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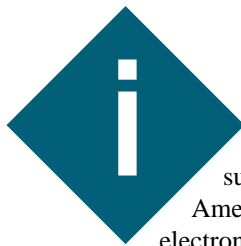
FEATURE ARTICLE

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Environmental Conditions

Part 2: Standards—Prepping Your Prototype

Just when you think your prototype is ready to take on anything, it's thrown into the environmental chamber and exposed to more conditions than you ever imagined. George walks you through the standards that help equip you for the test.



In Part 1, I suggested that North America's edge in the electronics industry will only come through the development of high-quality products. If a product comes back for any reason, we lose. My hypothesis is that the only way around returns is to make products that not only withstand the rigors of laboratory testing, but also stand up in the real world where there are wildly extreme environmental and electrical conditions.

After relating a couple of designer-nightmare stories, I told you about my good friend, the DO-160D, the Environmental Conditions and Test Procedures for Airborne Equipment. Although many designers gripe about standards such as these, I've always considered them to be excellent guides. Following the practices they outline can save you from much redesign and troubleshooting.

This month, I'd like to walk you through some of the DO-160D's significant sections. It should help you quickly identify where to look when you get going on your next design.

DRAINAGE

The first three sections of the DO-160D deal with general issues, procedures, and bureaucratic details. So, let's skip directly to Section 4, which is on Temperature and Altitude. The issues are mainly mechanical, such as the example I gave last month with the RVDT (rotary variable differential transformers).

Although I won't spend much time on packaging, you should note that the majority of electrical cabinets have a small breathing or drainage hole for pressure compensation and drainage. The hole, about $\frac{1}{32}$ " in diameter, rests in the bottom of the enclosure and drains condensed water. Although these openings may cause problems with rain, salt, fog, sand, dust, and EMC, the problems pale in comparison with the damage created by seal failures in hermetically sealed cabinets that cannot withstand atmospheric pressure changes. So, unless a hermetically sealed envelope is truly needed, it's best to offer drainage.

We may face an electrical concern at high altitudes where high-voltage potential exists at a low pressure and thus a spark-over might occur between adjacent components, including connectors. However, not many electronic controllers fall into this category.

When designing any equipment, it's our job to minimize the potential problem of an accidental short between two adjacent connector pins. Ideally, the pins should be assigned and circuits designed such that a short between the two pins could be sustained indefinitely without damage to the equipment.

TEMPERATURE

The second parts of Sections 4 and 5 deal with operating temperature and temperature variations. Here's where life gets interesting.

What you need to worry about are the high and low operating-temperature extremes. With avionics equipment, these temperatures range from -55°C (-67°F) to $+70^{\circ}\text{C}$ (158°F) but need to extend to low and high survival temperatures, most commonly set at -55°C and $+85^{\circ}\text{C}$ (185°F). Components must remain operational even during a temperature shock, when the temperature changes at a rate of $5^{\circ}\text{C}/\text{min}$. or greater. And, don't forget that equipment with forced cooling is tested under conditions in which cooling fails.

To pass the tests, equipment must operate without a glitch at maximum power dissipation throughout the operating-temperature range. In fact, we want to ensure that no component's internal temperature exceeds its derated maximum even at the highest operating temperature.

We do not need the system to operate at the survival temperature, although in many instances operating and survival temperatures are the same. But, here is where the real trial by fire is hidden. Down-powered equipment is soaked at the survival temperatures until all its parts have stabilized at those temperatures, and then it is powered up. At that instant, the men are separated from boys. Oscillators and switching power supplies either start up or sit idly before eventually giving up the ghost.

The problem is quite clear. Few electronic components are specified for this temperature range, especially at the low end. Military components, specified for -55°C to $+125^{\circ}\text{C}$ operation, not only cost many times more than the industrial- or extended-temperature-grade components, but they are fast disappearing from the market. Check the COTS sidebar to see what to do.

To ensure that a design works—assuming the maximum junction temperatures are derated to get the needed reliability—you have to consider the temperature dependency of analog and digital circuits because they manifest themselves differently. Thanks

to modern microelectronics, the temperature dependency of analog circuits is no longer too difficult to bring under control by careful design. In the end, it is often reduced to making sure that parts are judiciously derated, power supplies start up properly, and references are stable, either inherently or through internal or external compensation.

As a rule, you should use DC coupling of circuits only when DC operation is needed. Some sensors require temperature compensation, which the vendors often recommend. It's a good idea to stick to the recommended circuit. As an extreme measure, it may be necessary to measure the temperature by a separate circuit and apply compensation through software using a look-up table or a compensating algorithm.

