DfR Solutions

reliability designed, reliability delivered

Reliability of Wearable Electronics

June 11-12, 2014 TechSearch International Austin, TX

Who is DfR Solutions?

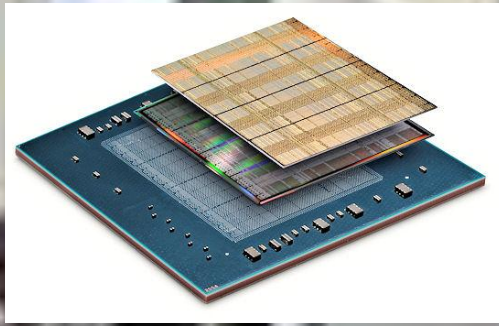
The Industry Leader in Quality-Reliability-Durability of Electronics

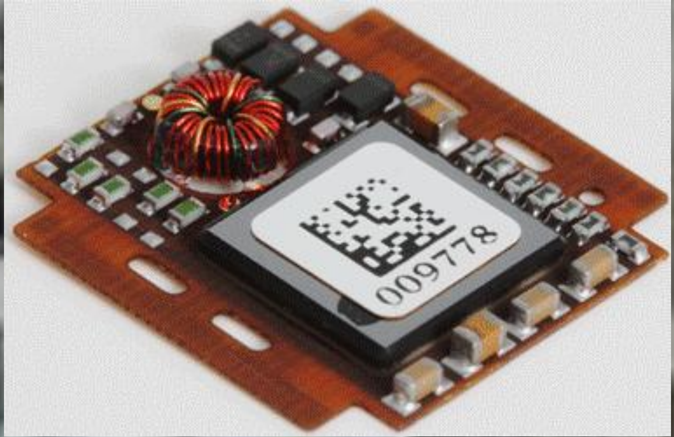
Fastest Growing Companies in the Electronics Industry
- Inc Magazine

Best Design Verification Tool
- Printed Circuit Design

2012 Global Technology Award Winner

Engaged with All Levels of the Supply Chain





What is Reliability?

- Reliability is the measure of a product's ability to
  - …perform the specified function
  - …at the customer (with their use environment)
  - …over the desired lifetime
- To ensure reliability, we have to think about
  - What is the product supposed to do?
  - Where is going to be used?
  - How long should it last?

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What are Wearable Electronics?

- Wikipedia: "…miniature electronic devices that are worn by the bearer under, with or on top of clothing."
  - That's It?!

- Alternative Definition
  - Technology attached to the human body or clothing that allows the wearer to monitor, engage with, and control devices, themselves, or their social network

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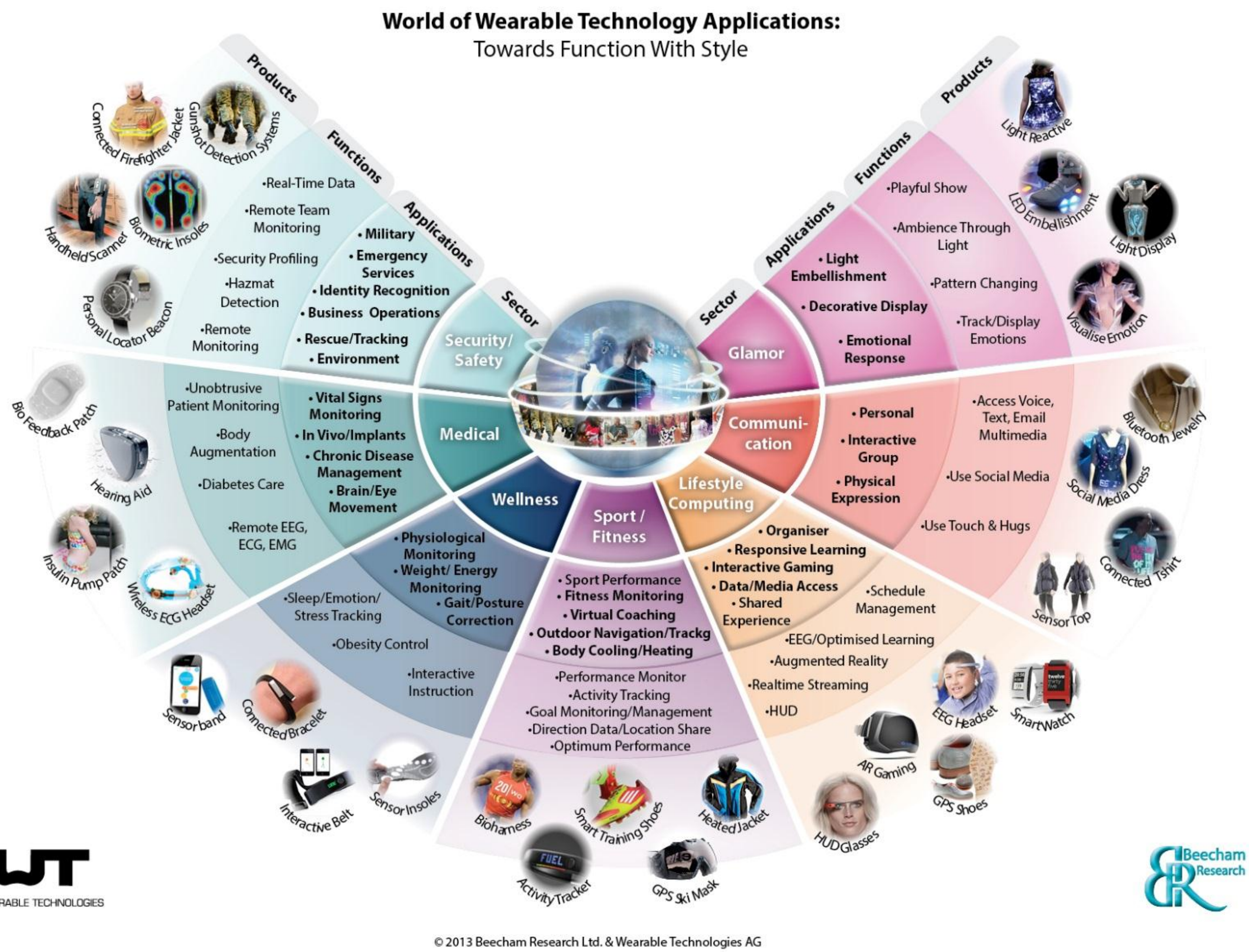
What are Wearable Electronics (cont.)



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Wearable Electronics Use Next Generation Technology

- What is 'Next Generation' Technology?
  - Materials or designs currently being used, but not widely adopted (especially among hi reliability manufacturers)

- Carbon nanotubes are not 'Next Generation'
  - Not used in electronic applications

- Ball grid array (BGA) is not 'Next Generation'
  - Widely adopted

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Next Generation Technology (cont.)

- Why is knowing about 'Next Generation' Technologies important?

- These are the technologies that you or your supply chain will use to improve your product
  - Cheaper, Faster, Stronger, 'Environmentally-Friendly', etc.

