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AUTOMATED DESIGN ANALYSIS™

웨어어블과 IOT 세상에서 신뢰성 설계

DESIGN FOR RELIABILITY: CASE STUDIES FROM THE WORLD OF WEARABLES AND IOT

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Sherlock Seminar

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What is Design for Reliability?

WHAT IS DESIGN FOR RELIABILITY (DFR)?

- 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

- Design for Reliability is a process for ensuring the reliability of a product or system during the design stage before physical prototype
  - Often part of an overall Design for Excellence (DfX) strategy

WARNING: DFR SOLUTIONS' DFR VS. OTHERS' DFR

- DfR: Focus is on activities before prototype
- Others: Focus is on the entire product lifecycle (HALT, root-cause analysis, reliability growth)

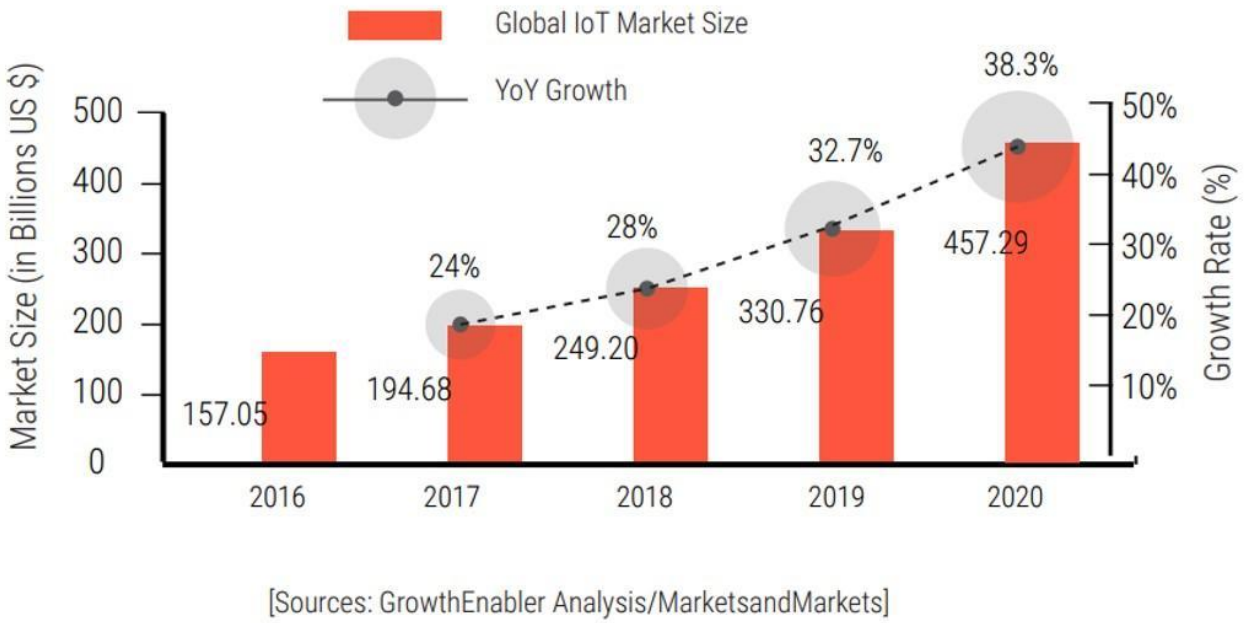
- DfR: Focus is on preventing single point of failures
- Others: Focus is on system-level failures and failure modes (safety)

WHY DESIGN FOR RELIABILITY (DFR)?

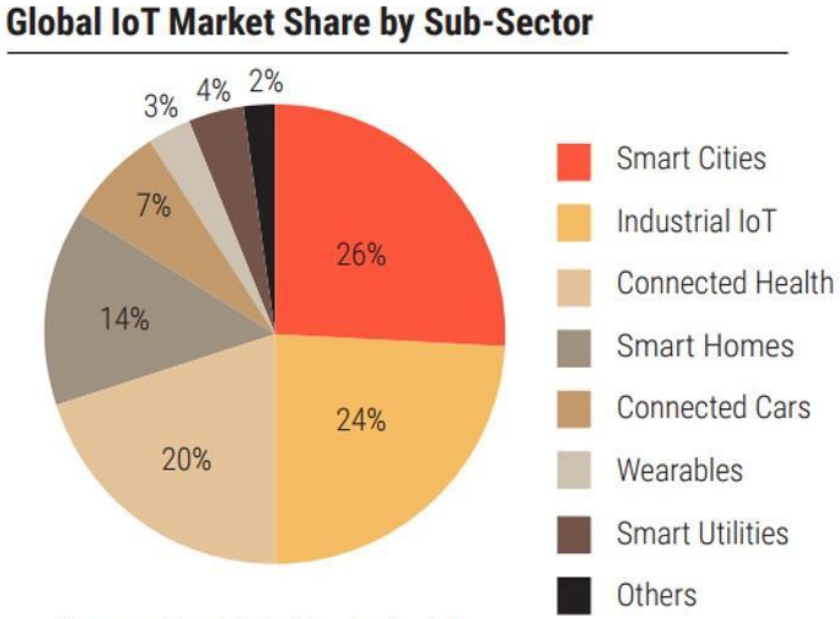
- The foundation of a successful product is a robust design
  - Provides margin
  - Mitigates risk from defects
  - Satisfies the customer

Why Wearables and IoT?

IoT MARKET IS HOT, HOT, HOT!



[Sources: GrowthEnabler Analysis/MarketsandMarkets]



[Source: GrowthEnabler Analysis]

https://www.forbes.com/sites/louiscolumbus/2017/12/10/2017-roundup-of-internet-of-things-forecasts/#20c655a01480

Why DfR and Wearables/IoT?

WEARABLE TECHNOLOGY IS NOT WORKING

- 24%: Wearables are too complicated to use
- 22%: Wearables did not set up properly
- 21%: Wearables did not work as advertised

Strong indications that wireless reliability
is a key player in this failure of wearable technology

Sourced: http://www.accenture.com/SiteCollectionDocuments/us-en/engaging-digital-consumer-new-connected-world.pdf

THINK WIRELESS IS EASY? ALREADY SOLVED?

J.D. POWER
McGRAW HILL FINANCIAL

2015 U.S. Vehicle Dependability Study: Technology is playing an increasingly critical role in perceptions of vehicle reliability.

specific problem symptoms grouped into eight major vehicle categories.

The top two problems reported by owners are Bluetooth pairing/connectivity and built-in voice recognition systems misinterpreting commands. These are also the most frequent problems reported by owners at 90 days, according to the J.D. Power 2014 U.S. Initial Quality Study.SM

"As we've seen in our Initial Quality Study, owners view in-vehicle technology issues as significant problems, and they typically don't go away after the ownership honeymoon period is over," said Renee Stephens, vice president of U.S. automotive at J.D. Power. "Furthermore, early indications from our upcoming 2015 U.S. Tech Choice Study show that vehicle owner expectations of advanced technology capabilities are growing. Owners clearly want the latest technology in their vehicles, and they don't hesitate to express their disapproval when it doesn't work. Their definition of dependability is increasingly influenced by usability."

Because issues with technology impact overall dependability, they also impact repurchase intent. The study finds that 56 percent of owners who report no problems with their vehicle say they "definitely will" purchase the same brand next time, compared with 43 percent of those who report three or more problems. Together with the fact that 15 percent of new-vehicle buyers indicate they avoided a model because it lacked the latest technological features—up from just 4 percent in 2014[2]—technology clearly plays a key role in affecting future purchase decisions.

Key Study Findings

- Among owners who experienced a Bluetooth pairing/connectivity problem, 55 percent say that their vehicle would not recognize their phone, and 31 percent say the phone would not automatically connect when entering their vehicle.

The top two problems reported by owners are Bluetooth pairing/connectivity and built-in voice recognition systems misinterpreting commands. These are also the most frequent problems reported by owners at 90 days, according to the J.D. Power 2014 U.S. Initial Quality Study.SM

RELIABILITY IS LETTING WEARABLE TECH DOWN

- "Another month, another bad experience with regard to reliability of wearable tech – this time with the Fitbit Flex. When the silicone<sic> wristband was only about a month old, it started coming apart….."
  - "Did you try turning it off, and then on again? How about charging it?"
- "After the first time you go through that dance, you realize it will never ever work. The failure mode is 100% catastrophic from the point of view of the user."

http://wearabletechwatch.net/2013/09/06/reliability-is-letting-wearable-tech-down/

http://forums.jawbone.com/t5/SUGGESTIONS/Is-the-UP24-Reliable-now/td-p/79393

DfR and Wearables/IoT

DFR PROCESS FOR WEARABLES/IoT

- Define reliability goals
- Establish the use case (environment)
- Select the right parts

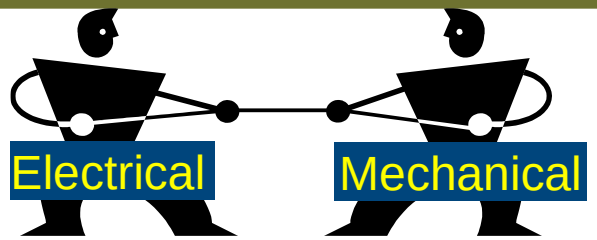
WHO CONTROLS WHAT?

Marketing / Sales

- Knows the market, but can you build it?

Engineering

- You can build it, but will anyone buy it?



