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reliability designed, reliability delivered

The Reliability of Wearable Electronics

Greg Caswell
Senior Member of the Technical Staff
gcaswell@dfrsolutions.com

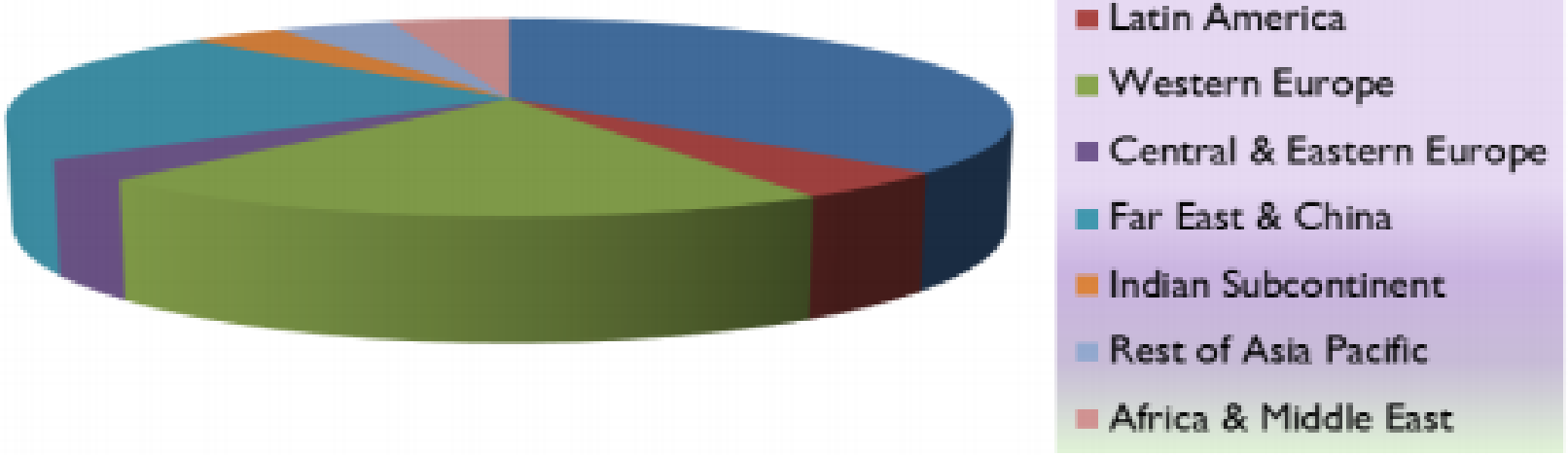
March 16, 2015 DfR Solutions Open House

Sound Familiar?

www.zitscomics.com

Wearable Electronics are hot, hot, hot!

Figure: Global Smart Wearables Hardware Revenue ($m)
Split by 8 Key Regions 2018: $19 Billion