- However…

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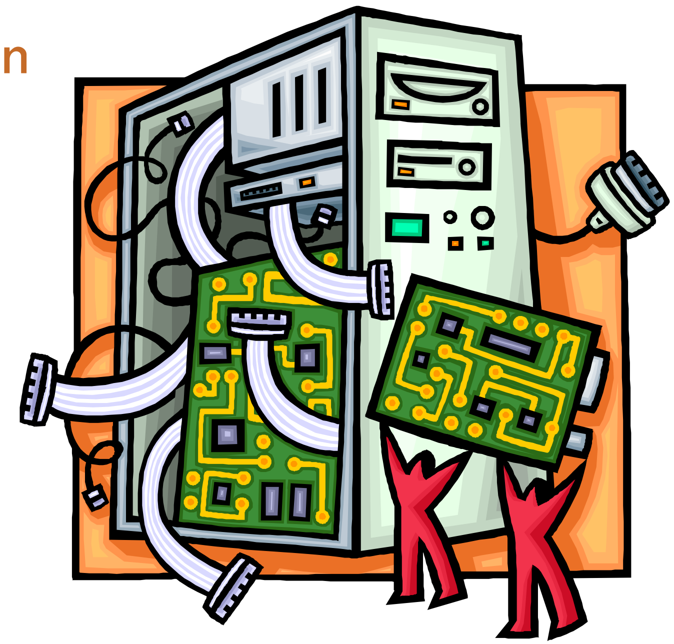
Reliability and Next Gen Technologies

- One of the most common drivers for failure is inappropriate adoption of new technologies
  - The path from consumer (high volume, short lifetime) to high rel is not always clear
- Obtaining relevant information can be difficult
  - Information is often segmented
  - Focus on opportunity, not risks
- Sources are either marketing mush or confusing, scientific studies
  - Where is the practical advice?



NextGen Technologies: The Reality

- Market studies and mobile phone markets can skew reality of market adoption
  - Annual sales of >100 million may be due to one or two customers
- Mobile phone requirements may not match the needs of wearable electronics
- Market studies exclusively focused on volume
  - More relevant may be number of customers
- Example: 0201 capacitors

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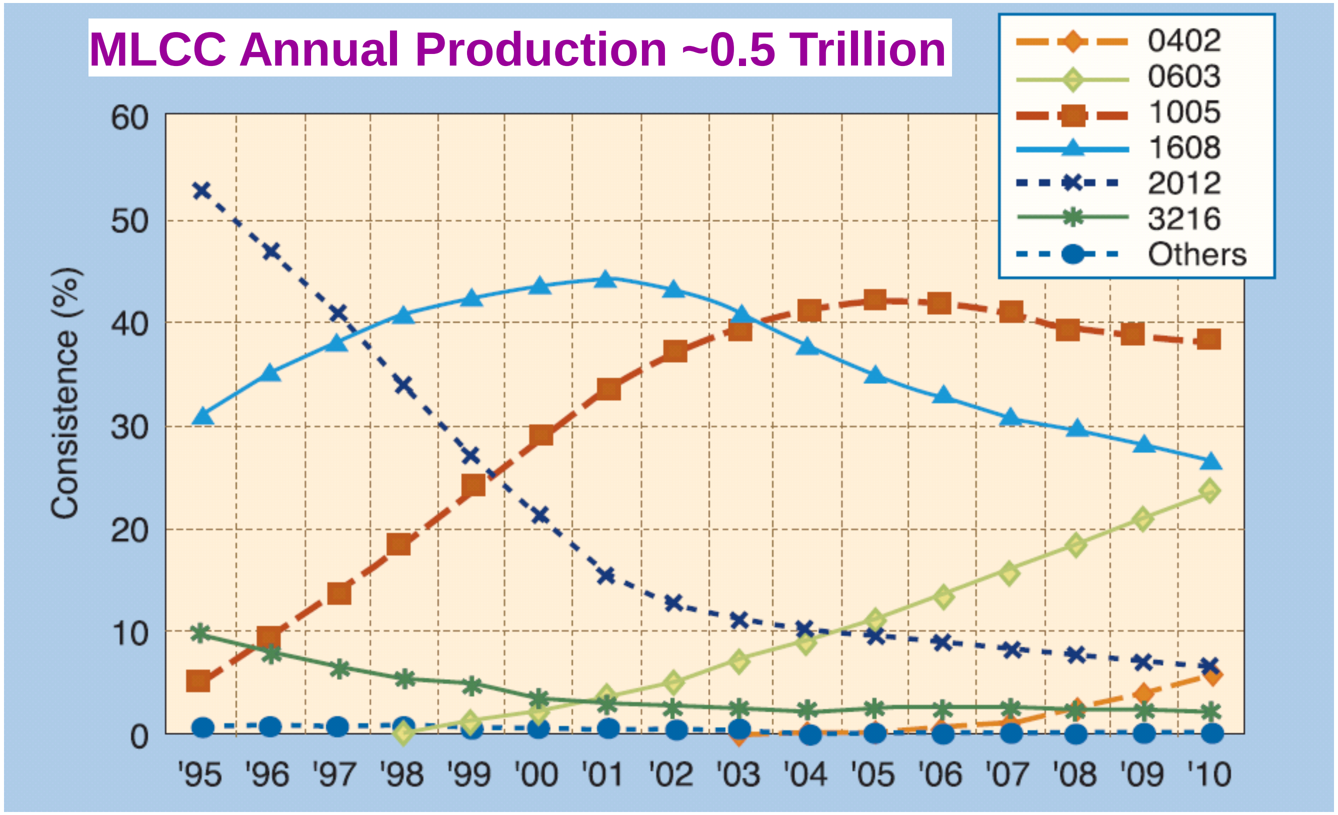
"The Smaller the Better" - 0201 Ceramic Capacitors

Metric	English
0402	01005
0603	0201
1005	0402
1608	0603
2012	0805
3216	1206



- Based on volume, 0201 capacitors were 25% of the multilayer ceramic capacitor (MLCC) market in 2010

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0201 Ceramic Capacitors: The Reality

- Actual high usage applications
  - Ultra small modules (primarily hearing aids) / high frequency

- Major users were limited to approximately 8 to 10 high volume companies in very benign environments and very limited lifetimes

- Attempts to integrate 0201 capacitor technology into more demanding applications, such as medical implants, resulted in quality issues, unexpected degradation, and major warranty returns