The Customer

- Always right, but did you miss something?

WHO CONTROLS WHAT? MITIGATING MISTAKES

- Make sure the Product Requirements flow from actual use case
  - Who will use it? How will it be used? Where will it be used? How long will it be used?
  - Avoids the "*You Don't Know What You Don't Know*"

- Limit focus on Specifications except for communication protocols and compliance requirements

- Consider use of internal checklist to ensure Product Requirements, whether from marketing or customer, are complete

HOW ARE WEARABLES USED?

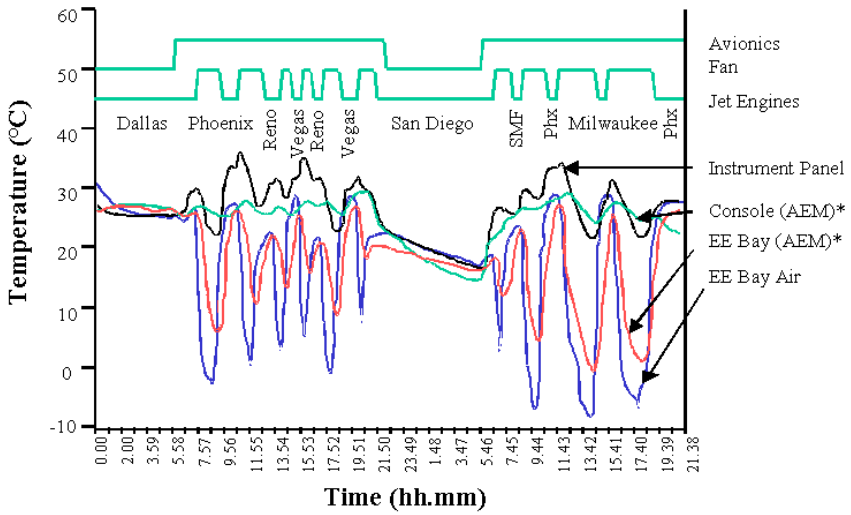
A Critical Action for the Wearable Tech Community

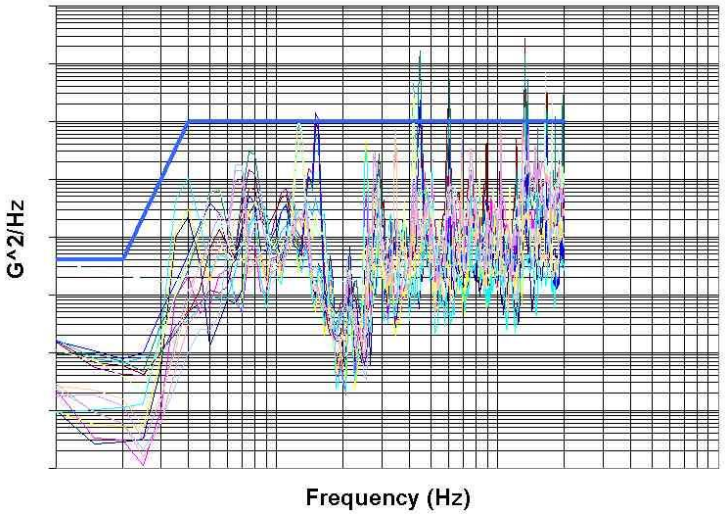
Where will they use it? How often?

FAILURE INDUCING LOADS - CHECKLIST

- Temperature Cycling
  - Tmax, Tmin, dwell, ramp times
- Sustained Temperature
  - T and exposure time
- Humidity
  - Controlled, condensation
- Corrosion
  - Salt, corrosive gases (Cl_2, etc.)
- Power cycling
  - Duty cycles, power
- Electrical Loads
  - Voltage,
  - Stati
- El
- g (Static and Cyclic)
  - strain
- Ra vibration
  - PSD, exposure time, kurtosis
- Harmonic Vibration
  - G and frequency
- Mechanical shock
  - G, wave form, # of events

And now we have to think about wear and wireless!

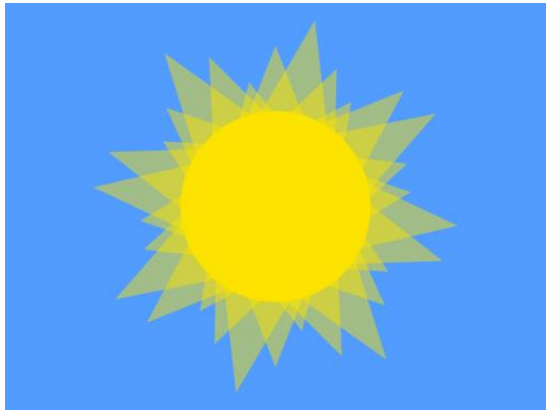




USE CASE EXAMPLE: IoT GATEWAY

- Shipping/Transportation (Truck Trailer)
  - Environmental Duty cycle? Depends

- Drive time is legally limited (<60 hours/wk)
  - Is 35% (60/168) duty cycle appropriate?
  - Class 8 (tractor-trailer) trucks average 100k km/yr, but 35% duty cycle at 100 kph results in 300k km/yr
  - Recommended 30% duty cycle



- Temperature is all the time (100% duty cycle)
  - Diurnal cycling + solar loading

USE CASE EXAMPLE: IoT GATEWAY (cont.)

Average American City

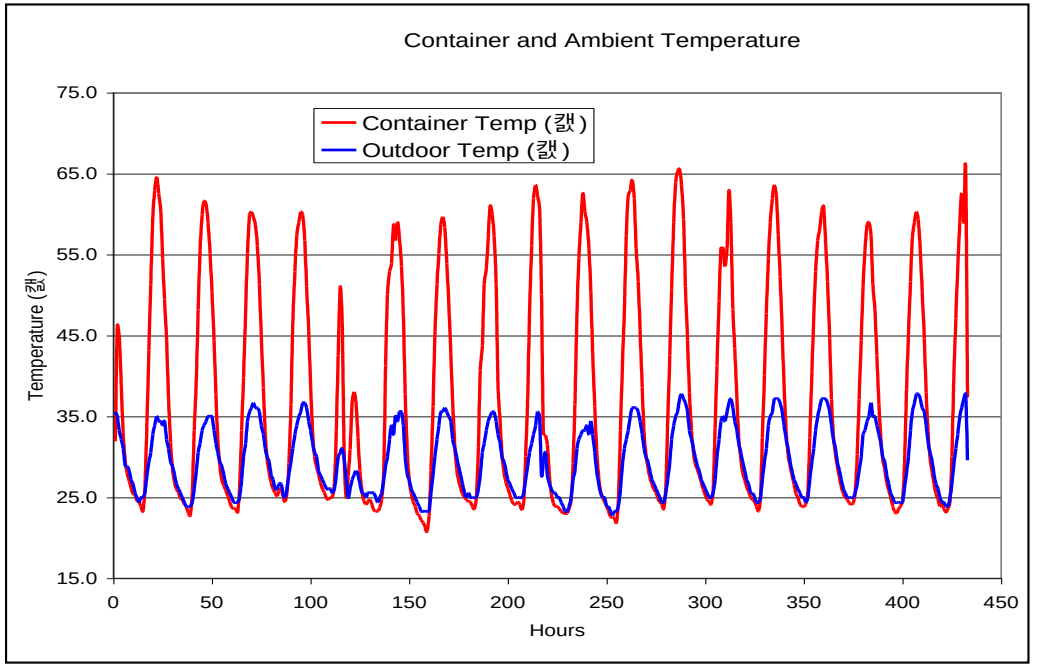
	Days	High	Low	Days	High	Low
Jan/Feb/Dec	63	10°C	0°C	27	40°C	0°C
Mar/Nov	42	15°C	5°C	18	45°C	5°C
Apr/Oct	42	20°C	10°C	18	50°C	10°C
May/Sept	42	25°C	15°C	18	55°C	15°C
Jun/Jul/Aug	63	30°C	20°C	27	60°C	20°C

Phoenix, AZ

	Days	High	Low	Days	High	Low
Jan/Feb/Dec	36	20°C	5°C	54	50°C	5°C
Mar/Nov	24	25°C	10°C	36	55°C	10°C
Apr/Oct	24	30°C	15°C	36	60°C	15°C
May/Sept	24	35°C	20°C	36	65°C	20°C
Jun/Jul/Aug	36	40°C	25°C	54	70°C	25°C

Solar Loading

- 30% duty cycle based on average number of clear days in USA
- 60% duty cycle based on average number of clear days in Phoenix