Source: Juniper Research

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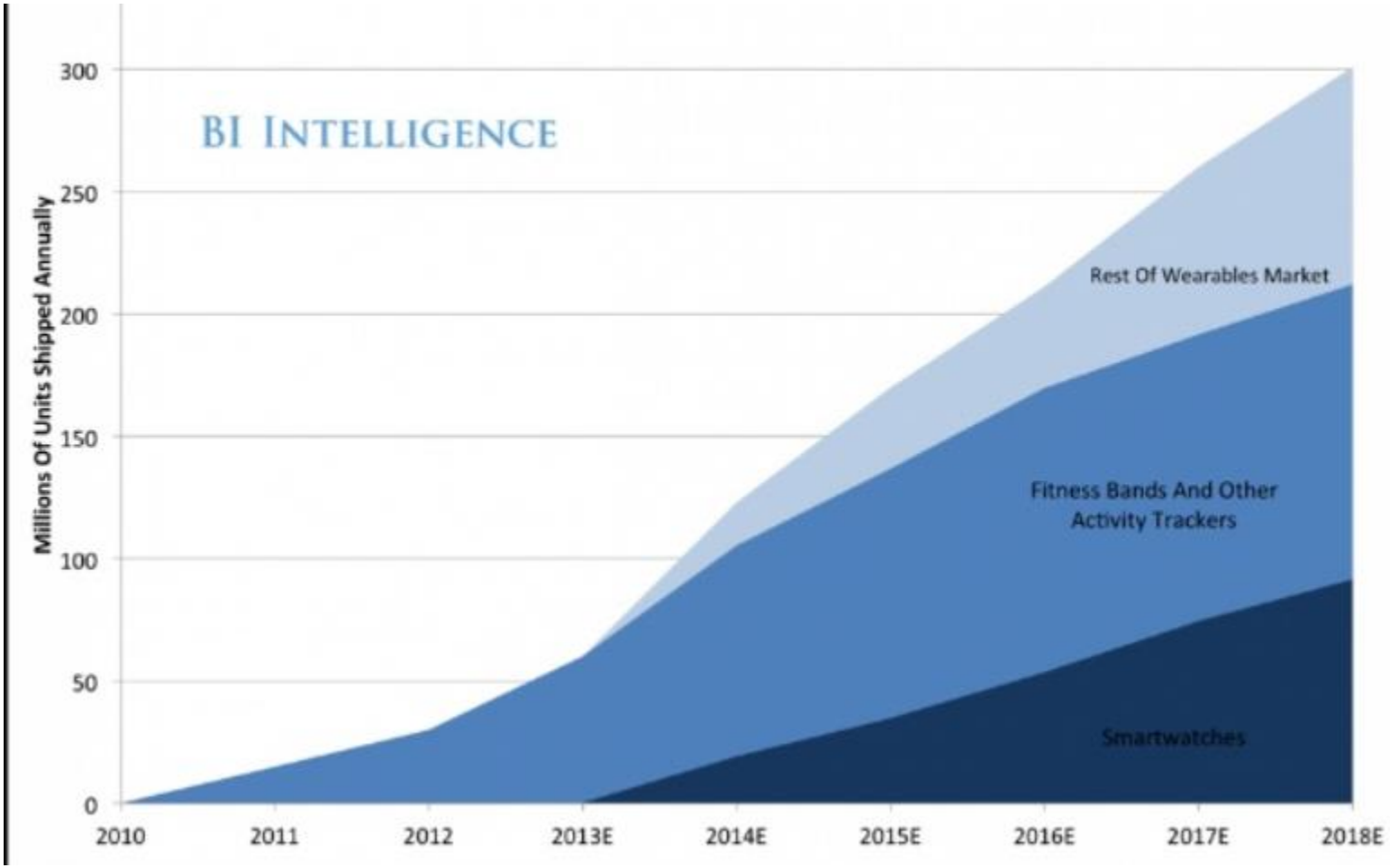
Wearables Market



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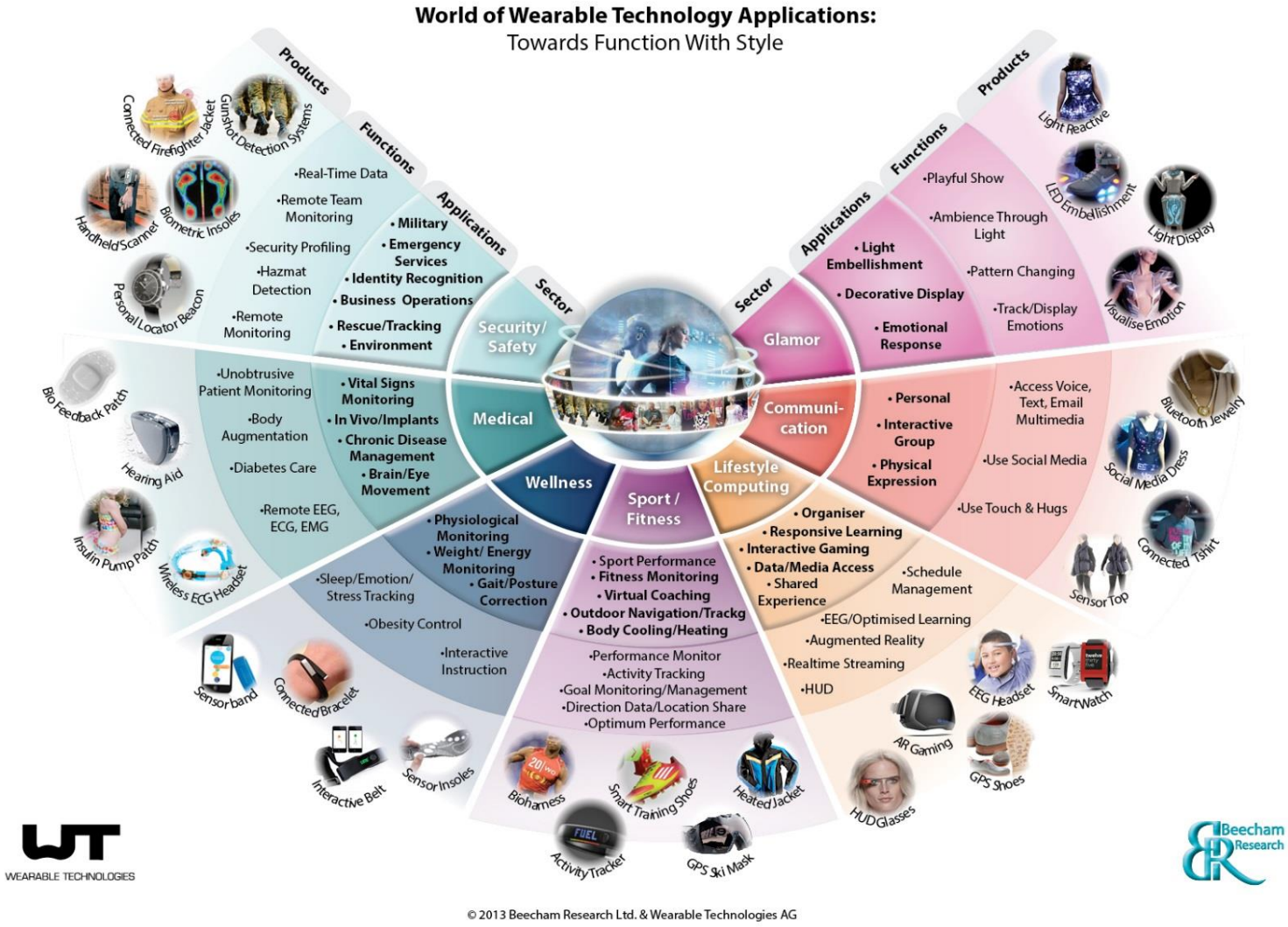
Wearable Electronics Applications



