Leave No Technology Behind

By Craig Hillman

Leave no technology behind—this slight twist on the mantra of the U.S. Armed Forces is a rusting signpost on the highway of consumer electronic innovation. From the DOS prompt to the RS-232 connector, from CTRL-ALT-DEL to the CD drive, there are an amazing number of technologies that are not left behind, even within an industry obsessed with the next big thing. Though, with the persuasive announcement that Moore's law is dead and buried (see Zvi Or-Bach's recent blog in *Solid State Technology* [1]), the perpetual risk of obsolescence may be reaching its swan song. A very quick side thought: it is thought-provoking to speculate on how the electronics industry will eventually take the form of the automotive industry, a market based on relatively stagnant technology. Because it will.

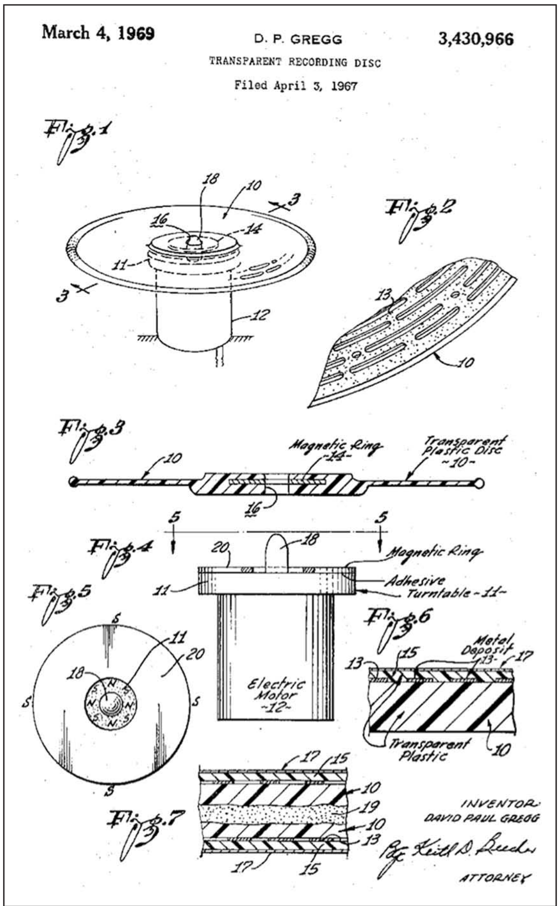

FIGURE 1. An image from U.S. Patent 3,430,966, Gregg's patent on optical disc media.

The primary, and often only, justification for older technology is compatibility. We (the corporate "we") have sold a trillion thing-a-bloops (or the consumer has a trillion thing-a-bloops), and it is very important that the next thing we sell is completely compatible with those thing-a-bloops.

Most consumers of electronic devices greatly appreciate this willingness to design to their existing hardware/software menagerie. And many other industries that extraneously also rely on consumer electronics—think industrial, aviation, and military—are even more grateful of this perpetuation of technology. However, as Apple has demonstrated numerous times, you can avoid being led astray by the ghosts of the past. And when companies continue to integrate older technology into newer designs, there are real risks that are often unknown or overlooked by engineering and management.

Two examples of this risk can be found in the slow drip of pronouncements (CNET, The Verge, Yahoo News, etc.) regarding the teething problems of disc drives (CD/DVD/Blu-ray) in the recently launched PS4 and Xbox One [2]–[8]. Now, I should be clear that I know nothing of the actual failure mode and root cause of these problems. And, if one reads the articles in depth, it can be seen that the two devices seem to be having different issues with DVD drives (Xbox One: grinding/clicking noise; PS4: ejection and playback). But having dispensed with these polite caveats, periodic, publicly visible forays into the morass of product failures provide an excellent canvas for engineers and managers to learn the challenges of technology integration.

THE TECHNOLOGY AMALGAM OF A DISK DRIVE

The fundamental optical disc drive technology that we still use today was first patented almost 50 years ago (Figure 1). It is a unique component in the world of electronics, as it is a combination of multiple, fundamentally different technologies. There is the electronic hardware (or circuit cards), the laser and associated optics, the motor, the mechatronics, the chemistry of the disc coatings, and the

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software that ties all of these aspects to together connects them to the overall system. As Russell's patent only starts to show, this is all really complicated (Figure 2).