FIELD ENVIRONMENT: MECHANICAL

Vibration

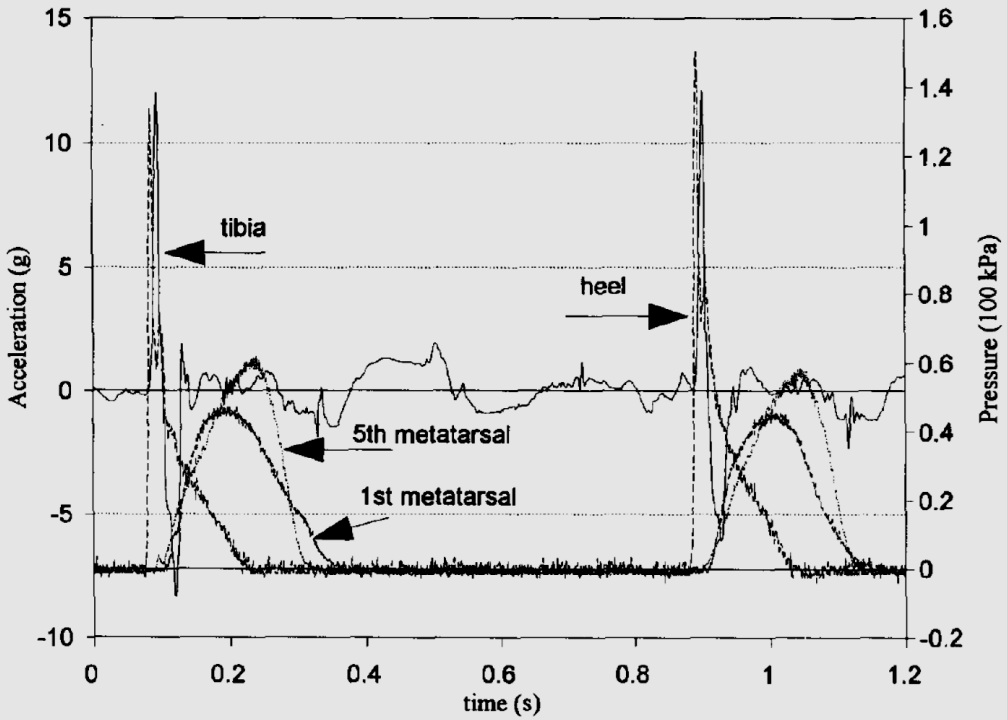


Fig. 7. Typical acceleration and pressure patterns recorded while subject was running.

es,
but could be repeated (i.e., shoes)

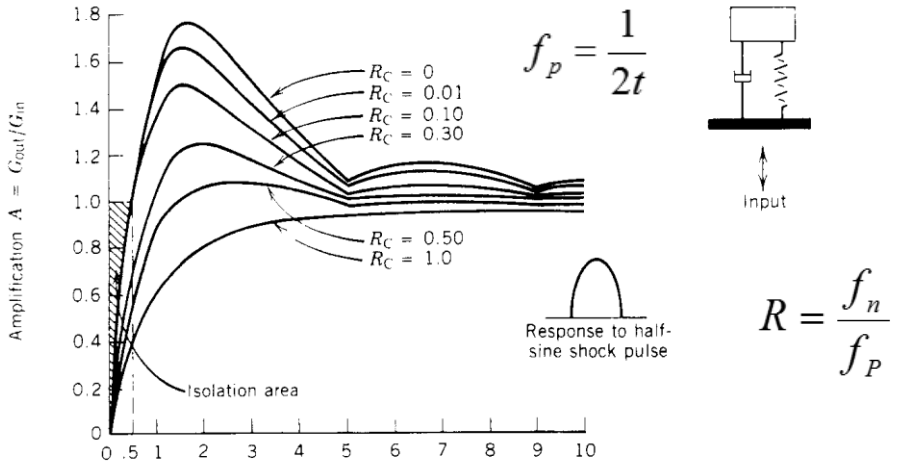
From IEC 60601-1-11 for medical wearables

- *acceleration amplitude:*
  - *10 Hz to 100 Hz: 1,0 $(m/s^2)^2/Hz$;*
  - *100 Hz to 200 Hz: – 3 db per octave;*
  - *200 Hz to 2 000 Hz: 0,5 $(m/s^2)^{2/}Hz$;*
- *duration: 30 min per perpendicular axis (3 total).*

- *peak acceleration: 150 m/s^2 (15 g);*
- *duration: 11 ms;*
- *pulse shape: half-sine;*
- *number of shocks: 3 shocks per direction per axis (18 total).*

DESIGN FOR RELIABILITY: SHOCKPROOFING

- When a PCB is subjected to shock, it will deform and then resonate at its natural frequency
  - Can cause a shock amplification if shock pulse frequency and the PCB natural frequency are close
- Rule of Thumb: PCB natural frequency should be at least 3X higher than shock pulse frequency
- Example: 10mS pulse
  - 50Hz pulse frequency
  - Board should be >150Hz
- Stiffen PCB
  - Mount points, standoffs, thicker board

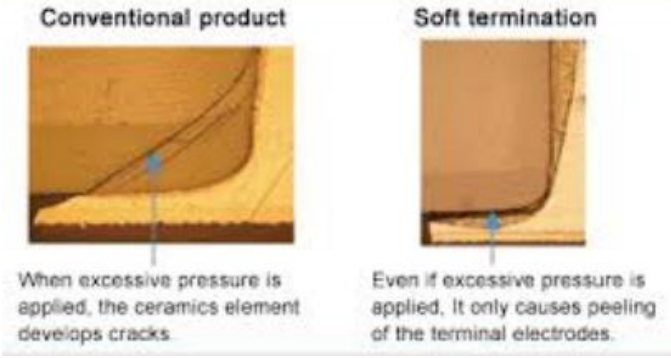


DESIGN FOR RELIABILITY: SHOCKPROOFING (cont.)

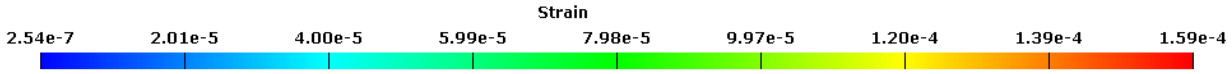
- Option 1: Reduce Excitation
  - Shock isolators (primarily for large electronic assemblies)
  - External cushioning (cell phone cases, bumpers)
  - Ejection of mass (battery pops out)

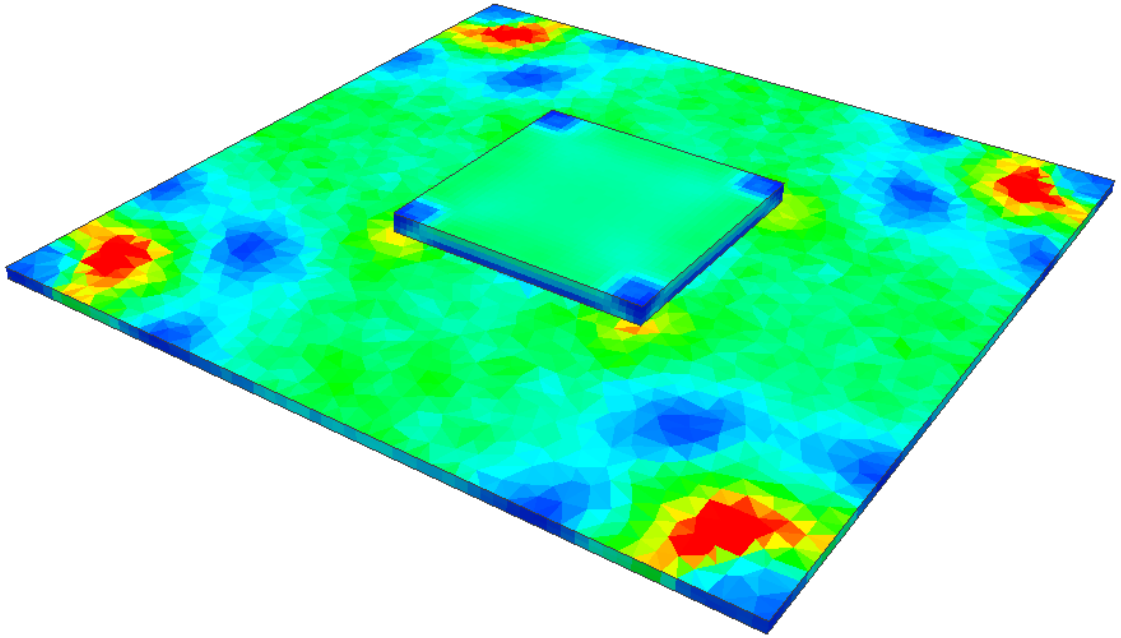
- Option 2: Stiffen Chassis
  - Stops the board from bending
  - Materials selection, design features (i.e., embossing, ribs, etc.)

- Option 3: More Robust Components
  - Component Selection (flexible leads/terminations)
  - Underfill/Edge-bonding/Staking