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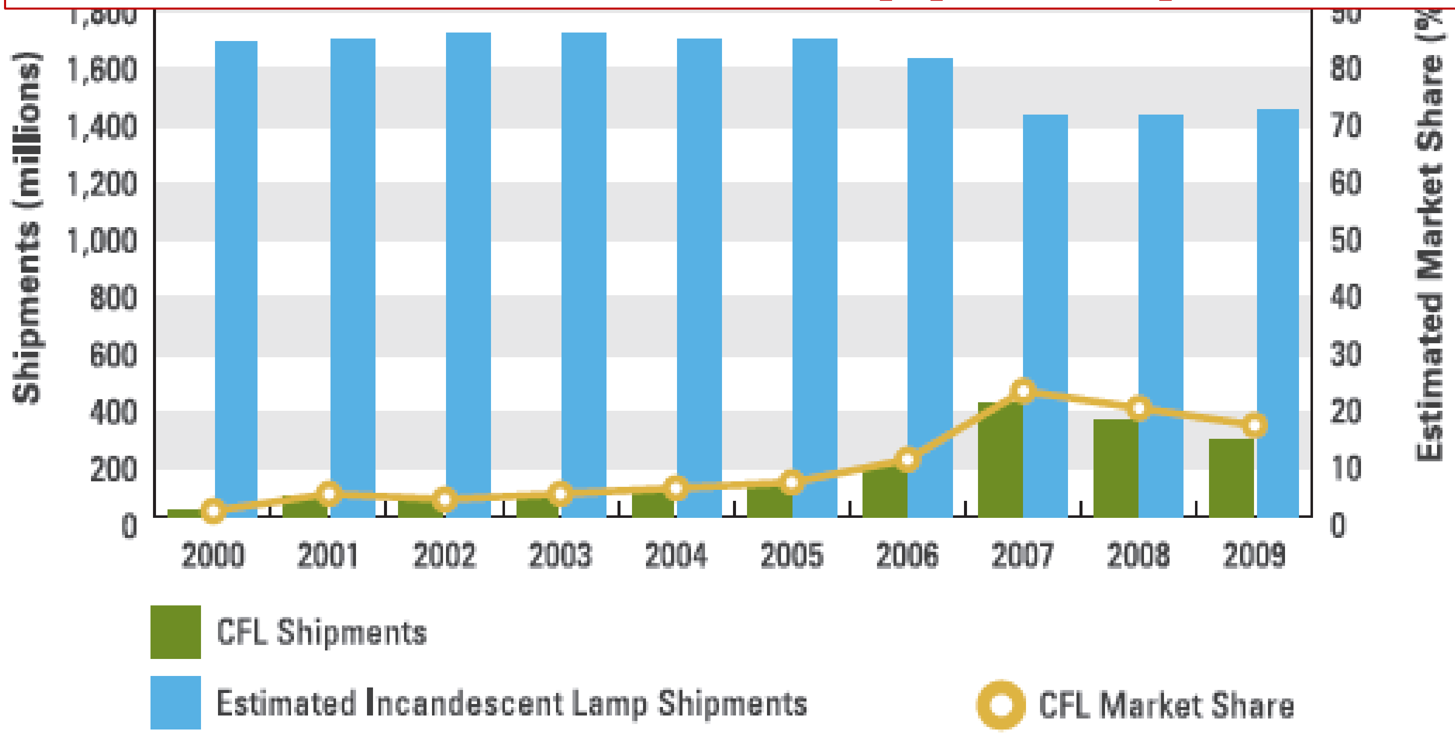
Examples of Next Gen Technologies in Wearables

- Embedded components
- Ultra-small components (i.e., 01005 capacitors)
- New substrate materials
  - Polyethersulfone, polyethylene terephthalate (PET), polyethylene napthalate (PEN)
  - Polyimide is not a next gen technology
- Printed connections
  - Silver inks, copper inks, nanosolders, conductive polymers
- Organic displays
- Power Via Supercapacitors

Why Care About Reliability? A Warning Lesson for Wearables

- "Durability"
- Case Study: Compact Fluorescent Lamps (CFLs)

Market Share has Dropped by >25%



CFL Market Profile: Data Trends and Market Insights, US Dept. of Energy, September 2010

CFL Reliability: Perception and Reality

- Prof. Siminovitch of UC – Davis has identified three (3) areas of dissatisfaction
  - Color quality
  - Dimming
  - Product longevity
- Numerous other websites / blogs have reported issues with CFL reliability

green.blogs.nytimes.com/2009/01/27/why-efficient-light-bulbs-fail-to-thrive/, Jan. 27, 2009, New York Times

- Rensselaer Polytechnic Institute (RPI) found early failure rates of CFLs between 2 to 13 percent
  - Returns higher in thermally challenging environments (reflectors, high switching)
  - Indications that power supplies play a major role in failures

Will LED Light Bulbs Best Your CFLs and Incandescents?, Popular Mechanics, August 4, 2010, http://www.popularmechanics.com/science/environment/will-led-light-bulbs-best-cfls-and-incandescents

Ensuring Wearable Electronics Reliability

- DfR at Concept / Block-Diagram Stage
  - Specifications
- Part Selection
  - Derating and uprating
- Design for Manufacturability
  - Reliability is only as good as what you make
- Wearout Mechanisms and Physics of Failure
  - Predicting degradation in today's electronics

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Specifications

- Two key specifications important to capture at concept/contract stage that influence reliability

Reliability expectations

Use environment

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Reliability Goals

- Identify and document two metrics
  - Desired lifetime
  - Product performance
- Desired lifetime
  - **Defined as when the customer will be satisfied**
  - Should be actively used in development of part and product qualification
- Product performance
  - Returns during the warranty period
  - Survivability over lifetime at a set confidence level
  - MTBF or MTTF calculation should be primarily an administrative or marketing exercise (response to customer demands)

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Desired Lifetime and Wearable Electronics

- What is the desired lifetime of wearable electronics?

- Rough equivalents: Clothes, shoes, watches, glasses, cell phones
  - Clothes: ??
  - Shoes: 3 months to 5 years (600 miles)
  - Watches: 3 to 20 years
  - Glasses: 2 to 5 years
  - Cell phones: 12 to 36 months

- With a new technology, there is an opportunity to influence expectations

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Product Performance: Warranty Returns

- **Consumer Electronics**
  - 5-25%
- **Low Volume, Non Hi-Rel**
  - 1 to 2%
- **Industrial Controls**
  - 500 to 2000 ppm (1st Year)
  - Depends on complexity, production volumes, and risk sensitivity
- **Automotive**
  - 1 to 5% (Electrical, 1st Year)
  - Can also be reported as problems per 100 vehicles