Apple Watch

Expect 40-42 million units to be sold in 2015

Why????

The typical iPhone user looks at his phone 110 times a day.

“Behavioral Shift”

100 apps at a cost of $350

Other apps: Pinterest, city mapper, BMW, Honeywell (house temp), Lutron (home management), Nike, American Airlines, Starwood Hotels

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Apple's Not Alone

ConnecteDevice Cookoo

I'm Watch

Meta SmartWatch

Qualcomm Toq

Magellan Echo

Sony LiveView

Omate TrueSmart

Neptune Pine

Martian SmartWatch

Samsung Galaxy Gear Watch

Pebble Steel

"Even though wearables are relatively new in terms of market maturity, it is clear that the market, for example the smart watch in particular, will be – as per smartphones – a somewhat crowded affair." – **Nitin Bhas, Juniper Research** (link)

FiLIP SmartWatch

Casio G-Shock

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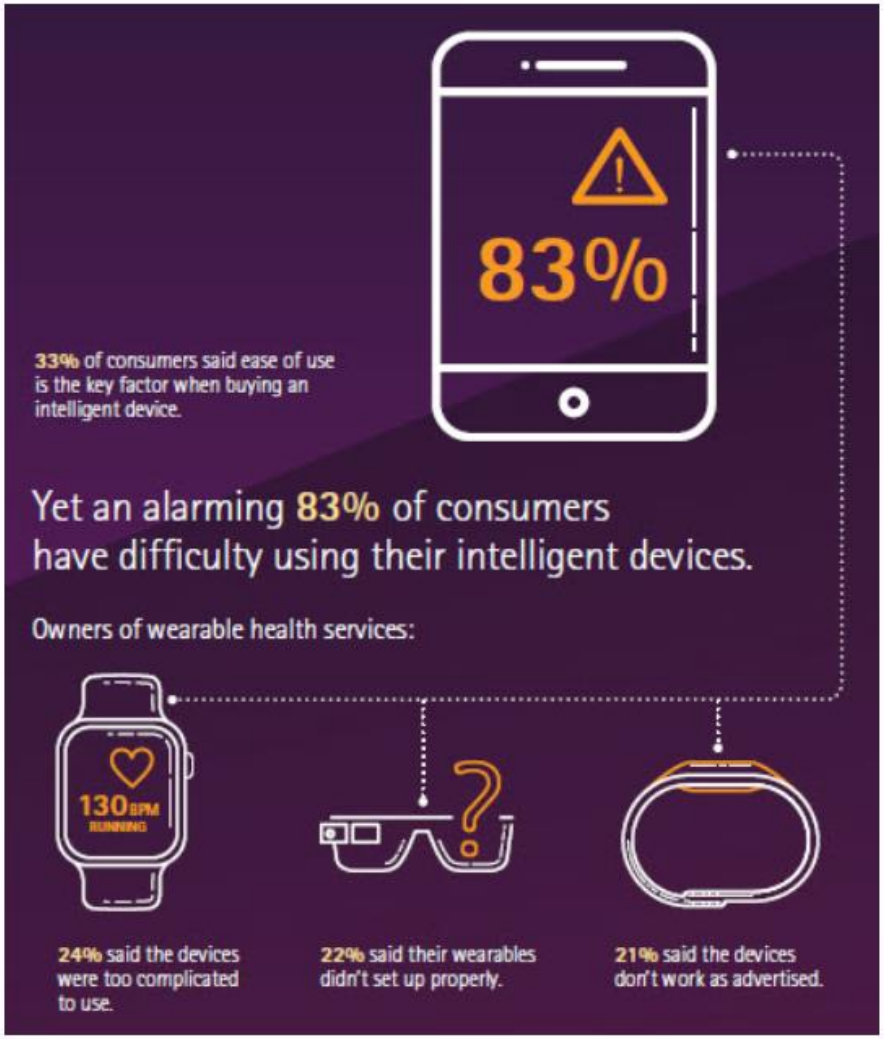
Hmmmm!!!