Start with electronics. Electronics are affiliated with many of the components that make up the disc drive: the dc brushless motors require electronics, the laser diode array requires electronics, and the interpretation of disc information also requires electronics (sometimes integrated with the disc drive and sometimes as part of the larger system).

We often forget that this mature technology still requires many of the same parts present in all electronic hardware: resistors, diodes, microprocessors, solder, connectors, and printed circuit boards. And each of these components must work, as the electronics industry has yet to figure out how to build in redundancy in a simple and low-cost manner.

The electronic hardware affiliated with disc drives has not evolved much over the past 20 years (Figure 3). The form factor has not changed because of the standardized size of an optical disc (120 mm in diameter) and a disc drive (5.25-in wide). As a result, the dramatic shrinkage in component size and packaging seen in smartphones has been relatively absent in optical disc drives. In a similar manner, the functional requirements have also stayed relatively stagnant (turn the motor, turn the diode on and off, etc.).

However, as with all electronics, the need to reduce cost is an ever-present driver. And nowhere is that easier than with electronic hardware. The dynamic marketplace, that is, East Asia, ensures the continued genesis of new companies hungry for revenue and stifles the natural consolidation and price stability that most other markets experience. OEMs, ODMs, and OCMs have become highly proficient in leveraging this downward price pressure. The result is a continual turnover in suppliers, which is a challenge in ensuring quality levels are maintained and environmental requirements are clearly elucidated.

For disc drives in gaming systems, the two key environmental requirements are temperature and mechanical shock loads. Temperature becomes quite critical because of the customer's dual expectations of high-end graphic performance and quiet operation. The only thing he or she wants to hear while blowing up distant planets is the sound of the explosion. The results, according to Vatche Arabian at Planet Extech, are case temperatures up to 50 °C and internal air temperatures that can exceed 60 °C (Figure 4). While these temperatures are not out of line with personal computers (my company, DfR Solutions, has measured a temperature of 55 °C on the bottom of a laptop during DVD playback), different internal configurations and usage profiles can result in local peak temperatures far in excess of normal consumer electronics. Xbox has promoted a ten-year lifetime, which is far in excess of the life expectations of laptops that experience similar temperatures (though, to be fair, the Xbox was found to have case temperatures approximately 10 °C below the PS4).

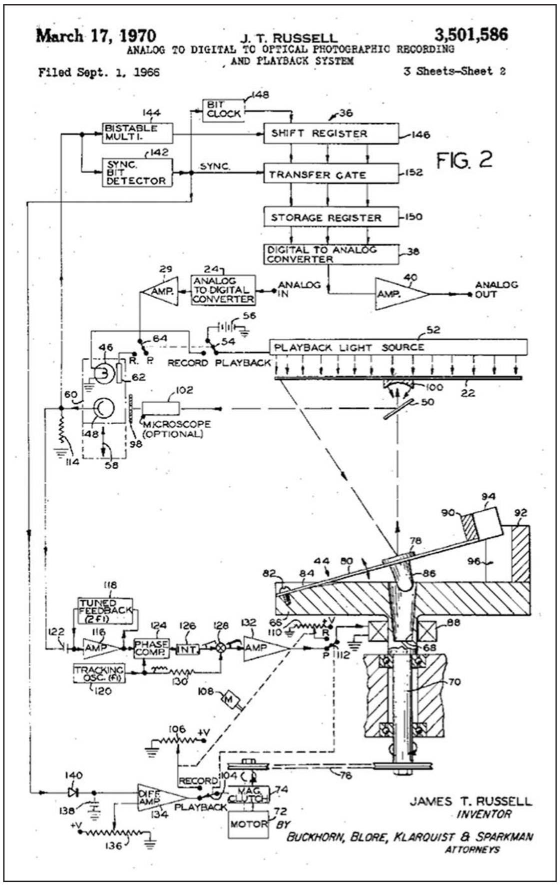

FIGURE 2. An image from Russell's patent on optical disc reading and recording system, U.S. Patent 3,501,586.