SHOCKPROOFING OPTION 2: CORNER STAKING

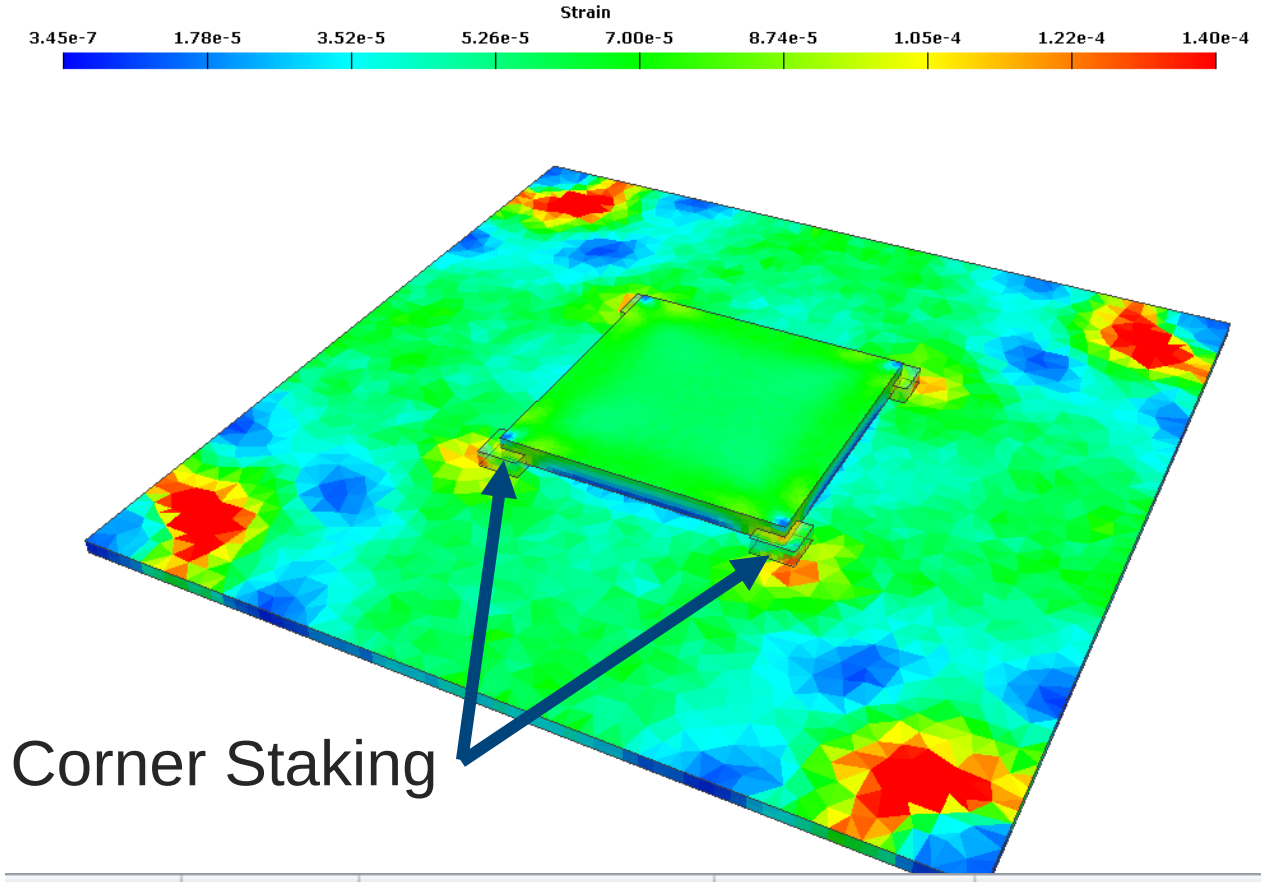




0.63% Probability of failure per shock event

RefDes	Lead ID	Max PCB Strain Event	Max PCB Strain	Max Part Strain Event	Max Part Strain	Max Lead Strain Event	Max Lead Strain
U1	1	Shock Event	5.4E-4	Shock Event	5.1E-4	Shock Event	5.4E-4
U1	111	Shock Event	4.7E-4	Shock Event	4.5E-4	Shock Event	4.7E-4
U1	18	Shock Event	4.4E-4	Shock Event	4.1E-4	Shock Event	4.4E-4
U1	128	Shock Event	4.1E-4	Shock Event	3.6E-4	Shock Event	4.1E-4

SHOCKPROOFING OPTION 2: CORNER STAKING



Corner Staking

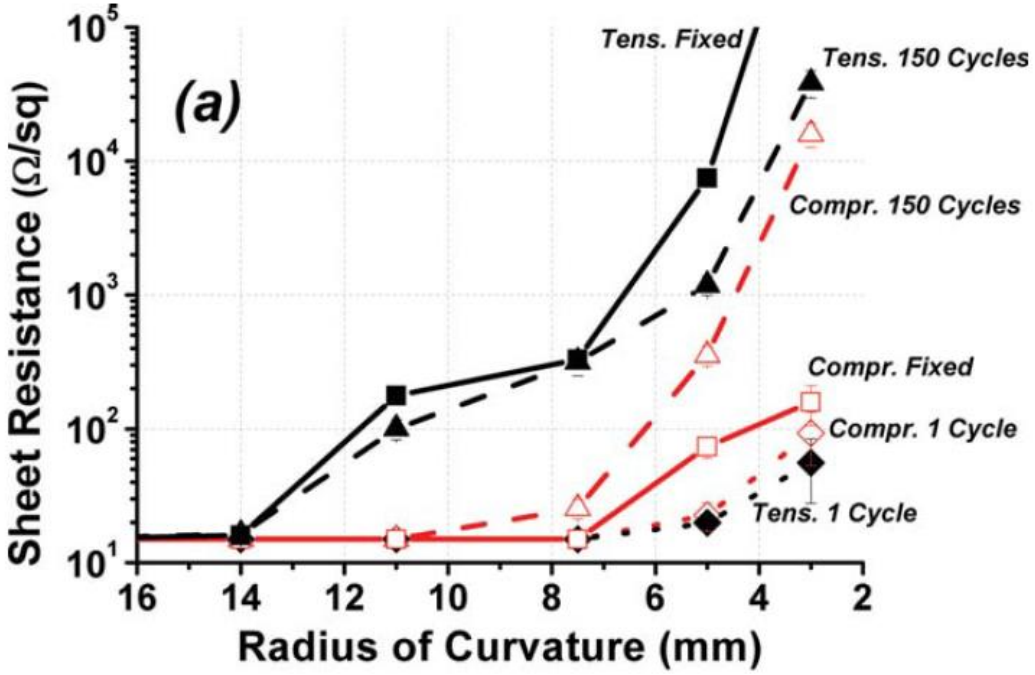
0.0000055% Probability of failure per shock event

6X decrease in ball strain

RefDes	Lead ID	Max PCB Strain Event	Max PCB Strain	Max Part Strain Event	Max Part Strain	Max Lead Strain Event	Max Lead Strain
U1	128	Shock Event	9.3E-5	Shock Event	9.3E-5	Shock Event	9.3E-5
U1	1	Shock Event	8.7E-5	Shock Event	9.0E-5	Shock Event	9.0E-5
U1	18	Shock Event	7.9E-5	Shock Event	8.2E-5	Shock Event	8.2E-5
U1	112	Shock Event	8.1E-5	Shock Event	7.5E-5	Shock Event	8.1E-5

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

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

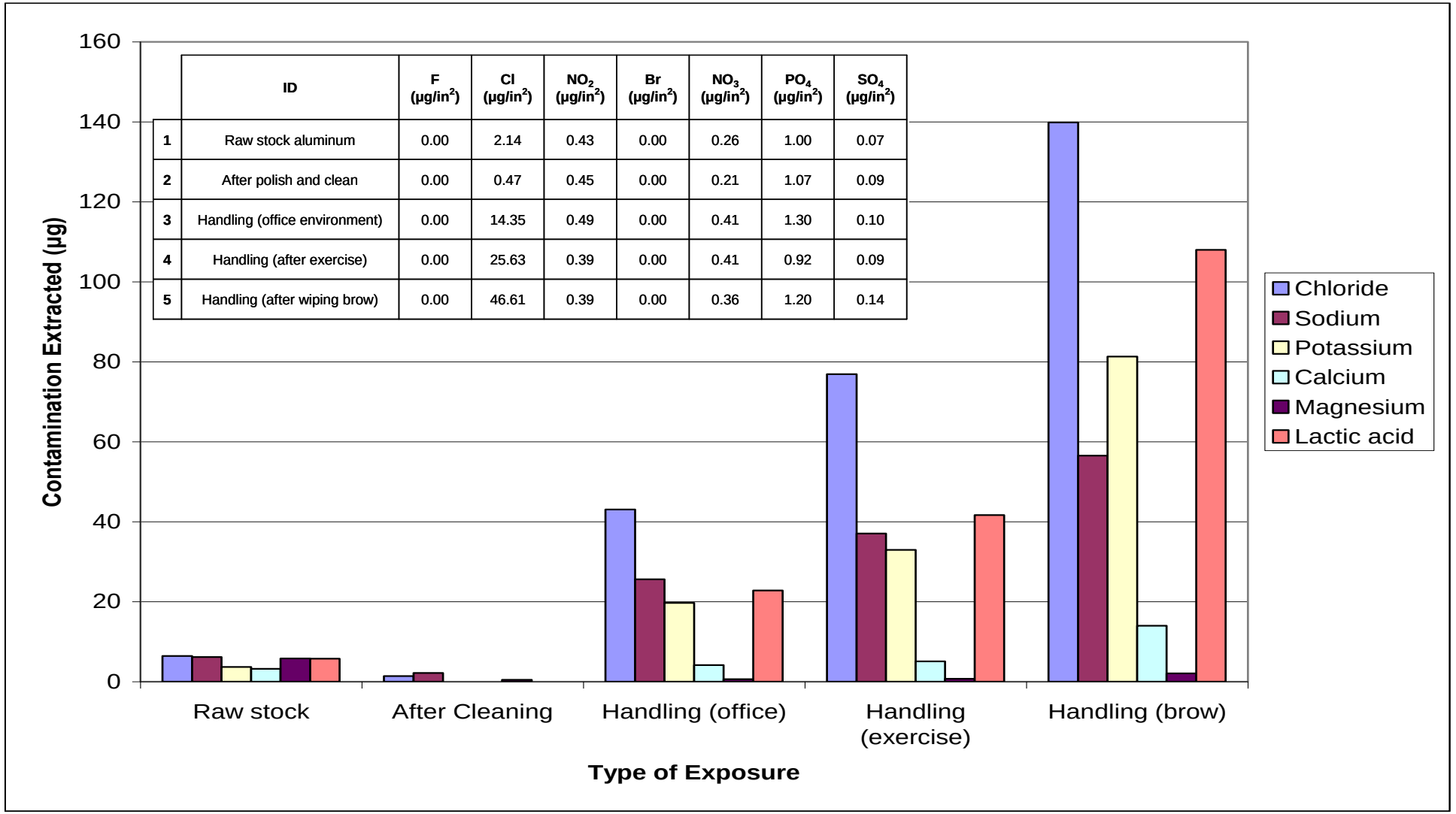


CORROSION: HANDLING / SWEAT

- 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.
- Different constituents of sweat can attack different elements of the wearable technology (contacts, windows, straps, etc.)