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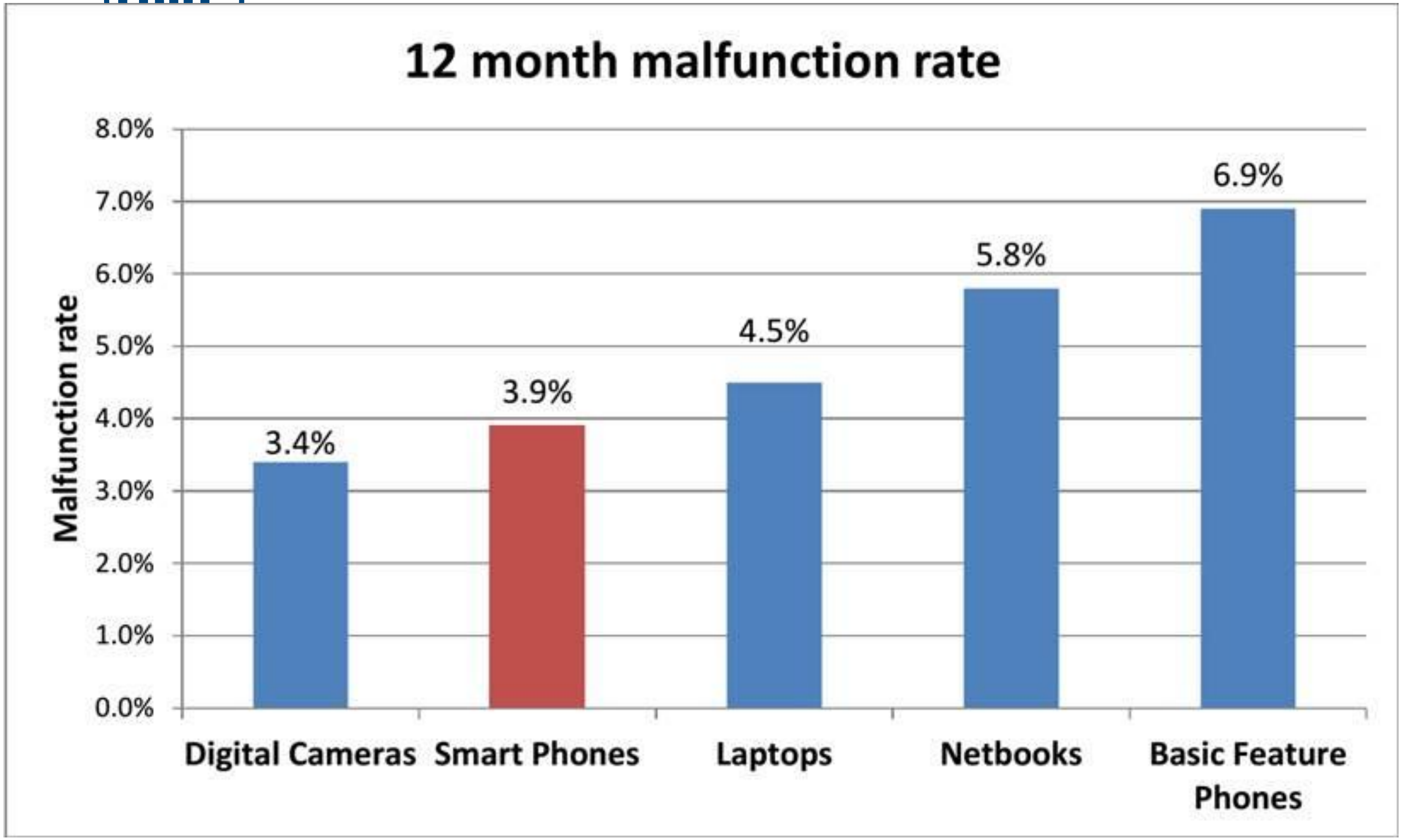
Product Performance: Warranty Returns (cont.)



- Square Trade

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Product Performance: Class III Medical

Family	Cumulative Failures	Duration (yrs)	Lifetime (yrs)	Units	Therapy Comprised	Therapy Uncomprised	Probability Device-Year (Hazard)
SecuraDR	0.0%	1	10	14000	0	0	0.00%
SecuraVR	0.0%	1	10	6000	0	0	0.00%
Maximo DR	0.1%	6	8	37000	8	26	0.02%
VirtuosoDR	0.1%	4	10	71000	19	15	0.03%
GEM III VR	0.3%	10	10	17000	9	27	0.03%
Intrinsic	0.2%	6	10	31000	7	36	0.03%
Maximo VR	0.2%	6	10	43000	12	33	0.03%
VirtuosoVR	0.1%	3	10	32000	9	4	0.03%
GEM III DR	0.3%	7	7	20000	11	27	0.04%
Marquis VR	0.4%	7	10	19000	15	27	0.06%
EntrustDR	0.3%	5	10	28000	6	37	0.06%
EntrustVR	0.3%	5	10	14000	5	21	0.06%
Marquis DR	0.8%	7	7	48000	100	79	0.11%
Onyx	0.5%	5	10	1000	1	3	0.10%
GEM	1.0%	10	10	22000	N/A	N/A	0.10%
GEM DR	1.2%	10	10	15000	N/A	N/A	0.12%
EntrustDR	2.8%	5	10	500	1	6	0.56%
VirtuosoDR (advisory)	28.3%	4	10	4000	2	490	7.08%

Product Performance: Survivability

- Some companies set reliability goals based on survivability
  - Often bounded by confidence levels
  - Example: 95% reliability with 90% confidence over 15 years

- Advantages
  - Helps set bounds on test time and sample size
  - Does not assume a failure rate behavior (decreasing, increasing, steady-state)

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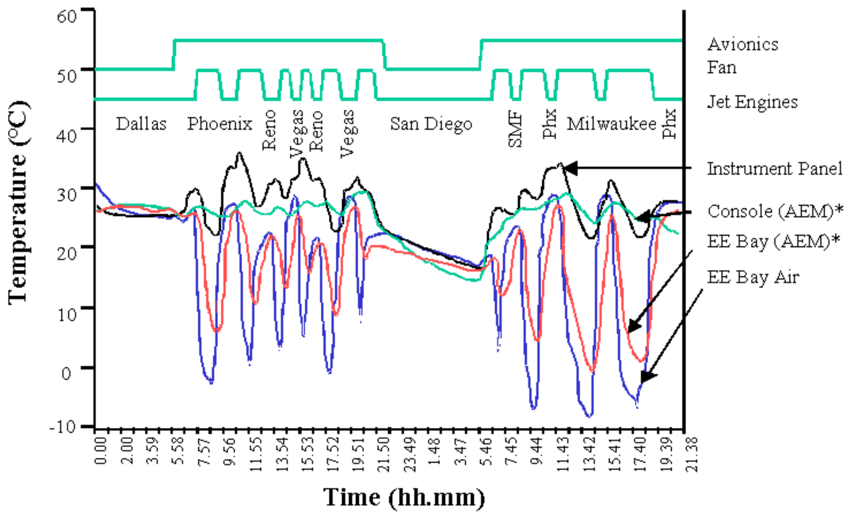
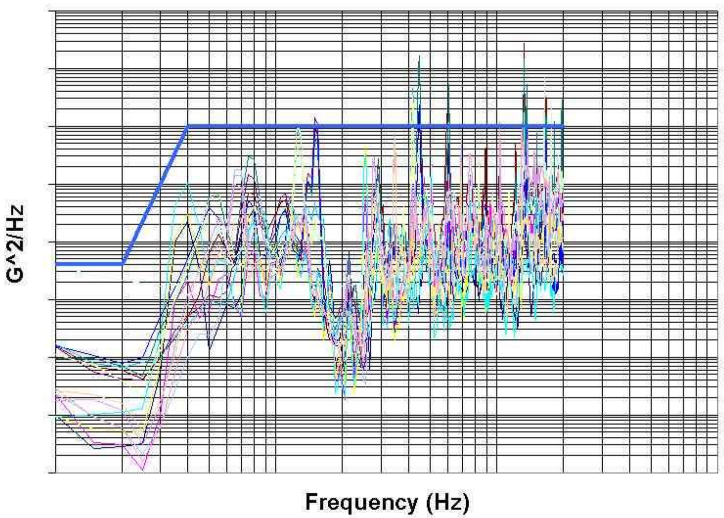
Identify and Quantify Failure Inducing Loads