Problems with temperature in digital circuits typically involve making sure that timing characteristics are sufficiently derated for operating margins throughout the temperature range. Present-day CAE (computer-aided engineering) tools are a great help in simulating circuit behavior under many different conditions.

In the end, the results of what I call (with a little disdain) "virtual design" are only as good as the mathematical model fed into the computer. Until someone can convince me that the model is 100% accurate, I'll stick my breadboard into an environmental chamber, like the one pictured in Photo 1, and see the results for myself.

HUMIDITY

Section 6 addresses humidity's effect on equipment performance. This is probably the last bastion of the COTS opponents, who hang on to the superiority of the ceramic packaging. This argument, however, becomes purely academic if the ceramic package is not available.

Nonetheless, we still need to decide how to address the effects of humidity on our circuits. The primary concern: long-term storage of components in places

like missile silos or depots, where moisture seeping into the components and circuit boards causes their eventual failure. Moisture also causes PCB surface leakage, especially in high-impedance circuits. The solution lies in the manufacturing process.

Therefore, during the storage of parts and the PCB assembly, care must be taken not to allow moisture to be trapped anywhere. Plastic encapsulated ICs (PEMs) can crack (pop) during soldering when moisture turns into steam. A dry, assembled, and soldered PCB needs to be conformally coated, sealing it from moisture penetration. In the simplest case, PCBs are sprayed or dipped in a specially formulated varnish. The most critical equipment must be vacuum coated with a uniform, 10-mm-thick plastic coat.

SHOCKS AND VIBRATIONS

Section 7, Operational Shocks and Crash Safety, primarily addresses mechanical concerns. These standards require us to make sure the unit does not fall apart and keeps operating correctly when it is exposed to mechanical shocks. For example, mechanical shocks and vibrations must not affect output from a LVDT (linear



Photo 1—This is the torture chamber for temperature, vibration, and humidity testing. Notice the slip table in front of the chamber. This, in conjunction with the cylindrical driver under the chamber, provides vibrations in all three axes.



Photo 2—The environmental chamber is computer controlled. Temperature and vibration profiles are programmed for the entire test sequence and run without supervision.

variable differential transformer) during normal operation. In many cases, the off-axis insensitivity of the LVDT can be used to our advantage. When it doesn't work, an electronics designer has to step in and design a means to filter the noise.

Crash safety is a destructive test, simulating the effects of an airplane crash on the equipment. Subsequent operation of the equipment isn't usually required, but it's important at the time of the crash that the equipment does not disintegrate, turn into a cluster bomb, or become a missile. It must stay intact in its intended mounting location.

Vibrations, which are covered in Section 8, are a continuation of the Operational Shocks and Crash Safety Standards. The requirements are tied to the type of the aircraft, with each having different vibration profiles for the frequencies and amplitudes found in its environment (a jet, propeller plane, helicopter, etc.).

This is the packaging guys' domain. The equipment is shaken and stirred for many hours in all three axes with sinusoidal, random, and a combination of both vibrations, including equipment

resonance found through a frequency sweep. The unit must stay intact and operate flawlessly during the test. Photo 2 gives you a first-hand look at the computer driving the environmental tests.

Electronics guys only get involved when parts need to be relocated on the PCB to prevent contact during vibration or when parts are microphonic, which usually has to be fixed by electronic filtering. Simulation tools help us analyze PCB layouts well in advance of testing to decide where and how the parts should be supported and the boards reinforced.

EXPLOSIONS

The ability to endure or not cause explosions, covered in Section 9, is a serious matter in more industries than just aerospace. The level of explosion-proof protection is defined by the system's operating environment. As a minimum, all equipment must ensure that there is no sparking within the equipment and that the temperature of its surfaces or components does not exceed the ignition point of gases.

How do you prove it? An infrared thermographic scan of circuit boards under full load shows temperature distribution and identifies hot spots. The scan also provides proof that all components are operating at the temperatures used for derating calculations. If nothing is running too hot, the reliability prediction and design assumptions are thus proven correct.

If equipment is exposed to explosive vapors, sparks or hot surfaces can cause an explosion. Such equipment needs to show that the explosion will be contained within the cabinet. An automobile spark plug is placed inside the equipment housing, while it is filled with gasoline vapors. The spark plug is fired, and the unit must stay intact. It's surprising to see what a little amount of vapor can do to an 8" x 6" x 2" aluminum cabinet milled out of a solid piece of metal and stuffed with components. A combustion engine regularly experiences the same kind of force.