HANDLING / SWEAT (CONT.)

	ID	F ($\mu g/in^2$)	Cl ($\mu g/in^2$)	NO_2 ($\mu g/in^2$)	Br ($\mu g/in^2$)	NO_3 ($\mu g/in^2$)	PO_4 ($\mu g/in^2$)	SO_4 ($\mu g/in^2$)
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



EXAMPLES OF SWEAT FORMULATION

- Defined by EN 1811 comprises 0.5% NaCl, 0.1% urea, 0.1% lactic acid and the pH adjusted to 6.6 with NH4OH.
- ISO standard ISO 3160-2 comprises 20 g/l NaCl, 17.5 g/l NH4Cl, 5 g/l acetic acid and 15 g/l d,l lactic acid with the pH adjusted to 4.7 by NaOH.
- Another mixture comprising 7.5 g/l NaCl, 1.2 g/l KCl, 1 [illegible] /l lactic acid, pH = 4.57.
- Another one used in Denmark compri[illegible] g/l Na2SO4, 0.4 g/l NH4Cl, 0.2 g/l urea
- Other mixtures com[illegible] /l Na2SO4, 0.2% urea and 0.2% lactic acid, pH adjusted to 4.5.
- Japanese mixture 1 is 19.9 g/l NaCl, 1.7 g/l urea, 1.7 g/l lactic acid, 0.8 g/l Na2S, and 0.2 g/l NH4Cl
- Japanese mixture 2 is 17g NaCl, 1500 ml CH3OH, 1 g urea, 4 g lactic acid made up to 1 liter by water.

Never Go Below pH of 4.5
Does Not Exist in the Real World

RAIN & WATER IMMERSION CHALLENGES

- Issue of exposure to water & rain must be addressed for wearable electronics to survive

- Some cell phone manufacturers coat the product with either a conformal coating or a superhydrophobic coating to protect the electronics

P2i perform protect improve

Semblant™

ACULON Performance Surface Solutions

H2O PROTECTION

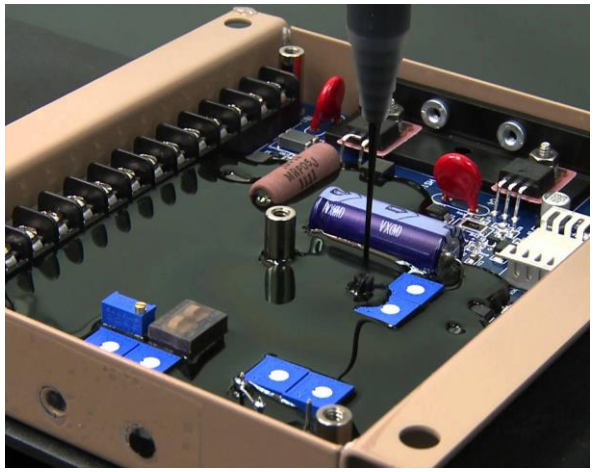
LiquiPEL™ WATERSAFE™ TECHNOLOGY

DESIGN FOR RELIABILITY: WATERPROOFING

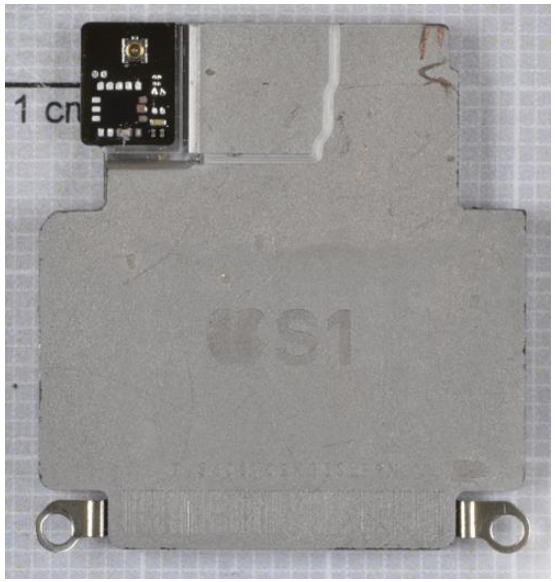
- Board Level
  - Encapsulation (Potting)
- Chassis Level
  - Sealed Plastic Housing (Ultrasonic vs. Laser)
  - O-Ring Sealing
  - Gaskets
- Moisture (Humidity) Issues

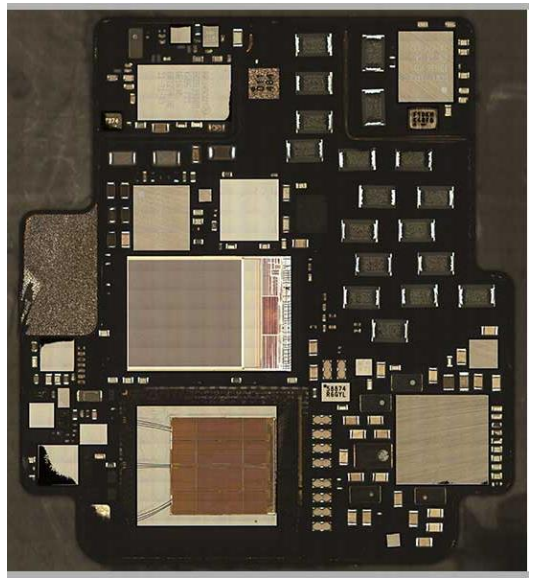
WATERPROOFING: ENCAPSULATION

- Common option for water-proofing is encapsulate the entire electronics in a polymer



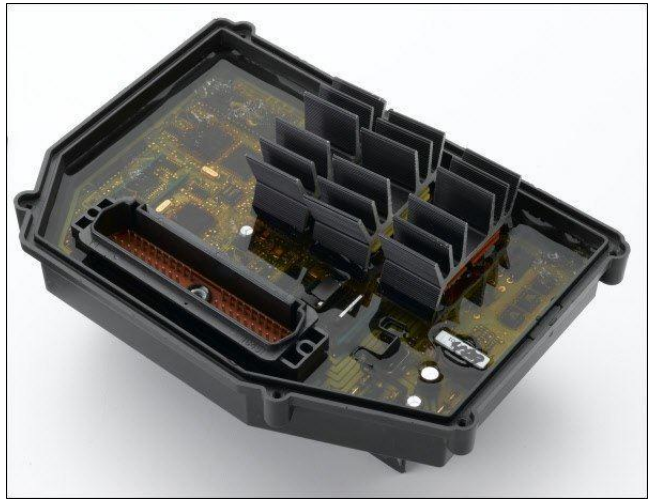
- Encapsulation takes many forms (including the iWatch!)
  - Includes potting and injection molding





WATERPROOFING: ENCAPSULATION (cont.)

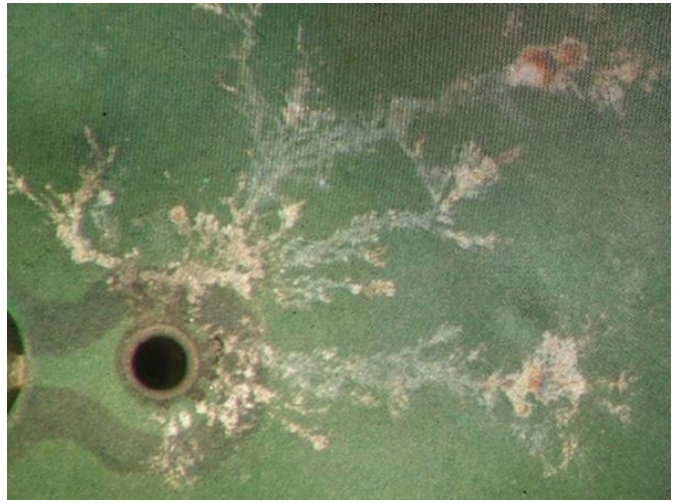
- Removes some constraints on housing design
  - No O-ring? No welding? No venting?
- Lower cost?
  - Some potting solutions are 50¢ (or less)
  - No tooling required



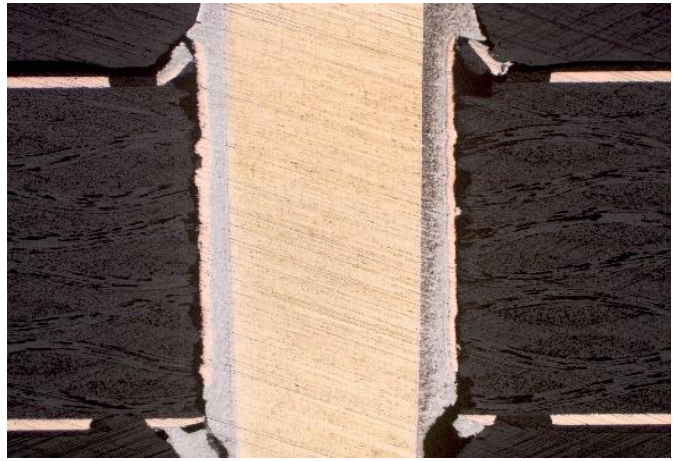
- Kill two (three? four?) birds with one stone?
  - Can provide water protection, shock protection, compliance with creepage/clearance requirements, and security from reverse engineering
- Better than conformal coating
  - Most coatings cannot withstand long-term contact with water

WATERPROOFING: ENCAPSULATION (cont.)