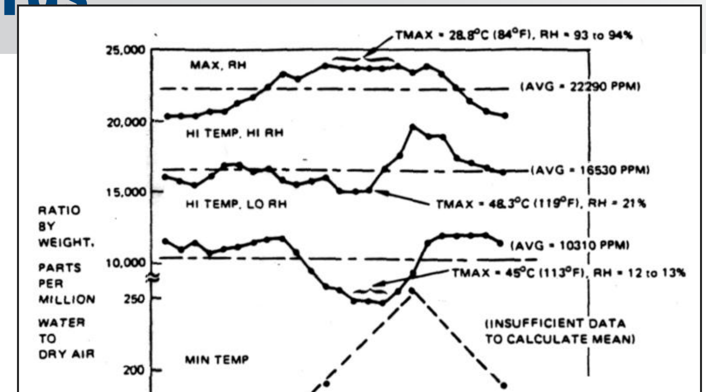
- Temperature Cycling
  - Tmax, Tmin, dwell, ramp times
- Sustained Temperature
  - T and exposure time
- Humidity
  - Controlled, condensation
- Corrosion
  - Salt, corrosive gases (Cl2, etc.), UV
- Power cycling
  - Duty cycles, power dissipation
- Electrical Loads
  - Voltage, current, current density
  - Static and transient
  - Electrical Noise
- Mechanical Bending (Static and Cyclic)
  - Board-level strain
- Random Vibration
  - PSD, exposure time, kurtosis
- Harmonic Vibration
  - G and frequency
- Mechanical shock
  - G, wave form, # of events





Identify Environment: Standards

- Usually, the first approach is to use standards
- However, existing standards do not work well with wearable electronics
- More geared towards permanent installations



MIL HDBK310

USE CATEGORY	WORST-CASE USE ENVIRONMENT Tmin °C	Tmax °C	ΔT(1) °C	t_D hrs	Cycles/ year	Typical Years of Service	Approx. Accept. Failure Risk, %	ACCELERATED TESTING Tmin °C	Tmax °C	ΔT(2) °C	t_D min
1) CONSUMER	0	+60	35	12	365	1-3	1	+25	+100	75	15
2) COMPUTERS	+15	+60	20	2	1460	5	0.1	+25	+100	75	15
3) TELECOM	- 40	+85	35	12	365	7-20	0.01	0	+100	100	15
4) COMMERCIAL AIRCRAFT	-55	+95	20	12	365	20	0.001	0	+100	100	15
5) INDUSTRIAL & AUTOMOTIVE PASSENGER COMPARTMENT	-55	+95	20 &40 &60 &80	12 12 12 12	185 100 60 20	10	0.1	0	+100	100 & COLD(3)	15
6) MILITARY GROUND & SHIP	-55	+95	40 &60	12 12	100 265	10	0.1	0	+100	100 & COLD(3)	15
7) SPACE leo geo	-55	+95	3 to 100	1 12	8760 365	5-30	0.001	0	+100	100 & COLD(3)	15
8) MILITARY AVIONICS a b c	-55	+95	40 60 80 &20	2 2 2 1	365 365 365 365	10	0.01	0	+100	100 & COLD(3)	15
9) AUTOMOTIVE UNDER HOOD	-55	+125	60 &100 &140	1 1 2	1000 300 40	5	0.1	0	+100	100	15

IPC SM785

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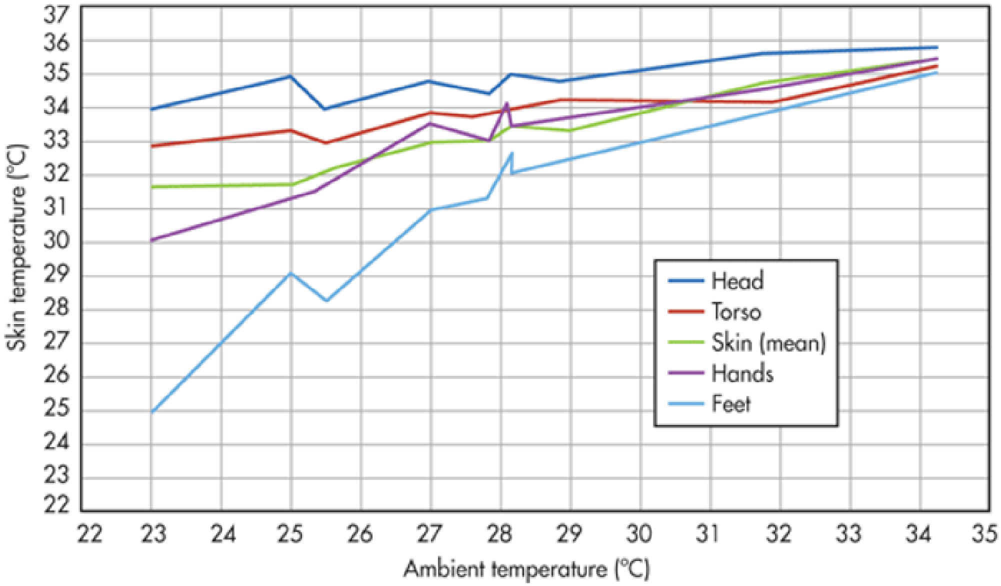
Field Environment: Temperature



- Maximum temperatures likely not a significant concern
- Typically far below ratings

- However, very cold temperatures (below -20C) could be a challenge
  - Especially in combination with a mechanical load

Temperature	Avg. U.S. CLIM Data	Avg. U.S. Weighted by Registration (Source: Confidential)	Phoenix (hrs/yr)	U.S. Worst Case (hrs/yr)
95F (35C)	0.375%	0.650%	11% (948)	13% (1,140)
105F (40.46C)	0.087%	0.050%	2.3% (198)	3.8% (331)
115F (46.11C)	0.008%	0.001%	0.02% (1.4)	0.1% (9)

Field Environment: Mechanical

- Vibration
  - Not typically affiliated with human body, but outliers can occur (especially with tools, transportation)
  - Examples: Jackhammer, reciprocating saw
  - Have induced failures in rigid medical devices

- Mechanical Shock
  - Drop loads can reach 1500g for mobile phone (some OEMs evaluate up to 10,000g)
  - Likely to be lower for lighter wearables, but could be repeated (i.e., affiliated with shoes)

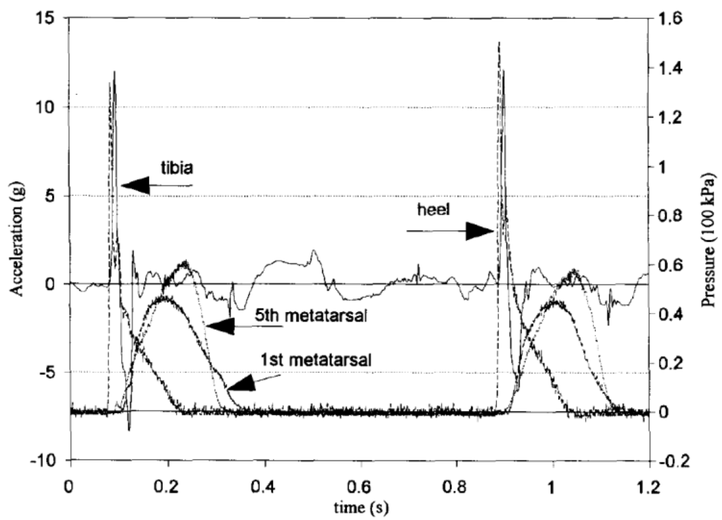


Fig. 7. Typical acceleration and pressure patterns recorded while subject was running.