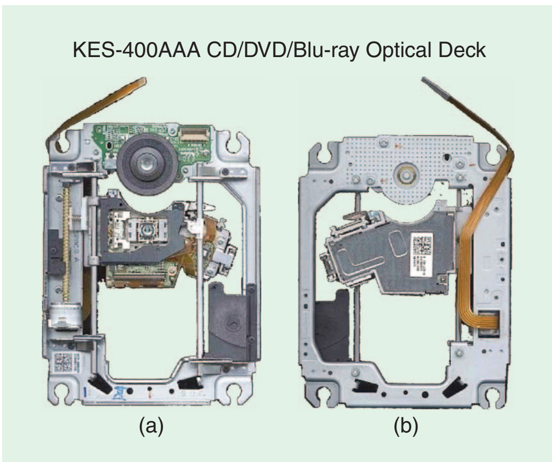

FIGURE 3. An example of the inner workings of an optical drive. (Photos courtesy of http://www.repairfaq.org/sam/cdfaq.htm.)

PRODUCT TESTING—AN INTERDISCIPLINARY CHALLENGE

Usage profiles can be especially challenging for manufacturers of consumer electronics. It is close to impossible to test all the variations in which a user might operate a device like a gaming console. Streaming video versus online gaming versus DVD playback can produce different temperature distributions, which can then vary depending upon the frequency of operation. Most personal computer OEMs attempt to identify a realistic worst-case condition. More robust methodologies that have seen limited implementation would either be the use of modeling with Monte Carlo simulation or monitoring of console conditions and temperatures with automated reporting to the OEM for analysis.

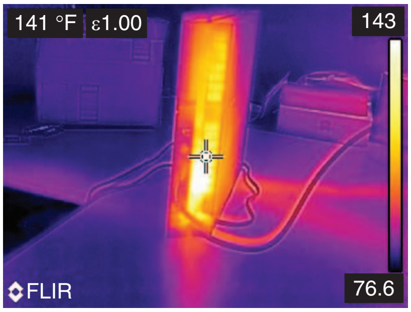

FIGURE 4. An infrared image of a Playstation in operation. (Image used with permission from Planet Extech/FLIR Systems.)

Mechanical shock is also a critical environment. While consoles should not be dropped (even when missing the high score by one point), OEMs realize that the process of transporting the unit from the factory to the home can be a jarring experience. One of the challenges of mechanical shock is the rapid transition from pass to fail with relatively minor changes to the mechanical design. A simple change from a high-cost metal standoff to a low-cost plastic clip (metal screws to plastic clips) can tip a robust design just enough to induce random failures driven by mechanical shock by shifting the maximum strain point, even if the displacements during shock experience limited change (Figure 5). The typical response to mechanical shock is to drop the entire unit under a variety of orientations, but this assumes those orientations replicate all the incidents in the field. In addition, as is often the case in a complex supply chain, form-fit-function changes can be made after all environmental testing is complete but before the product is shipped.

Electronics are actually the easy part of any investigation into insufficient performance, primarily because electronic hardware does not move (or, in the case of mechanical shock, does not move too much). Disc drives, on the other hand, are one of the few moving parts in electronic products, especially with the continued rise of solid-state drive technology (Figure 6). The spinning of brushless motors, turning of worm motors, and sliding along guide rails requires an understanding of tolerances, friction, and lubricant (not the typical areas of expertise for most electronic engineers).

The failure modes of the small brushless spindle motors found in optical disc drives motors are typically driven by the quality of the bearing assembly, which includes the bearings and the accompanying lubricant, and the tolerance between the stator and the rotor (Figure 7).

The bearing type within a disc spindle motor can vary by manufacturer. Basic options include angular contact ball bearings, hydrodynamic (self-generating) fluid bearings, and aerodynamic (self-generating) bearings. All three have their advantages and disadvantages within the operating range of optical disc drives (200–8,000 r/min). The tradeoff between these three technologies can potentially explain the grinding/clicking noises that have been experienced. Self-generating fluid bearings provide several advantages over ball bearings, including longer lifetimes, higher speeds, and better radial and axial