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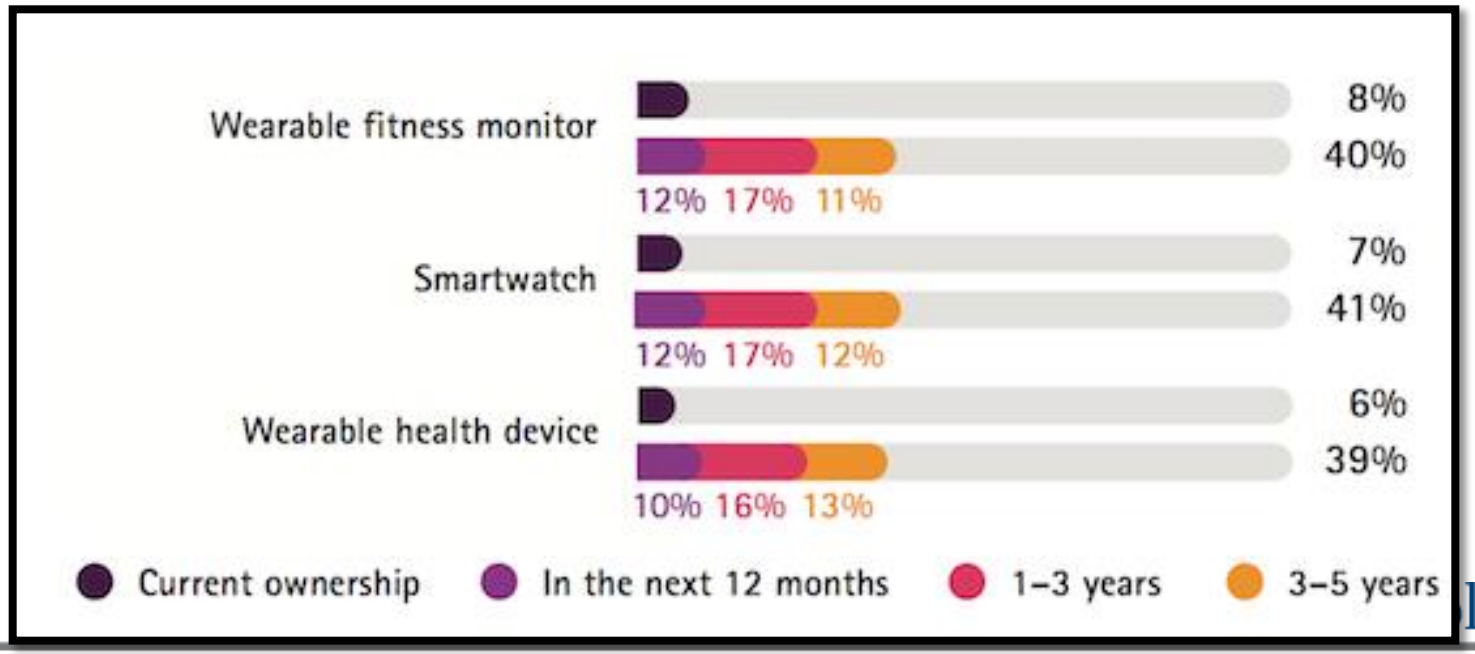
Wearable Users

- Survey finds that an especially high % of consumers have challenges using wearable health devices
  - 24% said the products are too complicated to use
  - 22% said they did not set up properly
  - 21% said they don't work as advertised