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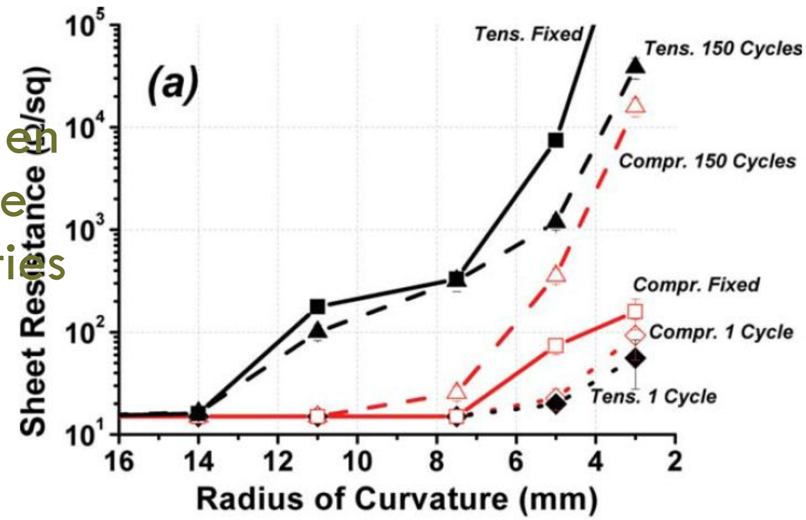
Field Environment: Mechanical (cont.)

- Bending (Cyclic / Overstress)
  - Often considered one of the biggest risks in regards to wearables
  - Certain human movements that induce bending (flexing of the knee) can occur over 1,000/day

- Case Study
  - There is indication that next-gen substrate materials experience a change in electrical properties after exposure to bending
  - Can be exacerbated by elevated temperature



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Corrosion: Handling / Sweat

- Composition of dissolved salts in water
  - Can include other biological molecules.
- Main constituents, after the solvent (water),
  - Chloride, sodium, potassium, calcium, magnesium, lactate, and urea.
- Chloride and sodium dominate.
  - To a lesser but highly variable extent, iron, copper, urocanate (and the parent molecule histidine), and other metals, proteins, and enzymes are also present.
- The main concern regarding sweat is as a source of chloride

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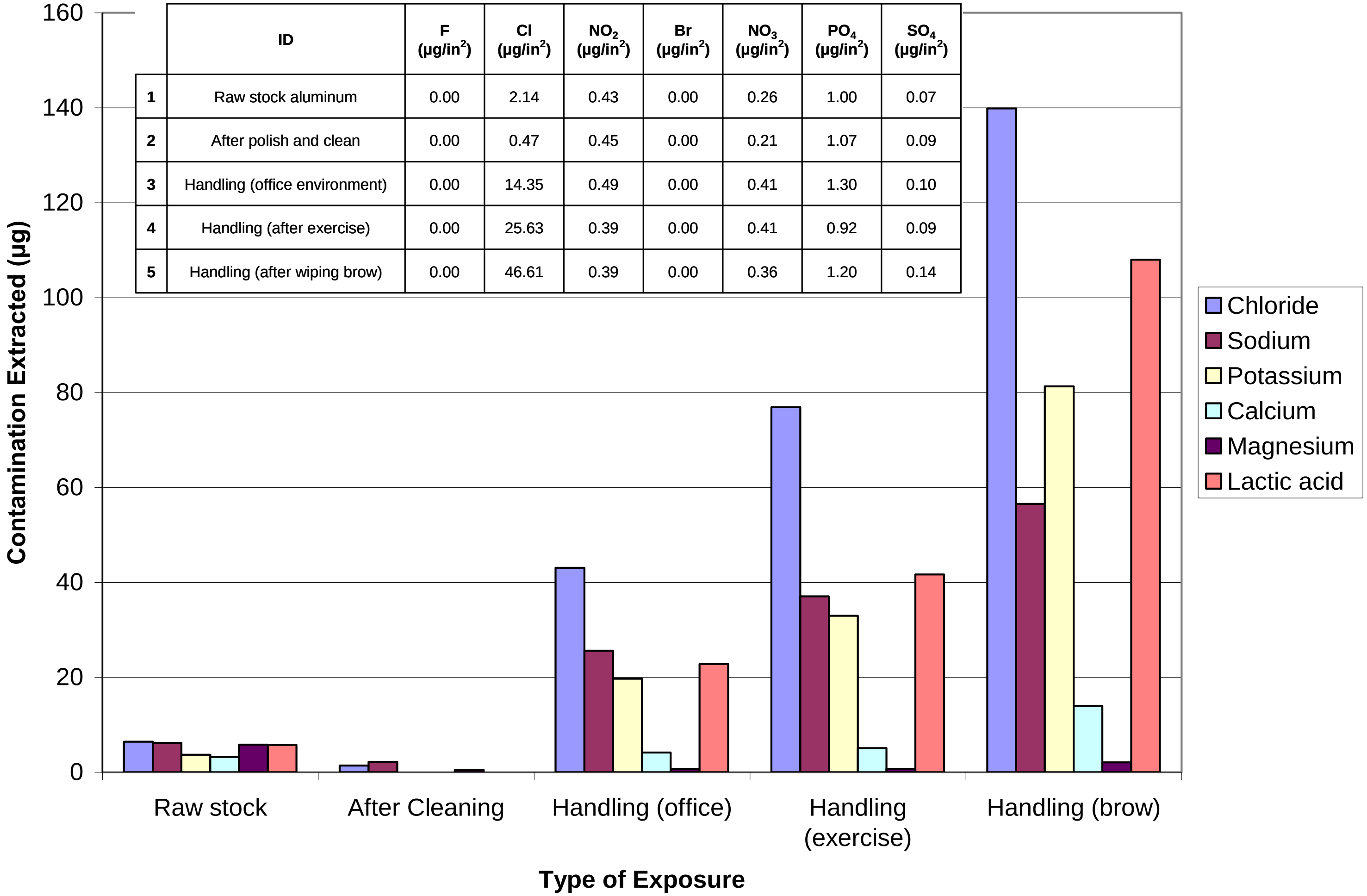
Handling / Sweat (cont.)