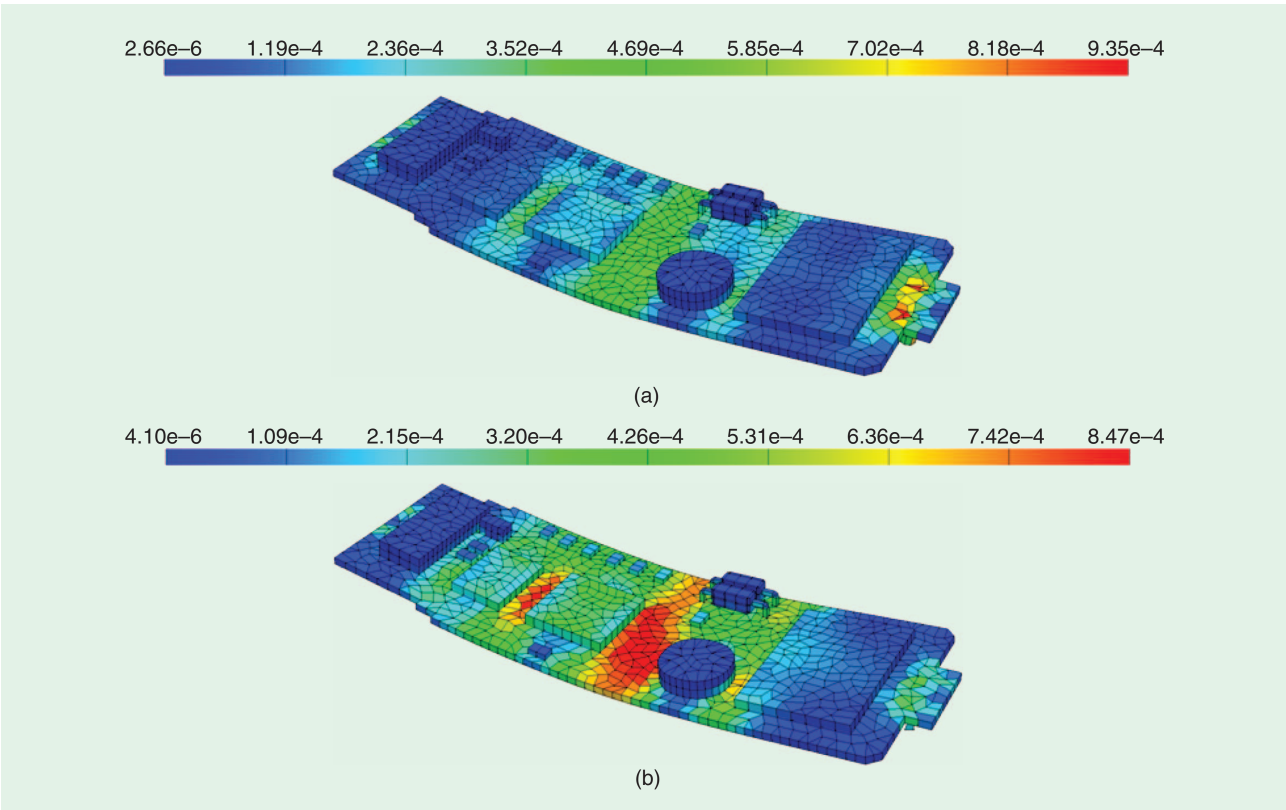

FIGURE 5. A shift from (a) metal screws to (b) plastic clips shifts the location of maximum strain.

rotational precision. However, these bearings also require tighter tolerances and can have greater instability, especially at lower rotational speeds.

For mechatronics, the balancing of tolerances is especially critical to quality and reliability. It is possible, hypothetically speaking, that the Xbox One design chose a motor technology that required tighter tolerances but provided higher performance and longer lifetimes. The end result was a higher risk of quality issues under certain use conditions. By comparison, the PS4 design may have incorporated traditional ball bearings. This would provide greater tolerance to variations in manufacturing, and therefore a lower defect rate, but the spindle motor may not last ten years.

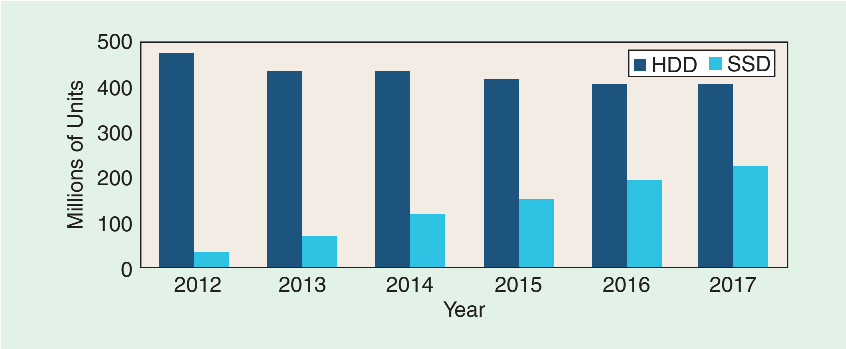

FIGURE 6. The worldwide shipment forecast for HDDs and SSDs in PCs. (Source: IHS Inc., April 2013.)