Locations with explosive vapors need intrinsically safe designs. Building for this kind of environment is a specialized field, guided by a strict set

of rules, which is a long way beyond the scope of this article.

THE NASTIES

Sections 10–14 address what I call the nasty tests. I'll just touch on these, as the responsibility for successfully passing these tests rests on the shoulders of mechanical designers.

Waterproofness classification divides equipment into several categories based on their operating location. It ensures that rain will not keep the unit from working. It takes care of places like a wheel well, which is an ugly environment for a controller. There, even the 1/32" breathing hole lets the driving rain in. A good conformal coating, as addressed in the humidity section, goes a long way towards compliance.

Fluids susceptibility, covered in Section 11, forces us to consider the corrosive effects of fluids, such as hydraulic Skydrol, cleaning solvents, and de-icing fluids, found in the working environment. Some of these agents are extremely aggressive but must not be allowed to damage our product.

Sand and dust (Section 12) are mostly a concern when moving parts are present (which includes relays, mechanical switches, and indicator lights). The amount of sand found inside electronic equipment with presumably nothing more than a single 1/32" (diameter) drainage hole is truly astounding.

Section 13's Fungus Resistance is usually addressed by analysis. We must show that no organic parts, which could serve as a nutrition for fungi in the tropics, have been used in the construction of the unit. Some older plastic insulation falls into this category.

Section 14 closes the environmental group with the nastiest test of them all—the Salt Spray. Salt fog has a tendency to squeeze into every nook and cranny, no matter how small. After exposure to a salt fog for several days, the inside of the 1/32" (diameter) hole-equipped cabinet looks like a salt mine. The only good protection is conformal coating.

COTS—COMMERCIAL OFF-THE-SHELF

From the beginning of time, military requirements have driven the standardization of components and materials for everything the military uses. During the advent of microelectronics, the military was in the forefront of identifying and approving standard components for use in military electronics. At the time, MIL components were the cream of the crop, hand-picked from production lines.

Because MIL components require additional screening, they are much more expensive than their commercial counterparts. Thirty years ago, MIL parts represented about 10% of the microelectronics market, which made them quite lucrative to their vendors. By the late 1980s, things started to change. First, the selection of MIL components was too limited. Because the registration of a new part is time consuming and costly, it took several years for a new component to make it to the approved parts list. By the time it made it to the list, it was obsolete. Selecting components for a new MIL-compliant design was an exercise in frustration.

At the same time, reputable microelectronics manufacturers, such as Motorola, Texas Instruments, Intel, National Semiconductor, and others, had tightened their manufacturing processes using statistical analysis to such an extent that MIL components were no longer better than their commercial brethren. In fact, most of them came from the same production lines and were just subjected to additional testing, which ran the risk of damaging the component in the process. Essentially, manufacturers were doing the equivalent of driving a car for 100,000 miles to certify it, then selling it as good and reliable.

Once large users of MIL parts realized that they could achieve the same reliability and performance with COTS parts and enjoy better selection at a fraction of the cost, the MIL components market went into a tailspin. It now represents only about 0.03% of the market and will probably deteriorate further, as there are hardly any SMT parts on the approved list.

Reputable equipment manufacturers now routinely use commercial (0–70°C) parts through the full MIL temperature range. They have in-house procedures for initial qualification of parts, followed by a sufficient derating, by testing a sample. Typically, digital parts are derated a minimum of 20% (e.g., an 8-MHz 68HC11 will not be run faster than 6 MHz) and semiconductors and passive parts are derated about 50% in working voltage and power dissipation. Production units are all subjected to an extensive ESS with power recycling at temperature extremes.

MIL components, also called established reliability parts, all have a calculated reliability prediction for any design, which is documented in the MIL-HBDK-217. With the introduction of COTS, the calculations have become more difficult. Taking the penalty that HBDK-217 prescribes for non-MIL parts results in an unrealistically low predicted reliability. Typically, data from components manufacturers cannot be translated into values useful in the handbook's calculation. Consequently, equipment manufacturers keep their own databases of parts and track failures.

Traceability, which has always been extremely important, is even more so with COTS parts. From their arrival at the incoming inspection through the life of the product, components are tracked by their batch or serial numbers.

IT'S THE BEACH FROM HERE?

After foraging through all of these tests and succeeding, you might think you're all set. But, as I'll show you next month, these tests are just the beginning of what you'll eventually have to face. So, strap your prototype in, there's more to come.

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Circuit Cellar's Resource Link page in August.

RESOURCE

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