	ID	F (µg/in²)	Cl (µg/in²)	NO_2 (µg/in²)	Br (µg/in²)	NO_3 (µg/in²)	PO_4 (µg/in²)	SO_4 (µg/in²)
1	Raw stock aluminum	0.00	2.14	0.43	0.00	0.26	1.00	0.07
2	After polish and clean	0.00	0.47	0.45	0.00	0.21	1.07	0.09
3	Handling (office environment)	0.00	14.35	0.49	0.00	0.41	1.30	0.10
4	Handling (after exercise)	0.00	25.63	0.39	0.00	0.41	0.92	0.09
5	Handling (after wiping brow)	0.00	46.61	0.39	0.00	0.36	1.20	0.14



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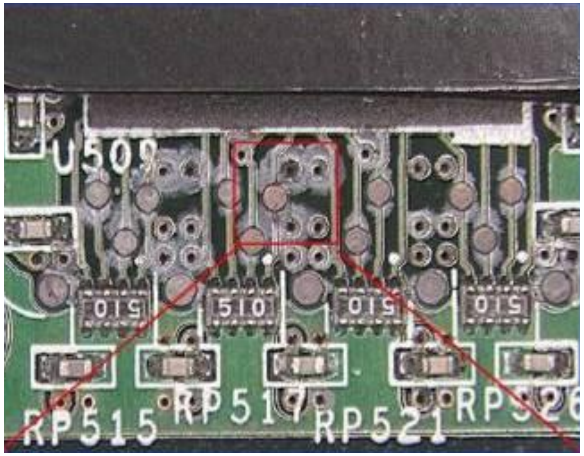
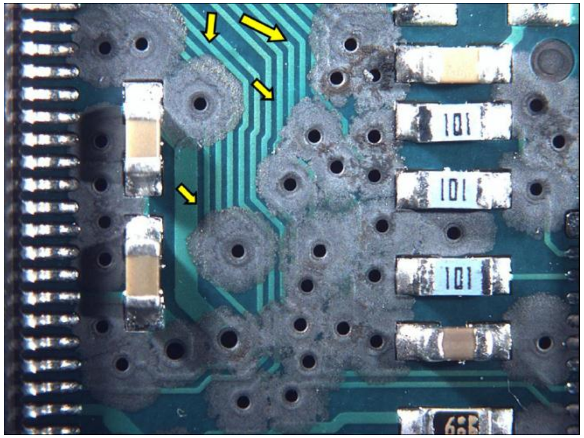
Influence of Pollutants: Creepage Corrosion

- Recent field issues with printed circuit boards (PCBs) plated with immersion silver
  - Sulfur-based creepage corrosion
- Failures in customer locations with elevated levels of sulfur-based gases
  - Rubber manufacturing
  - Sewage/waste-water treatment plants
  - Vehicle exhaust fumes (exit / entrance_ramps)
  - Petroleum refineries
  - Coal-generation power plants
  - Paper mills
  - Landfills
  - Large-scale farms
  - Automotive modeling studios
  - Swamps
  - Fast Food Restaurants
  - “Silicone is being used because it is soft and smooth”





P. Mazurkiewicz , ISTFA 2006

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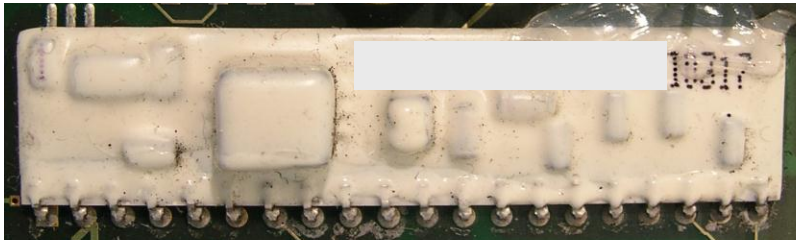
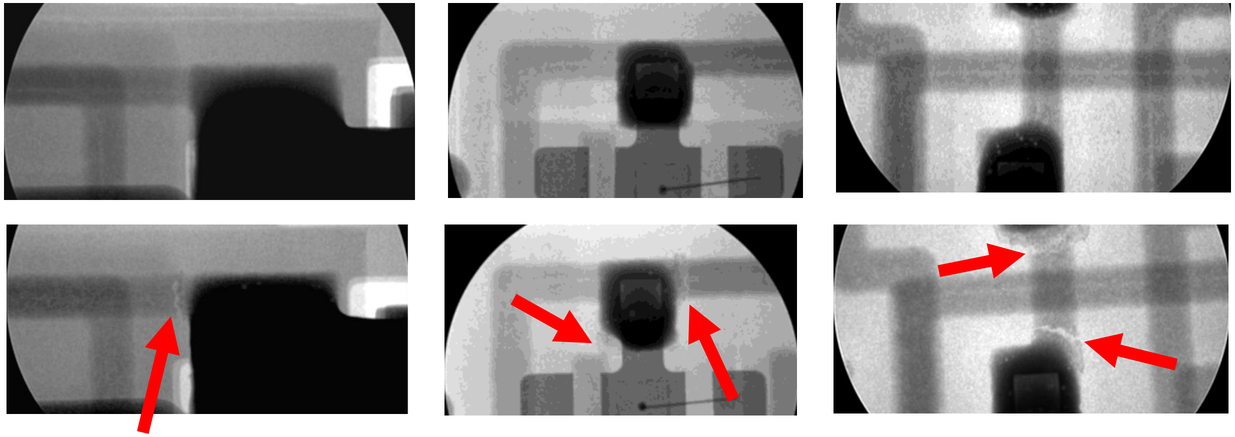
Sulfur Attack of Encapsulated Hybrid

- Silicone encapsulant, ceramic hybrid
- Used in industrial controls
- Customer reported failures after a few months in the field
- X-ray identified several separations