- Concentrate contamination
  - During dispense, liquid potting can gather and concentrate on-board contamination
  - High concentration levels can occur under low standoff components and where flow terminates



- Break components/solder joints
  - Driven by expansion/contraction during change in temperature
  - Dependent on potting properties, support, parts, and **volume**

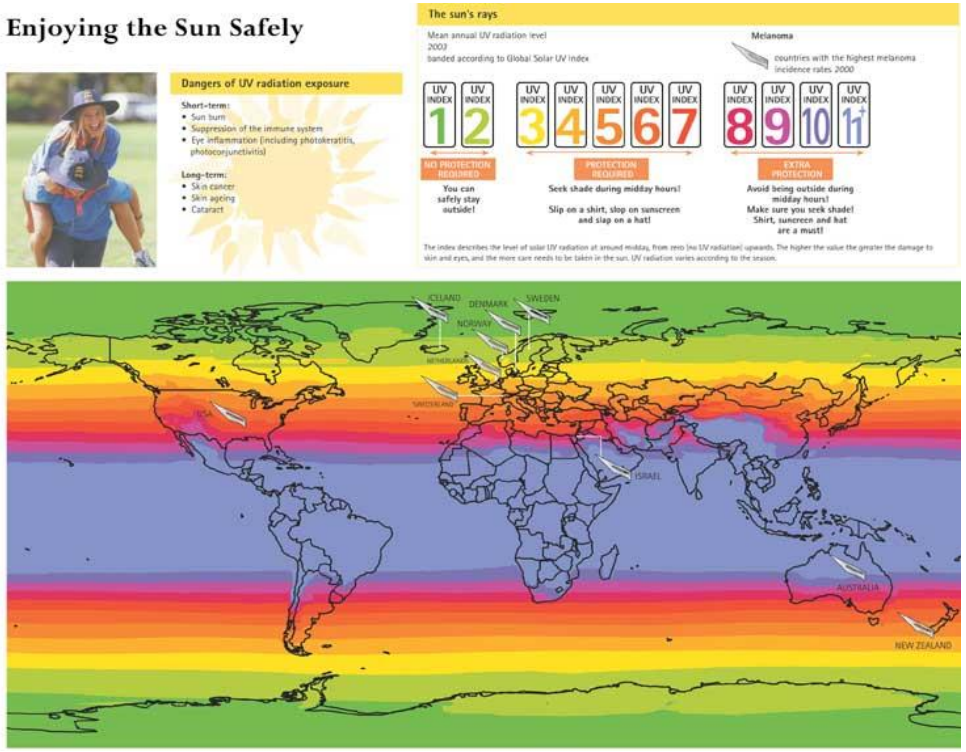


CORROSION: UV EXPOSURE

- Exposure to ultraviolet (UV) typically not sufficient to induce degradation in electronic materials
- However, combination of temperature, moisture, and UV can break 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 sunscreen lotion

UV EXPOSURE

Annual UV Intensity – Global Picture

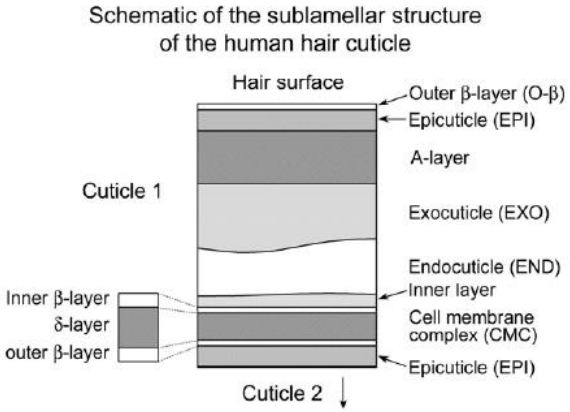


http://www.drb-mattech.co.uk/uv%20map.html

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

WEAR

Hardness of Skin and Hair Can Vary Widely (Ethnicity, Sex, Dryness)



	Hardness (GPa)			Elastic modulus (GPa)		
	Cuticle[a]	Cortex[b]	Medulla[b]	Cuticle[a]	Cortex[b]	Medulla[b]
Caucasian	0.32 ± 0.04	0.27 ± 0.02	~ 0.19	6.0 ± 0.4	6.5 ± 0.5	~ 5.5
Asian	0.39 ± 0.06	0.30 ± 0.02	~ 0.18	7.5 ± 0.8	6.7 ± 0.3	~ 5.8
African	0.24 ± 0.05	0.23 ± 0.06	~ 0.16	4.8 ± 0.6	5.8 ± 0.7	~ 5.0

DFR RULES FOR CONNECTORS

- Power and Ground should be Separated
- Each Mated Pair should be Shrouded
- Avoid Blind Insertion (increases risk of damage/mismating)
- Recommend Alignment Pins (limits off-axis mating)
- Connector should be Keyed (prevents reversal of I/O pins)
- Use Positive Retention
- Connector Wiring should have Strain Relief
- Do not use for Mechanical Support
- Specify Plating Material and Thickness

MATERIAL AND PLATING GUIDELINES [GOLD]

- Connections and environments
  - Hi-speed digital or critical connections
  - Low voltage (<5V) and/or low current (<10mA)
  - Corrosive environment (gases such as H2S, SO2, Cl2)
  - Risk of micromotion (>5-10 µm)

- Material specifications
  - Be-Cu or P-bronze base
  - Ductile nickel underplate (50-150 µin)
  - Soft gold (Au) plating
  - >10 µin/Flash (single insertion);
    15 µin (1-200 insertions);
    30 µin (>200 insertions); 50 µin (hi-rel)
  - Porosity spec

- Contact specifications
  - 50-100 grams contact force
  - Minimum of 2 contacts; 4 preferred
  - Adequate contact wipe – 0.010" min.
  - No mating with tin plating

MATERIAL AND PLATING GUIDELINES [TIN]

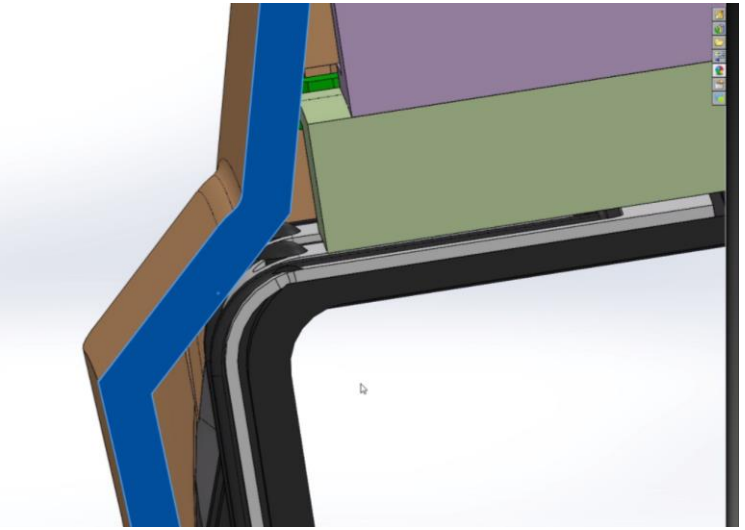
- Mechanical stability critical
  - Lubrication is a potential mitigation
- Minimum 100 gram normal force
- Minimum 100 microinch thickness
- Not recommended for operating conditions above 100C

- Adequate contact wipe – 0.010” min.
- Do not use to make or break current
- No mating with gold!

DfR FOR CONNECTORS: WEARABLE DEVICE

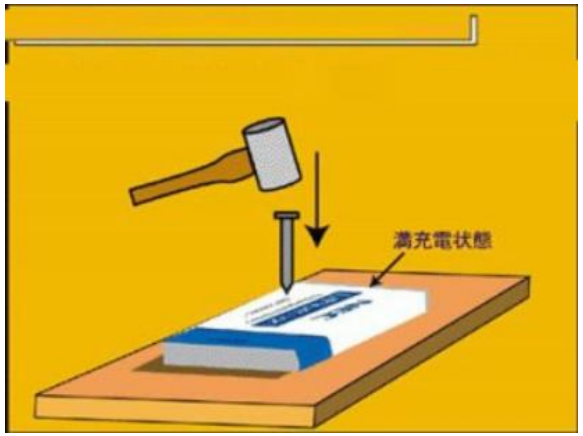
- Performed design review
  - Focus on connections, battery pack, mechanical construction

- Key findings
  - Recommended battery-to-electronics system be modified to a combined tombstone/leaf spring solution to reduce number of connections from three (3) to one (1)
  - Modified existing plating architecture (Au/Pd/Au) to USB specifications (30uin Au/50uin Ni)
  - Replaced Be-Cu with lower cost phosphor bronze



DESIGN FOR RELIABILITY FOR BATTERIES?