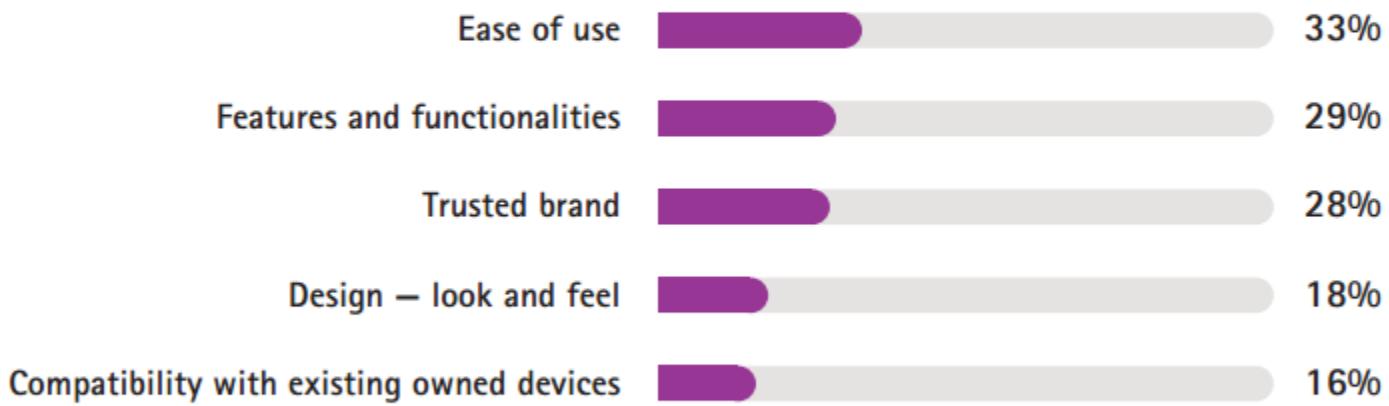
Sourced: http://www.accenture.com/SiteCollectionDocuments/pdf/accenture-digital-consumer-new-connected-world.pdf

How do they select?

- Reliability is not on the list
  - "Trusted brand" is as close as it gets to quality or reliability

FIGURE 4 | FACTORS IN PURCHASE DECISION FOR INTELLIGENT DEVICES

Which of the following factors have been or would be the most important when making your decision to purchase an intelligent device?



BASE DEFINITION: All respondents owning or planning to buy an in-vehicle entertainment system, a wearable health device, a wearable fitness monitor, a home surveillance system, a smart thermostat or a smartwatch in the next 12 months (n=9110)

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

Samsung

- Issues with GearFit
- Not compatible with many cell phones
- Failure to connect
- Poor apps
- Finding new apps very difficult

- Launched prematurely

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Players

Source: IMS Research, World Market for Wearable Technology - 2012

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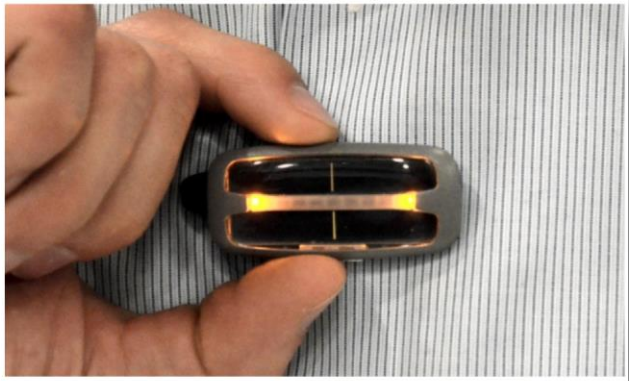
Wearable Tech is Everywhere…..

SunFriend

AiQ smart clothing


SunSprite

Wrist Wallets

- The wallet is migrating to the phone
- Apple is leading this technology
- Security issues still abound
- Lots of new companies jumping in in 2015
- Batteries in belts and wristbands, sensors in shoes

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New Applications

NeuroOn: World's First Sleep Mask for Polyphasic Sleep

FreeWavz: Smart Earphones With Built-In Fitness Monitoring

runScribe: Wearable for the Data-Driven Athlete

Carry Less, Adventure More: Survival Belt

New Applications

Beddit Sleep Monitor

Smart Sunglasses

January 5, 2015

Montblanc TimeWalker Urban Speed e-Strap add-on to your current watch

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Family Oriented

Disney's MagicBand is a battery assisted **RFID** tag allows you to:

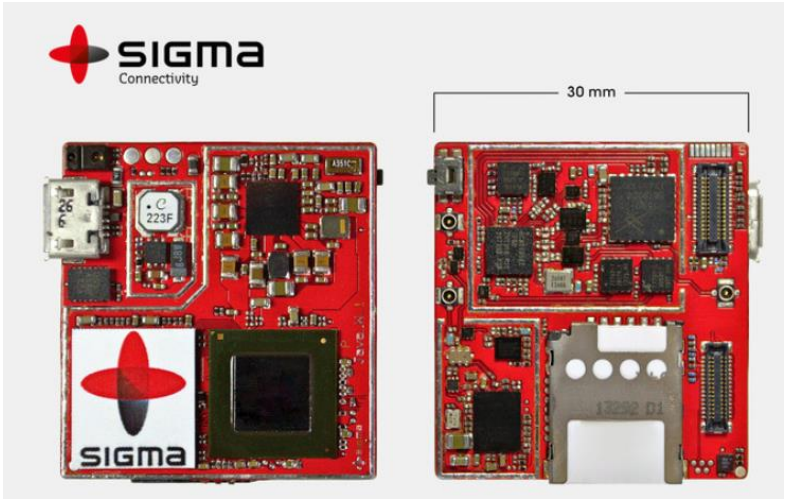
- Unlock the door of your Disney Resort Hotel room
- Enter theme and water parks (with valid admission).
- Check in at FastPass+ entrances.
- Connect Disney PhotoPass images to your account.
- Charge food and merchandise purchases to your Disney Resort hotel room (only available during your hotel stay).