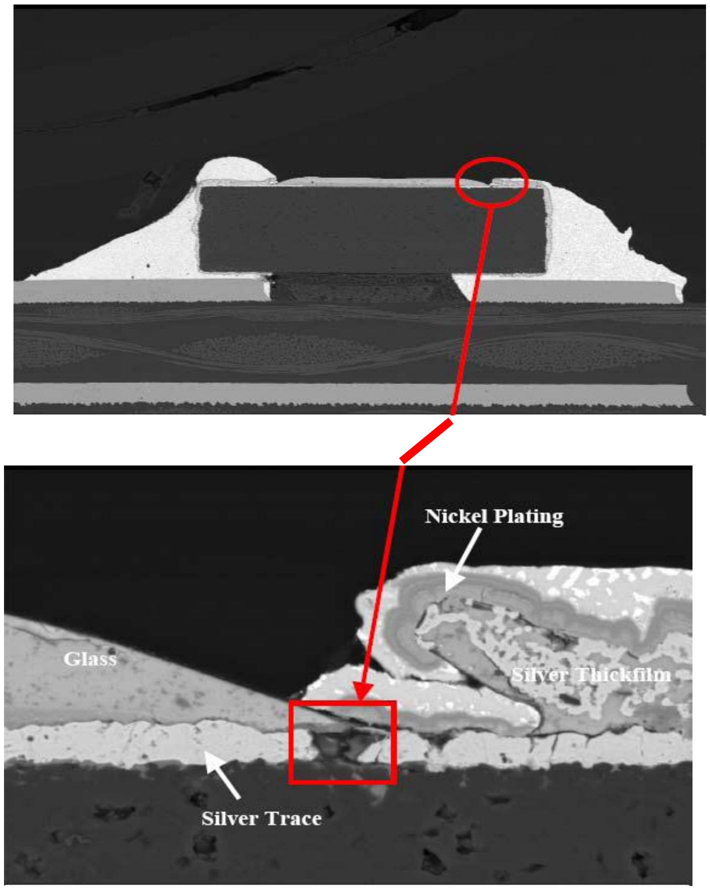
‘Good’ hybrid

‘Bad’ hybrid



SMT Resistors-Sulfidation from Sulfur Exposure

- Sulfur attack of silver occurs at the abutment of the glass passivation layer and the resistor termination
  - Cracks or openings can allow the ingress of corrosive gases,
  - Reaction with the silver to form silver sulfide (Ag_2S)
- Large change in resistance
  - r_{Ag} = 10^{-8} ohm-m;
r_{Ag2S} = 10 ohm-m
  - Up 20K ohms (0.01 x 0.01 x 0.5mm)
- Manufacturers' solutions
  - Sulfur tolerant – silver alloys
  - Sulfur resistant – silver replacement



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Corrosion: UV Exposure

- Exposure to ultraviolet (UV) is typically not sufficient to induce degradation in electronic materials
- However, a combination of temperature, moisture, and UV can induce scission in polymeric chains
  - Exact combination, and specific portion of the UV spectrum, is not always well characterized
- It has been documented that stress corrosion cracking has been caused by sun tan lotion

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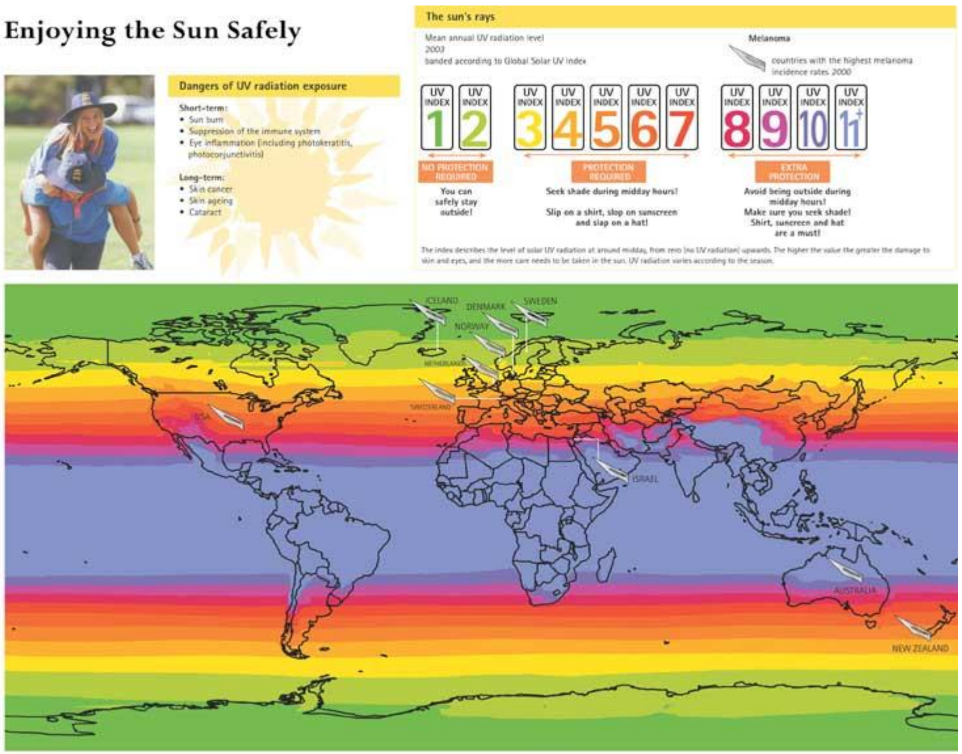
UV Exposure

Annual UV Intensity – Global Picture



http://www.drb-mattech.co.uk/uv%20map.html

Annual UV Energy Calculations by City			
City	Latitude	Average Total Energy at 340nm (W*hr/m^2/nm)	Average Annual Total Radiant Dose at 340nm (kJ/m^2/nm)
Singapore	1	426	1532
Paris, France	48	499	1796
Sao Paulo, Brazil	22	553	1991
Tokyo, Japan	35	570	2053
Guatemala	14	648	2334
Miami, FL	25	661	2380
New York NY	40	661	2381
Barcelona, Spain	41	662	2382
Brasilia, Brazil	15	662	2383
Melbourne, Australia	37	708	2549
Buenos Aires, Argentina	34	727	2618
Baghdad, Iraq	33	732	2634
Minneapolis, MN	44	735	2647
Townsville, Australia	19	743	2673
Madrid, Spain	40	748	2694
LA, CA	34	767	2761
Phoenix, AZ	33	869	3129

- Of Cities listed, Phoenix has highest avg annual exposure. Note: Model is isolated to UV. Humidity is not included.

Other Challenging Environments for Wearables

- Washer / Dryer
- Cleaning fluids
- Mud / Dust / Water

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Environment (Best Practice)

- Use standards when…
  - Certain aspects of your environment are common
  - No access to use environment

- Measure when…
  - Certain aspects of your environment are unique
  - Strong relationship with customer

- Do not mistake test specifications for the actual use environment
  - Common mistake with mechanical loads

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How Have Wearable Consumer Electronics Failed?

- Sweat
  - It has been documented in blogs that Apple iPOD Nano's have shorted out due to sweat
- Strain relief
  - Wearable on clothing, attached by a cord to power device, failed prematurely due to a lack of strain relief
- Plasticizer
  - First-generation of Amazon Kindle wiring insulation cracked/crumbled due to the use of non-optimized plasticizer formulation
- Cyclic Fatigue
  - Initial video game controllers experienced fatigue of solder joints on components attached to the backside of the push buttons

Follow the Toyota Example (Case Study)

- Traditional approach: Design radiator for a specific vehicle based on mechanical specifications written for that vehicle

- Toyota considers a range of radiator solutions based on cooling capacities and the cooling demands of various engines that might be used.
  - How the radiator actually fits into a vehicle would be kept loose so that Toyota's knowledge of radiator technology could be used to create the optimum design

- Toyota's system is "test & design" rather than the traditional "design & test."
  - Toyota engineers test at the fundamental knowledge level so they don't have to test at the later, more expensive stages of design and prototyping

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Conclusion

- Wearable electronics are an exciting revolution in our engagement with ourselves and the world around us

- However, there are clear risks
  - Wearables will be using new technology that has not been fully characterized
  - They will be placed in environments that are not fully considered by the designer

- There will be unexpected failures, resulting in delays in product launch and potential advisory notices, if wearable manufacturers do not use industry best practices and physics of failure to qualify their technology

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Thanks!!

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