Death by Tin Whiskers:
The inevitable collision between political and environmental correctness and proven good design.
By: Walter Shawlee 2 © 2012 by Sphere Research Corp. rev. 1.7 (2,045w)

At our home and office, we recycle everything we can. I have converted our lighting to low power LED and CFL lights, and I drive a pretty efficient Honda, and not very far or often. We have a big backyard garden, collect our roof rainwater for irrigation, and I think I do a pretty good job of minimizing my impact on the universe at large. But the entire concept of the mandatory RoHS (Removal of Hazardous Substances) regulations scared me right from the first time I heard it. Like many green initiatives, it sounds reasonable, maybe even laudable, but then fails catastrophically in implementation because not enough thought was given to the inevitable consequences.

Europe has spearheaded many industrial changes that I truly appreciate, and often am amazed that we do not embrace as readily in North America. Their requirement for any significant AC operated electronic equipment to have power factor correction is a huge leap forward, and all by itself could ease electrical distribution woes in many areas just through reducing peak current stress on the electrical grid. I upgraded my own computer to a PF corrected supply, and switched to a super efficient low idle-power laser printer to take advantage of this technology. The electro-magnetic emission standards for monitors and similar equipment was an equally great change, as was their early recognition of the dangers of carpal tunnel syndrome in data workers, and the need for better ergonomic design in work areas. All excellent ideas, and I was happy to see them implemented, but importantly, all were the result of solid engineering and thorough study.

The RoHS initiative, on the other hand, adopted in the EU in 2003, and which took full effect on July 1, 2006, made some fatal mistakes right out of the gate. It was enviro-**policy** driven, not science driven, which did not bode well. It simply assumed that the specified chemicals and processes were foolishly used for no good purpose in the electronics industry, and their resulting elimination could only bring joy, health and happiness to all.

The largest blunder was the mandated removal of Lead (Pb) from the assembly of all electronic equipment. Now this rule is even more idiotic when you consider that sweeping exceptions were made for ubiquitous things like car batteries, the endless gel-cell lead acid batteries used everywhere for emergency lighting, and every computer UPS on the planet. That massive lead use was OK, just don't **solder** anything together inside with lead. They were then forced to make many additional exceptions for such categories as "essential medical and monitoring equipment", and to permit existing items like power plants, nuclear reactor instrumentation, and so on to remain or the program would have been simply impossible to implement. That should have been a very strong clue right there that problems were right around the corner.

The items removed under the RoHS rules include Lead (Pb), Mercury (Hg), Cadmium (Cd), Hexavalent Chromium (Cr6+), Polybromated Biphenyls (PBB), Polybrominated

Diphenyl Ether (PBDE), and Acrylamide. The three non-metals are all flame retardant additives for plastics. You no doubt noted Mercury, Cadmium and Lead are all used extensively in batteries, but this was glossed over and dealt with in the EU "Battery Directive" which requires them to be recycled (without initially providing an actual way to do so), and is laced with exemptions for everything from power tools to medical equipment. Cadmium Telluride (CdTe) use is also specifically exempted for photo-voltaic solar cells, but is not allowed for the ubiquitous high current switch/relay contacts as Cadmium-Silver (CdAg) widely used in aviation.

If you care for irony, then you will love the fact that all those energy efficient compact fluorescent lamps (CFLs) ARE RoHs compliant even though they contain mercury far beyond the allowable limit. They are now flocking to landfills world-wide dispersing mercury into the water table on an unprecedented scale with minimal recycling.