No reliability data evident

Wearable GPS Tracker for Kids

TINITELL - Wristphone for kids

- 2G GSM SIM card for connectivity, to power the voice calls and GPS tracking
- Battery good for an hour's talk time on a single charge or seven days on standby
- It's also water resistant and sandbox proof, to ensure it's robust enough for outdoor child's play



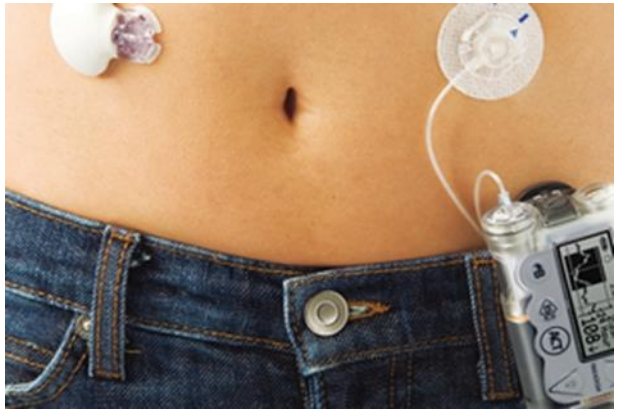
Website states unit is water resistant.
No other reliability information

How Wearables Intersect with the Cloud and the IoT, Joseph Wei, CPMT Wearables Workshop

Wearing the Cure

- 29.1 million people in the US with diabetes
  - 350,000 using wearable insulin pumps
- Lux Research: clinical wearable devices should surpass their consumer counterparts in revenue by 2020

Beauty and Wearable Tech:
Miss Idaho Proudly Displays Her Insulin Pump



Medtronic's MiniMed Paradigm Revel Insulin pump senses blood sugar in real time

Will We Use Health Wearables?

Source: HRI/CIS Wearables consumer survey 2014

- $200 million went to wearable technology from investors for digital health
- 7.6 million devices shipped in just the US – a 200% increase over last year
- Linkage to insurance companies could lower costs but privacy and data protection issues need to be resolved
- However, consumers want low cost and many want their employer to cover the cost

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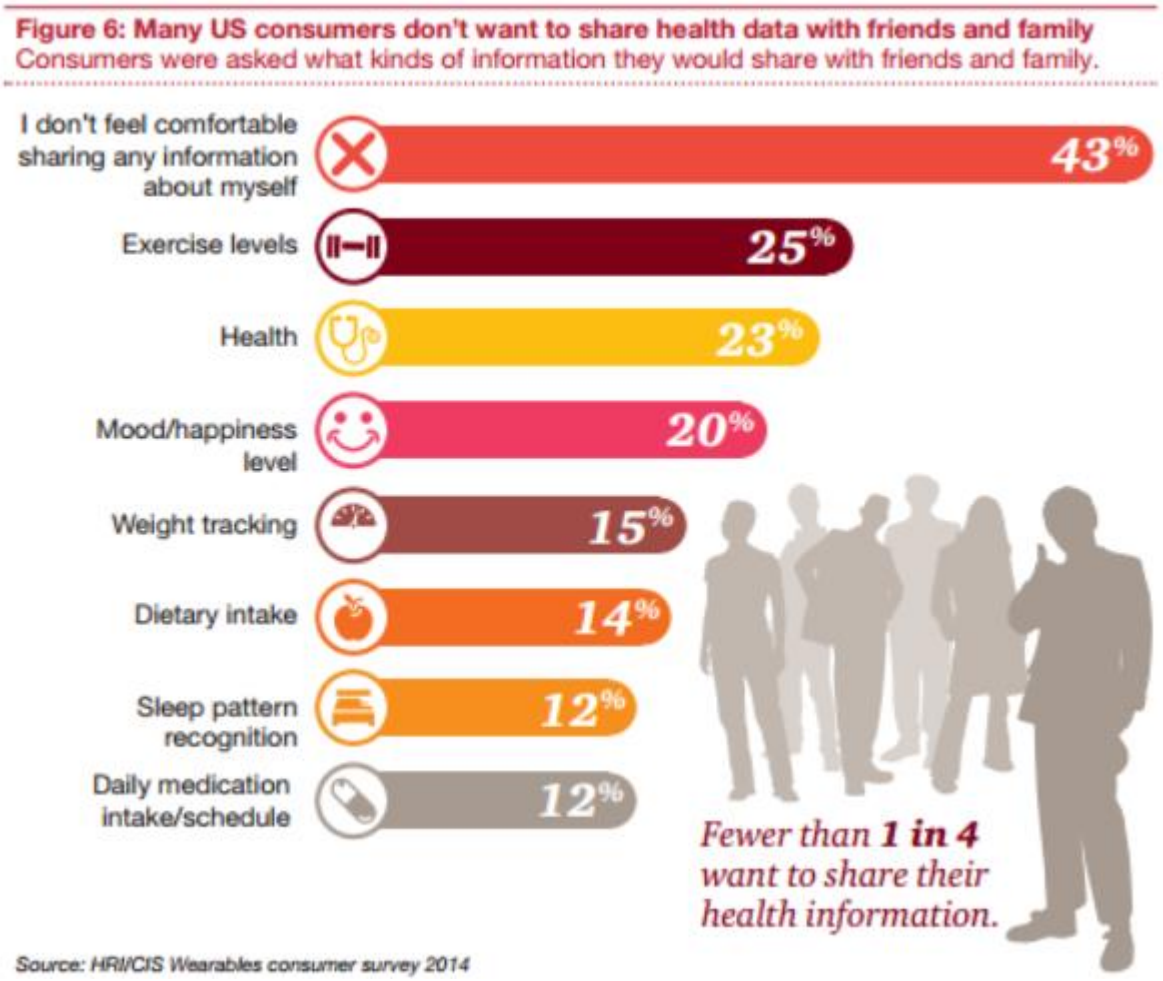
Want to Share Your Health Data?