- With explosion of IoT, companies whose core competency is not batteries are using lithium ion batteries to build products
- Up until 2010 – mostly brand name batteries
  - Big device manufacturers with significant investments in battery quality
  - Now many smaller players – customized pouch cells with exotic form factors to provide form factor flexibility
- Does design play a role in the reliability and safety of Wearable/IoT batteries?



Battery Management System

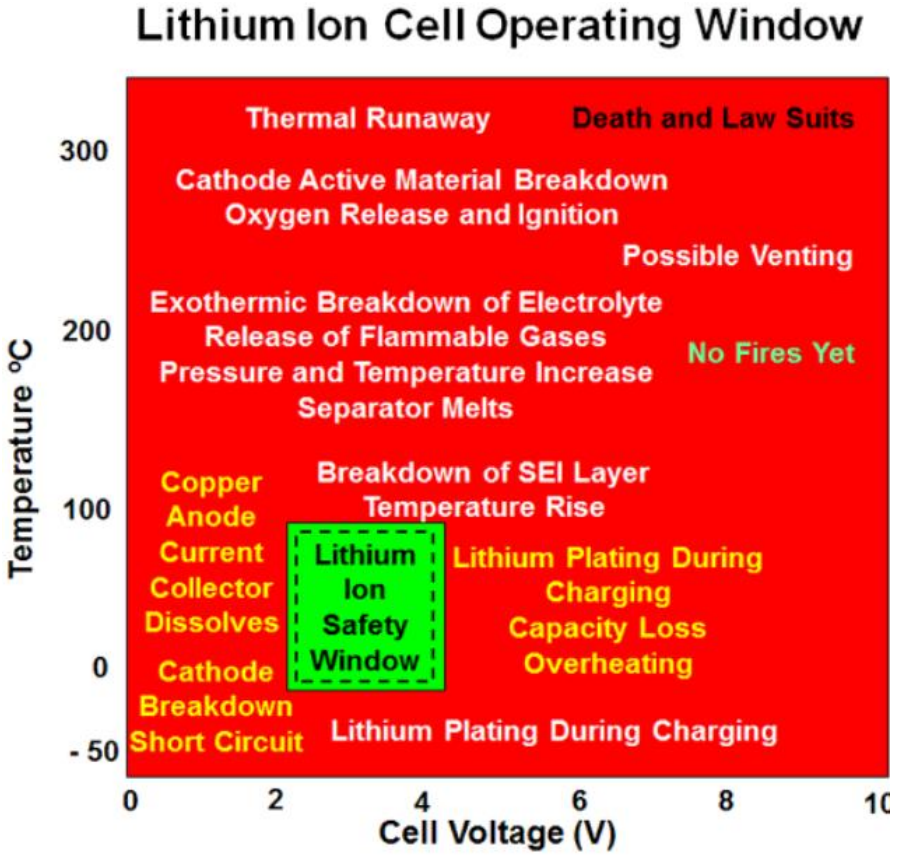
BATTERY REAL LIFE FIELD FAILURES

- Occur at ppm levels
- Are related to internal shorts
- Internal shorts are not mitigated by battery safety systems
- Mostly due to manufacturing defects; some are design related

DESIGN FOR RELIABILITY: LITHIUM ION BATTERY

- Narrow operating window must be respected through-out battery life cycle
  - Manufacturing, application design, battery storage, warehousing, transportation and use

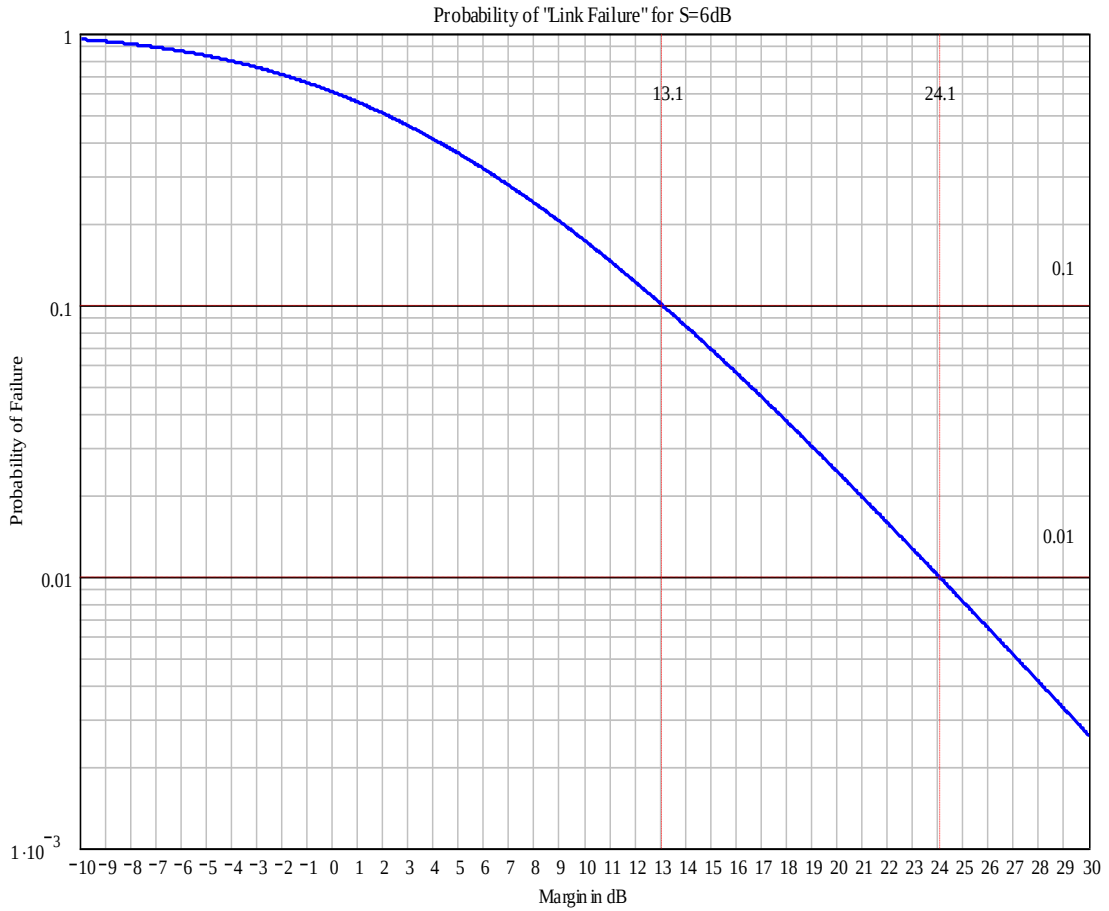
- Lack of battery quality control, application integration issues, and proper storage procedures will push batteries outside the operating window



DESIGN FOR RELIABILITY: LITHIUM ION BATTERY (cont.)

- Pouch cells are sensitive to mechanical stress
  - Due to surrounding electronics/insufficient clearance/device assembly processes.
  - Need at least 10% margin for battery expansion at end of life
  - Latent mechanical damage is created and this is exacerbated by charge-discharge cycles, increasing risk of thermal events

- How have we traditionally met reliability goals in wireless?
  - Margin, Margin, Margin
  - Testing, Testing, Testing



RELIABILITY = MARGIN = POWER

- Relationship between transmitted and received power
  - $P_r = P_t \times G_t \times G_r \times \left(\frac{1}{4\pi \times f}\right)^2 \times \left(\frac{1}{d}\right)^n$
    - G is gain, f is frequency, d is distance, and n is the path loss exponent (location dependent)

- Need greater reliability?
  - Higher power, Better antenna, Higher antenna
    - This is key for wearables! Google Glass (head) has better transmission than Nike (foot)

Location	n	σn
Retail Store	2.2	8.7
Home	3	7
Office	2.6	14.1
Factory	3.3	6.8
What About Wearables?		

http://www.digikey.com/en/articles/techzone/2011/aug/comparing-low-power-wireless-technologies

The Path to Margin is Paved With Problems…

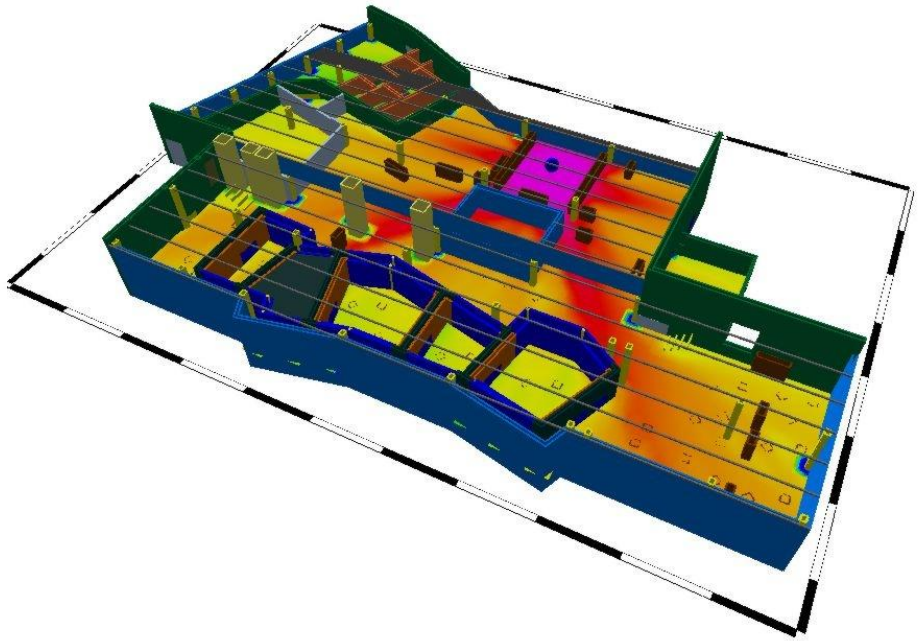
…Lower Battery Life, Higher Cost, Larger Design,
FCC Violations, Slower Data Rates, etc.