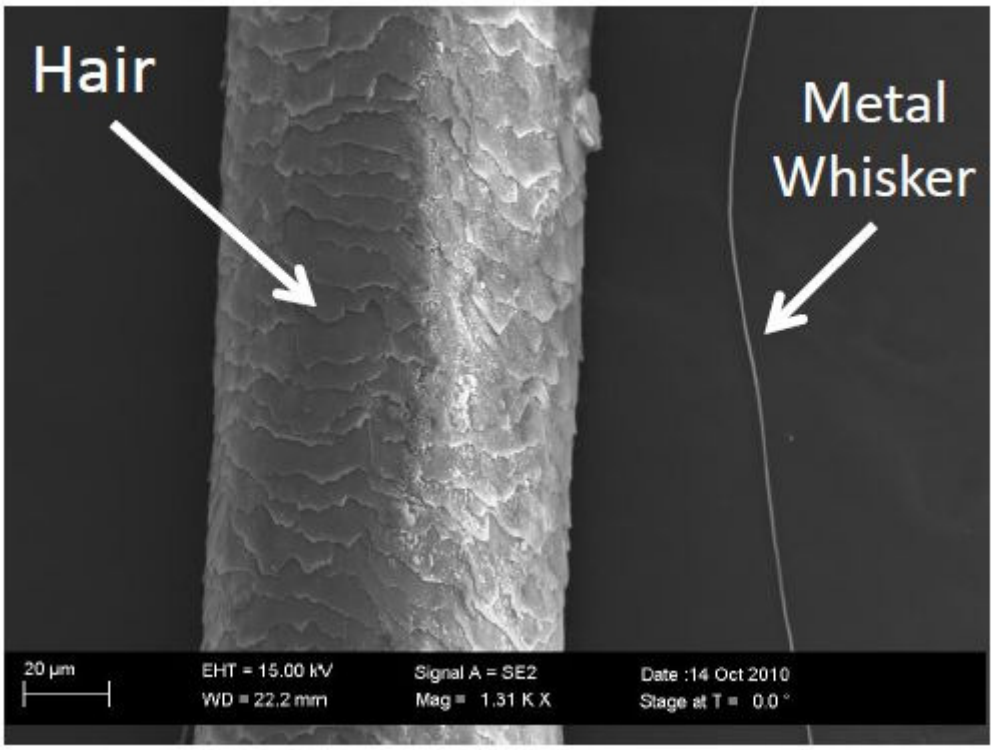
The actual task that was NEEDED, and is STILL needed, is the efficient recycling everywhere of electronic waste, but instead, the mandate was to remove these substances, and frankly to continue recycling and disposing of them badly. Just for some clarity, the total world use of Lead (Pb) is approximately 90% for batteries, **and the amount used in electronics (excluding batteries) is all of 2%.** So, of course, target the 2%. Further, of the lead in landfills (the supposed concern of this directive), the overwhelming majority is coming from disposal of TV CRTs, monitors and so forth, which can contain up to 2kg of lead per tube, NOT from circuit board assemblies, by a massive ratio of 9 to 1. Later WEEE (Waste Electrical and Electronic Equipment) regulations attempt to improve recycling and waste disposal, but long after the biggest wave of toxic material was already dumped thanks to RoHS deadlines.

Now enters the pivotal issue for avionics makers. No specific exemption was granted for civil avionics production, with the single possible interpretation that "fine pitch" devices could be soldered with lead-bearing solder within a product. This is a rather problematic area, as the "failure" to pass RoHS compliance is only to be over 0.1% lead content (1000ppm) on any single homogenous component, not by the total device weight. It's pretty hard to pass that limit and use lead anywhere.

Decades of research went into the perfecting of electronic soldering technology, finally culminating in high performance eutectic alloys like Sn63/Pb37 with almost perfect phase change characteristics, resulting in very high quality joints of high mechanical strength. On the other hand, soldering with non-lead solders like Tin/Silver/Copper alloys (SnAgCu) has some very significant issues. It generally requires ~30ºC higher temperatures which is stressful to components, wetting (adhesion to parts and tracks) takes longer and is not as effective, plus joints tend to be more brittle, and are now subject to both vibration and thermal cracking. Visual examination for bad connections is no longer really possible, as all lead-free joints look like "cold solder" joints. All events that are very bad news in the aviation world.

The most serious issue with the abandonment of lead in solders is the fault mode known as **Tin Whiskering**. This is a phenomenon so bizarre, it almost sounds like science

fiction, but it is (sadly for us) all too real, and frequently fatal to circuit operation when it occurs. The chemical mechanism is poorly understood, but tin plated leads and solder joints (without lead) begin to grow tiny straight hair-like crystals with or without current flowing. These can extend from track to track, pad to pad, between any leads and other metal areas. The tiny whiskers (much smaller than a human hair) are highly conductive, and can result in catastrophic or intermittent circuit failure. Amazingly, no PCB surface treatment, post coating or solder masking will prevent it. This is a mechanism largely unique to tin (Sn) plating or solders that contain no lead, but can also occur in some other metals from Palladium to Zinc, but generally requires elevated temperatures or pressures, while tin whiskering occurs in all normal Earth environments, and even in space.



Comparison of tin whisker growth to human hair (courtesy NASA)

So, it's rational to ask, after a few years of RoHS policy in force, does this effect ever really cause any problems? As it happens, yes, and some examples are so spectacular, it's amazing they have not reversed the policy for RoHS. In Europe, the most impressive example was the billion dollar (yes, $1,000,000,000) recall of Swatch watches from Switzerland, as use of lead free solder caused a roughly 5% watch failure rate in 2006. It's worth noting that the "solution" to this problem was yet another rule exemption, and lead was again used in Swatch construction. A real RoHS policy triumph there.