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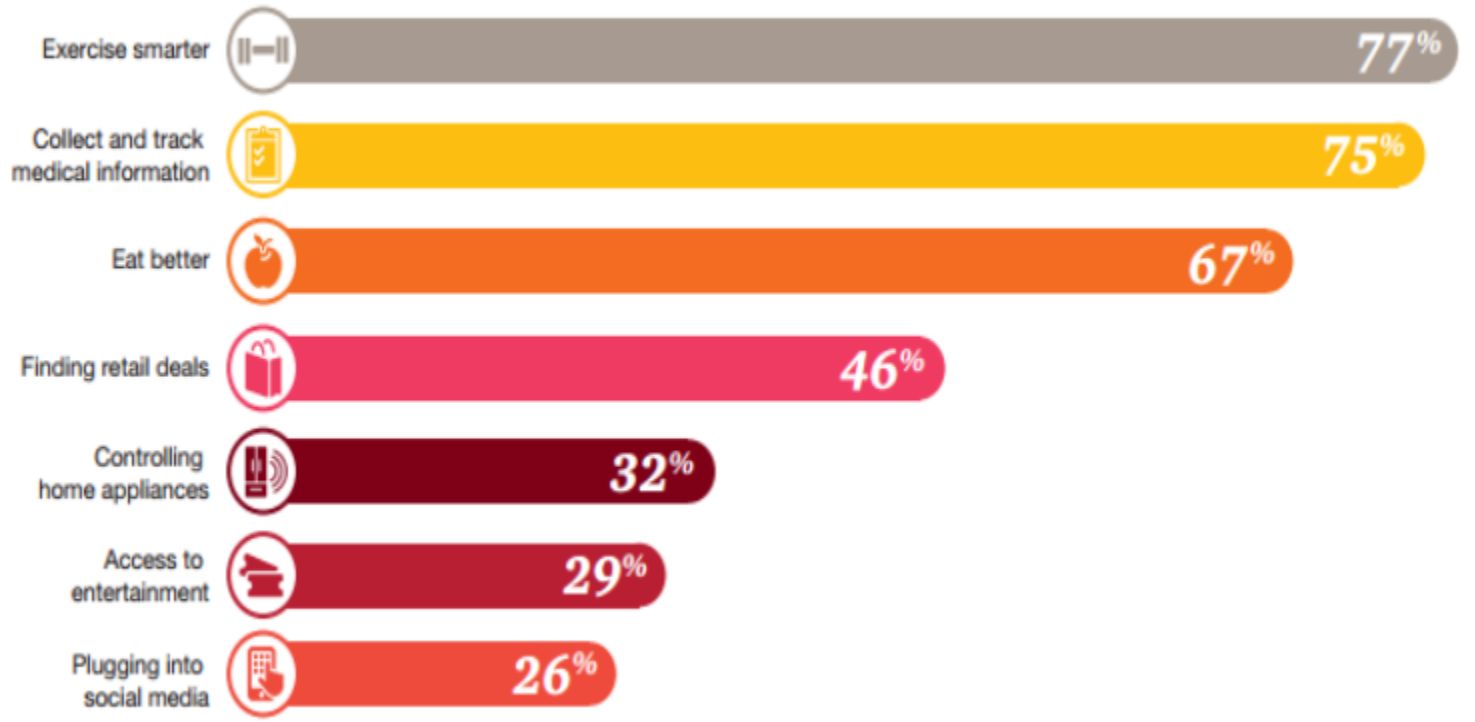
What Do Consumers Want from Health Wearables

Figure 3: Health tops list of information US consumers want from wearables
Consumers were asked what information they want to receive from wearable technology.



