor broadcast with every clock cycle. Fixing those problems were largely an exercise in recognizing that ground is not an absolute.

Everything's got impedance. It doesn't matter if it's a 2-in. thick bar of solid copper or that 3-ft cable. If you pump current into a conductor under some set of conditions, it's going to start looking like something other than a perfect connection. Power system designers worry about millohms, and RF people are concerned with nanohenries. Be it mega-amps or gigahertz, a single node starts to look like separate nodes with voltage variance in between.

It's like two boats bobbing around in the ocean. Handing a beer between boats in rough water is a messy process at best. Calmer seas are needed to get that cold brew over. In design, a stable ground is needed for a reliable system and a clean passing of signals. There is no such thing as a perfect ground or a perfect connection. But as engineers, we can make it good enough for most situations.

Grounding Solutions

Engineers run into grounding issues in three areas: in multi-board distributed systems, within a single printed-circuit board (PCB), and inside a chip. All suffer grounding problems, with similar issues. Bigger physical dimensions tend to cause problems at lower frequencies. Most of us have designed boards at one time or another, so that's our emphasis here.

As a start, provide a common single point for grounds to come together. In a bigger system with multiple boards in a chassis, this is usually a point on the metal frame. Within a chip, the I/O ring establishes a ground rail, usually with a cut to avoid a ground loop. Within a PCB, this is best done as a dedicated ground layer.

Some people call this "star grounding" to a single point. Multiple paths back to common ground are fine, but loops and currents between different ground locations should be avoided. Currents in ground loops will cause the ground potential to twist like a potato chip.

Speaking of potato chips, what do you put in your PCB sandwich? The layer stack used is important to the end result. Cost constraints may drop board layers down, but four layers with ground, power, and two signal layers is a good starting point. Most designers are strong fans of a dedicated layer for ground and nothing else.

This works pretty well as long as you avoid the temptation to slice up the ground to route traces. Think about it. A slice down the middle of the ground plane creates a ground current loop. Trying to use extended traces for ground introduces a network of inductance, which falls apart at high frequencies. The solid dedicated ground layer is simple and reliable, and it gets it done.

In your design, you need to follow the currents both coming and going. What does this mean? Most designers know about getting power into a device, but they tend to think less about what happens to currents going out through the ground. Those same surge currents in your power are going to appear in your ground return.

Kirchhoff's Current Law gets you both coming and going. Depending on how you route and decouple things, both paths affect power stability and ground bounce. An awareness of the return path gets people to think out their grounding more intelligently.

When in doubt, ground it out. Nothing should float unattached. If you have bare space on boards, flood the empty regions with copper and an aggressive collection of vias to the internal ground plane. This provides a well-defined environment for signal traces. Instead of two adjacent signals that couple to each other, I prefer a set of signals with a low impedance ground between them.

Short and tight is the goal. Many boards are interconnect spaghetti with the system grounds added as an afterthought. Getting your grounding in place before signal routing is generally a good approach to getting this right. Messing up one signal involves, well, just one signal. Messing the grounding up can corrupt the entire system.

Minimize series vias on your ground paths and maximize parallel vias. Ideally, component grounds should drop directly to the ground plane. Depending on board thickness and via dimensions, each via adds between 0.5 and 3 nH of inductance.

For comparison, a bond wire inside a chip will be 3 to 20 nH depending on wire length. It all has impedance, and it all adds up. This becomes important when fast transient currents turn that path into a voltage differential.

A mixed-signal board's floor planning and grounding are tied together. The analog parts on the floors of these boards should be separated. Analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and other analog front ends should be off in their own corner.

The analog side of the system then uses those separate sections and their grounds. For example, the ADC's "ground corner" gets tied back to the common point ground where the ADC passes its digital results back over to the rest of the board.

When passing ground connections between boards, you need to plan for dynamic variance between grounds. The strategy is still short and tight, with more parallel connections for lower total impedance.

Some dynamic variance is unavoidable, though. Especially for distance cable connections, use architectures that can deal with ground variance. Things like differential signals, low-voltage differential signaling (LVDS), optical isolators, and common-mode chokes are some of the techniques available.

In Practice

A lot of what's mentioned here should be old news for many designers. But considering how often I see these issues pop up, some designers must be unaware of proper grounding strategies.

We haven't gone into factors like signal routing, path balancing, shielding of signals, and other details in reducing noise and improving reliability under stress and strain. Also, special situations may arise. But generally, what's described here works well for most designs.

If you build something on top of Jell-O, getting the rest of it right just won't happen. The foundation is the ground. Everything else builds on top of that.

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