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Ask Kaboom

Your Tech Answer Man

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Failure Modes

A long time ago, I wrote a column called "The Way It Goes," in which I described the typical failures found in various kinds of parts, along with the relative frequency of failures, arranged by type of component. Let's take another look at that, this time concentrating on failures in semiconductors, which are by far the most common. Also, let's look at how a failed active component affects the parts around it. Just why do things stop working?

Reliability

If you're old enough to remember tubes, you probably recall pulling the tubes from your malfunctioning TV (or watching your dad do it) and taking them down to the local convenience store. There, you popped them into a socket on a giant tester and checked the tubes' emissions. Usually, one was quite low, and a new $3 tube was purchased. You got home, put them all back in and, wow, the set worked again.

Imagine doing that today! Widespread use of the transistor swept the old tubes and that big tester into oblivion, where they belonged. When solid-state circuits came along, we were promised they would be rugged, reliable and pretty much permanent. Were the manufacturers lying? Kind of. See, the transistor had the *potential* to be all those things, but getting it to actually live up to its promises was, and still is, something else.

At First

The earliest transistors were made of germanium. This material is a good semiconductor. In fact, it exhibits less voltage drop in the "on" state than does the silicon we use today. Unfortunately, it had other problems, the worst of which was its physically fragile nature. Even a little heat, or a good bump, could fracture a sliver of germanium, causing these parts to be very failure-prone. The average tube could easily outlast the average germanium transistor. Today, germanium is used only in special cases which require the smaller voltage drop. You can still buy germanium diodes, but the transistors are all but gone, thank goodness.

Cool, Man

The tubes wore out because they had to operate at high temperatures in order to work. For a tube, heat is a necessary element. Also, because of the heat and the amount of power being dissipated, other components, such as resistors and capacitors, got fried too. (More on that later.) For a transistor, though, heat is no more than an unfortunate byproduct, because the electronic energy travels through solid matter (hence the "solid-state" moniker), so it doesn't need to be heated up to get it to fly through space. But, transistors do get warm. Sometimes, they get downright hot, especially if they have to handle lots of current.

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And, as with any material, high temperatures can break down molecular bonds and destroy the device. But what about small-signal parts which don't generate significant heat? Why do they break down?

Zap

One of the biggest causes of component failure is static discharge. A good zap will destroy just about anything, because the rampaging electrons actually burn a hole between layers of the semiconductor, allowing signal electrons to go where they don't belong. And, it's a cascading effect; once the damage starts, the applied power continues it until a total short occurs. And, although you'd think it would be an instantaneous process, as the old song goes, "it ain't necessarily so."

Transistors and ICs designed for very small signals and/or low-power operation tend to have extremely thin boundaries between layers; that's a big part of the reason small voltages can traverse them and operate these devices. It is, however, also a recipe for disaster. Even a small static discharge can punch a nice hole in such thin layers. But, if it's a small hole, the device may continue to work! Over time, though, the hole will get bigger until the device finally fails. It can take months. CMOS chips have built-in protection diodes to help prevent static damage, but it can still happen, especially when the parts are lying around loose. MOSFET transistors, which use essentially the same construction, also are vulnerable. It's not uncommon for a CMOS part which has been damaged by static discharge to work fine for quite awhile and then suddenly short out, so long after the damaging event you can't even remember it happened. I've seen RAM chips do that. Nonetheless, because of its ultra-low-power, cool operation, CMOS is perhaps one of the most reliable technologies we have and, without it, most of the little, battery-operated toys we enjoy so much, such as pocket TVs and mini CD players, couldn't exist.

Made That Way

There's another cause of semiconductor failure, and you can't do anything about it. Like anything else, the structures inside transistors and ICs aren't perfect; they often have extremely small bubbles and holes in them. We're talking sub-microscopic here; it takes a scanning electron microscope to see them. Over a period of months, or even years, electron flow through holes can cause enough damage to begin a short. Also, believe it or not, imperfections can narrow a conductor's effective area enough that it presents enough resistance to generate a small amount of heat. It ain't much but, at this size scale, it doesn't take much! Microscopic aluminum conductor lines can actually melt. Big chip makers employ chemists whose sole job it is to study these molecular phenomena and try to devise ways to prevent their formation. And, as the lines get smaller and smaller, the problem gets worse. If we're ever going to have reliable, affordable multi-megabit RAM chips, this issue will have to be resolved. As it stands now, manufacturing processes are a lot better than they were just a few years ago. That's a big reason why chip densities have risen so much, bringing us 486 micros and such.

The Bumpy Road

Can semiconductors actually break, in the physical sense? As I mentioned before, germanium was prone to doing that. Silicon is a great deal sturdier but, yes, it can happen. I've seen transistors fracture, especially if they were hot when the shock occurred. I've never seen an IC do it, though, but I suppose it could. Crystals, which aren't semiconductors, of course, but are made out of quartz, which is quite fragile when sliced thin, are the worst offenders. If you drop your rig onto a hard surface and any of its crystal oscillators stop working, suspect the crystal right from the start. I can't count the number of bad crystals I've run into, and many of them died from physical shock.

Can't Touch This

You don't need the high voltage of a static discharge to damage a semiconductor. Sometimes, even just a few volts will do, particularly with MOSFETs. And, believe it or not, just touching a lead can occasionally do the dirty deed, thanks to induced voltages and weak, unnoticeable static build-up on your body. That's why people who work with CMOS and MOSFET parts a great deal wear those grounded wrist straps. If you don't have one, it's a good idea to touch something grounded, like your scope ground, after you sit down and before you stick a finger on the circuit board.

The Domino Effect

In the tube days, enough power was being dissipated, and enough heat being generated, to damage resistors, capacitors and coils even when there wasn't anything wrong with the circuit! But with solid-state circuits, that's rarely the case. Sure, there are some power-handling circuits which can heat up and cause those old-fashioned troubles. Power supply regulators and power amplifiers come to mind. But in most circuits, signals are small, and the amount of power being dissipated is so tiny that there just isn't the potential to make much heat.

But, when a semiconductor dies, it often can do some damage to other parts. The usual cause is a shorted transistor or diode's pulling too much current through another component, heating it up to the point of destruction. Typically, the victim is a resistor of low value. Obviously, you can't pull a great deal of current through a 10k ohm resistor running off a 12-volt supply, no matter what you do; even if you put the resistor directly between the two supply rails, you'd only have 1.2 mA flowing, for a total power dissipation of 14.4 milliwatts. Most resistors are rated for at least 250 mW, so there's no problem. But, if the resistor is only, say, 10 ohms, now you're talking trouble, because enough current can flow to heat and crack the resistor. Consequently, emitter resistors in power amps are ripe for damage when the finals short out. Very often, they'll have small cracks which make them open or intermittent. Coils also can be blown that way, because they usually have low DC resistance. But, the heating effects which used to ruin capacitors in the tube days are all but gone; unless a cap is nearly touching a big power transistor, chances are it'll be unaffected by a blowout.

I hope you've enjoyed this little meander through the world of dying semiconductors. As the years go by, the parts get more and more reliable, but they still go and probably always will. Oh well, at least they don't have filaments to burn out. Now, let's look at a letter:

Dear Kaboom,

My Ramsey 2 meter kit radio picks up a lot of intermod. Granted, I live near some big commercial VHF towers, so I can't really fault the rig. Still, I'd love to be able to actually use it! Is there anything I can do to reduce the mess?

Signed,
Barn Door Open

Dear Barn Door,

The Ramsey kit performs about as well as most radios, but the company makes a special filter just for problem areas like yours. Give them a call and they'll tell you all about it.

73 'til next time, de KB1UM.