And ten years can be a real challenge for the red and blue laser diodes within the optical disc drive (red for DVD and blue for Blu-ray). Laser diodes have a well-known degradation mode. Depending on the system design, either the power output gradually decreases over time or the drive current necessary to maintain the power output gradually increases. The actual mechanisms that induce this degradation vary depending on the chemical makeup and architecture of the laser diodes. Examples mentioned in the literature include electromigration at the contact interface between the metal electrode and the semiconducting diode, the formation of nonradiative centers due to nucleation and growth of lattice defects, and the oxidation of exposed facets.

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In continuing the theme of this article, the laser diode is an older technology (seven years older than the optical disc drive) but not a mature technology. The need to 1) reduce wavelengths (red to green to blue) and 2) increase power have resulted in new architectures and new epitaxies in which the failure mechanisms are not well characterized. These include mechanisms that drive gradual degradation and those that can induce catastrophic failures. Almost a decade after its commercial introduction, the understanding of the failure behavior of blue laser diodes and its dependence on manufacturing variability is still being investigated. As an example, the influence of an artifact as straightforward as solder voiding and its effect on thermal runaway can be highly dependent on laser technology and the use environment. Most existing qualification test schemes fail to consider the synergistic combination of high power and power cycling on this failure mode, even though this can replicate a common usage pattern in gaming consoles.

FIGURE 7. The inside of a brushless motor used in an optical drive. (Photo courtesy of Dmitriy Abaimov, http://elabz.com/upgrading-a-dvd-spindle-three-phase-bldc-motor/.)

Software then ties all of these components together into a functional system. And, like the interface between components in other of these systems, its interaction and dependency on the operating characteristics of the hardware are often overlooked. There can be ten times as many software engineers as hardware engineers involved in the development of today's electronic technology, and fully half of them are involved in testing various aspects of the software execution (and this will only grow with the increasing adoption of agile development practices. Whether with waterfall, agile, or some other development philosophy, the testing of software and the testing of hardware is separated by a wide chasm.

There is an increasing realization that the physical drifts and upsets of the real world play a critical role in overall software performance. Some organizations have responded to this by introducing combinatorial stress testing (like HALT) into the software validation process. Best-in-class organizations have started to introduce Monte Carlo parametric modeling of hardware characteristics into software performance testing. Modeling tries to respond to the reality of the capability and the time limitations of the integration of new suppliers of older technology.

CONCLUSIONS

In summary, Silicon Valley and the rest of the electronics world should continue its focus on the latest and greatest technology.

Graphene, quantum dots, 3-D ICs, and supercapacitors provide us the excitement and anticipation that make being an engineer great. And as we make this new technology a reality and incorporate it into a product, we should have at least one eye (and maybe an ear as well) on the older technology that provides the product foundation and compatibility with the wider world. This eye should be aware of how design, materials, quality, and environment influence the behavior and robustness of this older technology. It should also realize when information is simply lacking (even for 50-year-old technology!) and more conservative design principles are necessary. The ear should listen to ensure that all requirements are clearly communicated all the way down the supply chain. And when time is of the essence, simpler, easier to use simulation tools should take the place of system-level testing to ensure that all changes, even form-fit-function, do not affect the user experience.

Revolution is exciting, but evolution is never as easy you think (just ask Darwin).

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Craig Hillman (chillman@dfrsolutions.com) is the chief executive officer and managing partner of DfR Solutions. He earned his B.S. degree in metallurgical engineering and material science from Carnegie Mellon University, his Ph.D. degree in materials from the University of California, Santa Barbara, and his postdoctoral fellowship at Cambridge University. His specialties include best practices in design for reliability, lead-free strategies for transitioning to lead-free, supplier qualification (commodity and engineered products), passive component technology (capacitors, resistors, etc.), and printed board failure mechanisms.

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Society News *(continued from page 29)*

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—Peter Corcoran

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