WIRELESS – IT IS NOT ALL ABOUT THE TEST

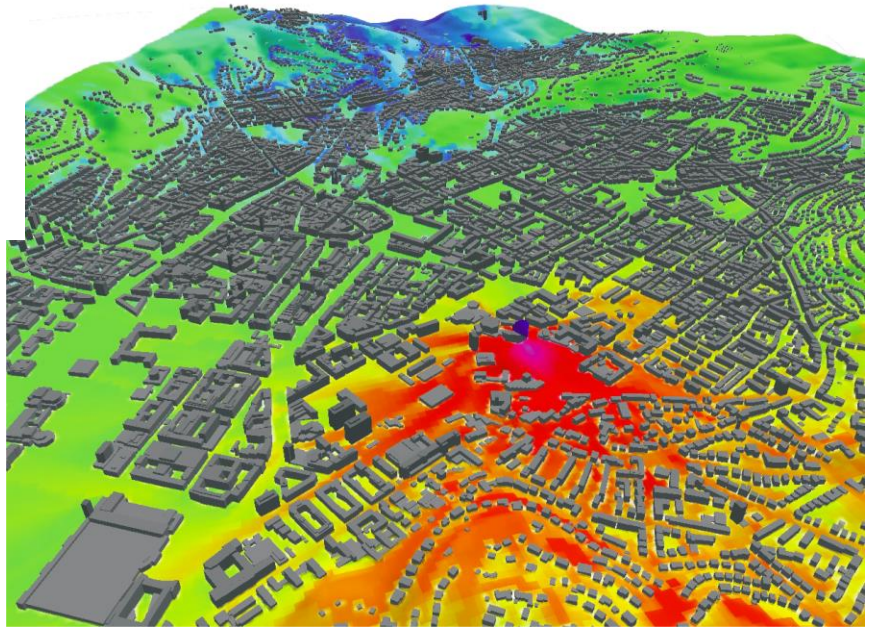
- Higher Reliability Applications (Military/Industrial) Rely on Lots and Lots and Lots of Field Testing
  - Is this Practical for Wearables?

- Everyone Else Relies on Standards (Compliance). But…
  - Compliance Is NOT Reliability
  - Wearables need to be more reliable than traditional Bluetooth/ Wi-Fi/RFID (always available)
  - Cell Phones Buy Spectrum (no interference)

SIMULATE, SIMULATE, SIMULATE



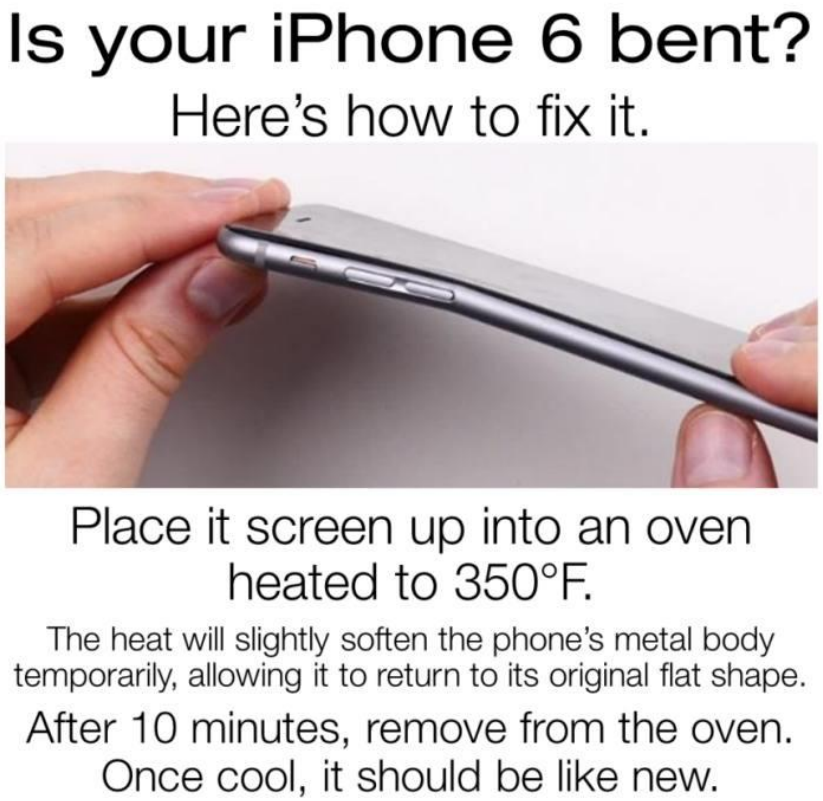
- Sophisticated tools (site-specific) are now available to perform Wireless Reliability predictions



OTHER CHALLENGING ENVIRONMENTS FOR WEARABLES

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

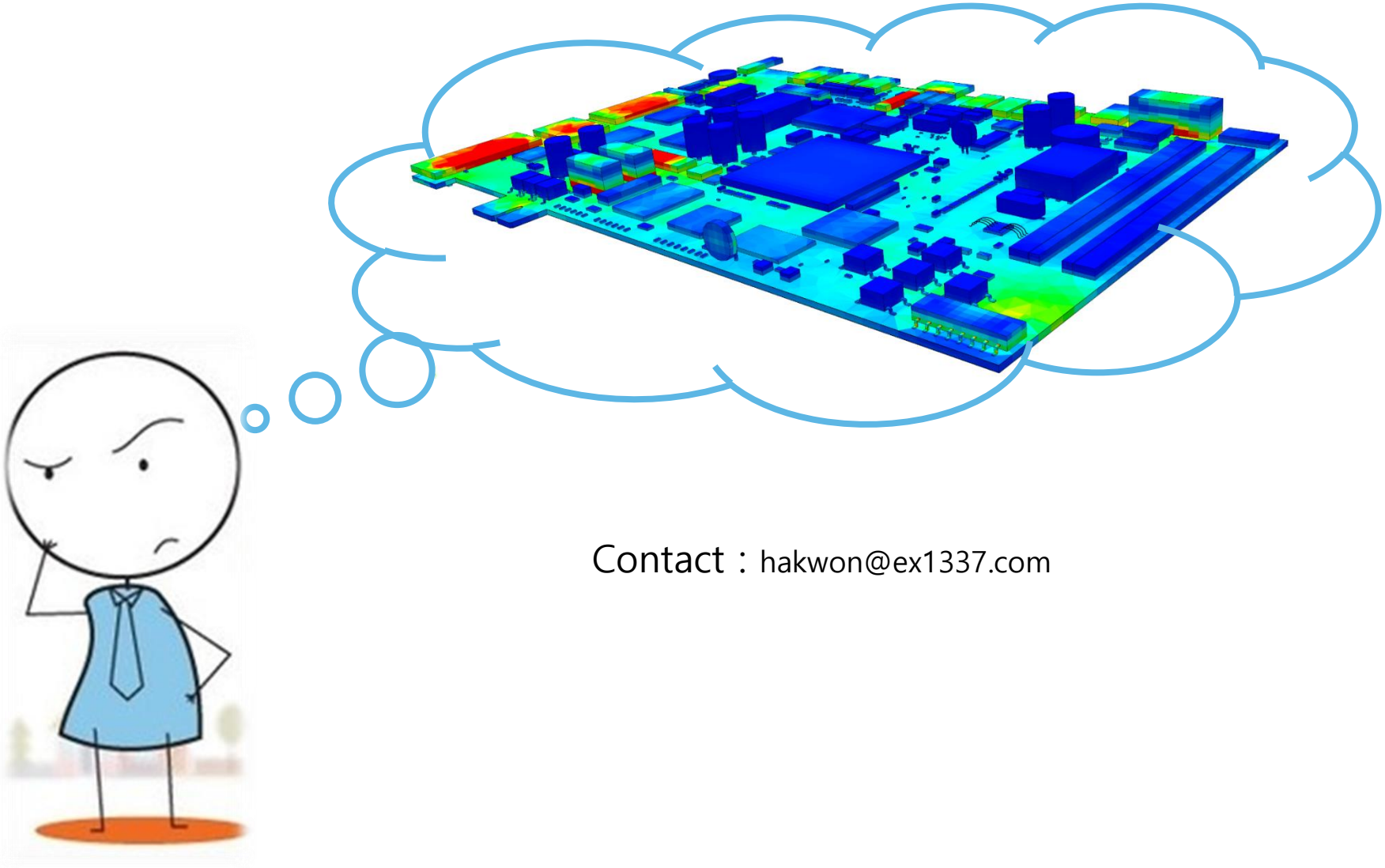
IF YOU DON'T UNDERSTAND THE USE ENVIRONMENT…



CONCLUSIONS

- Wearables and IoT are an Exciting Revolution!
- There are Clear Risks
  - Wearables use new technology that hasn't been fully characterized
  - They'll be placed in environments not fully defined
- Do Not Rely on 'What Has Everyone Else Done' or 'Agile Development' (Code Name: Customers as Guinea Pigs)
  - Bring Knowledge and Simulation into the Design Process

Questions?



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