My personal favorite remain this incident: NASA became involved in the analysis of the bizarre "runaway acceleration" problems supposedly affecting Toyota cars and produced a landmark report on this topic in 2011 (see link below). Their eventual discovery was tiny tin whisker growth inside the pedal control sensor. They showed its existence, and

clearly demonstrated its cause as the factor that triggered the effect noted by a surprised Camry driver, and then generated detailed test guidelines on how to locate them in future cases (not a trivial issue). Tin whisker growth was caused between pure tin plated control leads. In addition, tin whisker growth was seen in the as yet non-failed parts, indicating the process is ubiquitous in all the design examples, and is in no way a rarity.

In addition, NASA identified several total satellite failures due to tin whisker growth including Galaxy VII or PanAmSat in 2000, Solidaridad 1 or SatMex in 2000, and Galaxy IIIR or PaAmSat in 2006. All caused by tin whisker growth in pure tin plated relays. Many tin whisker faults were also identified in Shuttle electronic systems, and corrected. The joint ESA/NASA Cassini spacecraft plasma spectrometer failure last June was recently identified as a tin whisker induced problem after nine months of investigation.

NASA also revealed the reason why the planet is not flooded with failed RoHs items, which is amazingly simple. All exposed metal surfaces begin to oxidize or undergo surface conversion of many kinds, and these layers tend to be insulating in nature. Tin whisker growth produces mechanical contact, but not NECESSARILY electrical contact as a result of elapsed time. Enough differential potential, and minimal distance are the determining factors that convert the whisker growth to a fault event. Conduction generally occurs with differential of over 2.6 volts, making convention ohmmeter tests useless. High vibration and intense physical shock sometimes did not break whiskers already grown, and other studies found loose whisker fragments could lodge between contact surfaces and cause shorts. . The only bright spot in any of the studies was the discovery that matte tin plating of leads produces roughly 1/3 the whiskers that shiny tin plating does.

When RoHS was implemented, they realized that there were potential soldering problems with the removal of lead, but forged ahead anyways, since this was “clearly” the right policy. The first effect of the RoHS policy was a massive disposal of lead bearing parts, since their continued use had a distinct cut-off date and dumping penalty after that time. This caused a world-wide surge in lead contamination of land fills as everything from CRTs to components were dumped before their disposal would be prohibited by law. One vendor I deal with in the UK destroyed his entire inventory of CRTs because they sold slowly, and he did not want to face the huge cost problem of disposal once the deadline was past. Rather than simply allowing these parts to phase out over time, the rush to forcibly implement RoHS triggered the very environmental contamination effect it was meant to prevent.

US military programs now already avoid tin plated items and lead free solder, as does NASA, but the relentless push to impose a single world standard for component procurement is slowly making tin plated IC and other component items the only available ones. The eventual outcome of this policy has serious field failure and QA ramifications for all electronics manufacturing.

This is clearly a problem that has to be addressed for the avionics industry sooner rather than later. Either a clearly worded exemption from lead use is required, or the frankly ineffective removal of lead from electronic assembly construction rule should be abandoned. **This misguided policy has introduced a random failure mode into every item now being made under these standards or with RoHS compliant parts**, a simply unacceptable risk for all involved. Plus, the ridiculously small (2%) targeted lead-use area fails utterly and completely to address the very real concerns of lead toxicity in the environment. Clearly, all these issues are something worth thinking about, and their impact on our industry and all of us is significant if no useful action is taken.

Toyota Tin Whisker Problem Links:
http://www.eetimes.com/design/automotive-design/4234246/Toyota-accelerations-revisited-hanging-by-a%E2%80%94tin%E2%80%94whisker?Ecosystem=test-and-measurement

Full NASA report:
http://nepp.nasa.gov/whisker/reference/tech_papers/2011-NASA-GSFC-whisker-failure-app-sensor.pdf

Detailed Tin Whisker Study:
http://etd.library.miami.edu/theses/available/etd-03082008-125933/unrestricted/kcoureySp08.pdf

Guide to RoHS compliance:
http://www.rohsguide.com/rohs-faq.htm

Rockwell Collins request for Avionics Exemption:
http://ec.europa.eu/environment/waste/stakeholders/individual_bus/rockwell/rockwell.pdf

CFL's and RoHS:
http://www.element14.com/community/community/legislation/rohs/blog/2011/12/19/use-of-mercury-in-cfls-compact-fluorescent-lamps-is-it-worth-the-risk

Cassini spacecraft details:
http://www2.electronicproducts.com/NASA_engineers_solve_device_malfunction_mystery_onboard_Saturn_tracking_spacecraft-article-fajb_nana_cassini_march2012-html.aspx