Source: HRI/CIS Wearables consumer survey 2014

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Why is Reliability a Challenge?

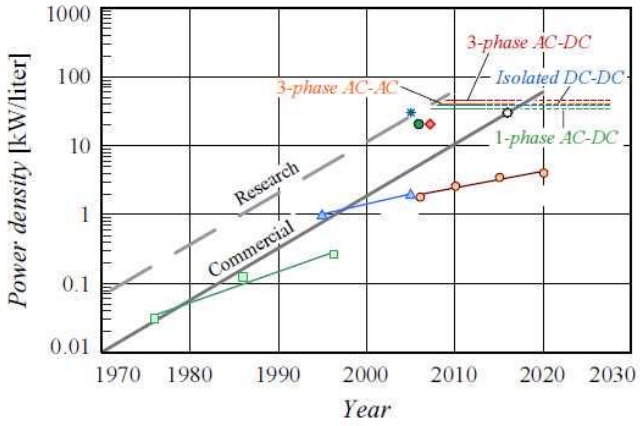
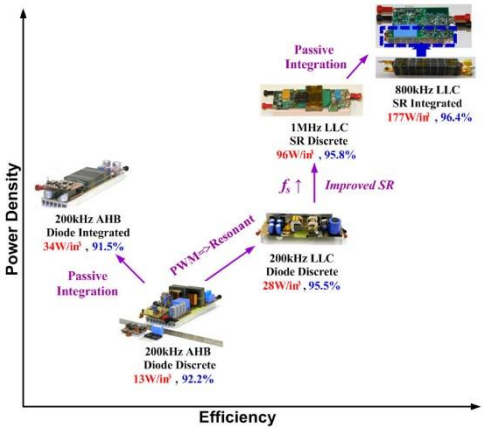


Figure 2. Power density trends of commercial and research systems and the Power Density Barriers.

Everything is Hot



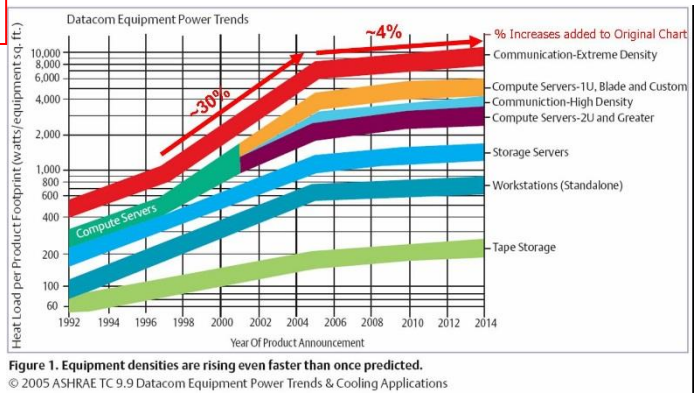


Figure 1. Equipment densities are rising even faster than once predicted.
© 2005 ASHRAE TC 9.9 Datacom Equipment Power Trends & Cooling Applications

Everything is Mobile

Everything is Everywhere

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But "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 silicon 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

How Have Wearable Consumer Electronics Failed?

- Sweat
  - 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

Terrible Wearables: Hall of Shame

- "In taking blood pressure readings, the Withings blood pressure monitor failed every time (but one), all at the same point"

http://wearabletechwatch.net

- Contacts rubbing skin raw
  - Heat & sweat
    - http://www.n3rdabl3.co.uk/2014/07/lg-g-watch-charging-points-cause-injury-users/

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Terrible Wearables: Hall of Shame

- Fitbit Recalls Force Activity-Tracking Wristband Due to Risk of Skin Irritation
  - Complaints of itchy, irritated wrists
  - Allergic contact dermatitis
    - Either the nickel that's in the stainless steel part of the device
    - Or adhesives or other materials used in the strap

Terrible Wearables: Hall of Shame

- "Sunscreen melted my Nook"
  - A tiny warning on the can reads it can damage some fabrics materials or surfaces.
  - http://bcove.me/hh5yfn26

Pavlok: Is This a Wearable Device for You?

- Habit-forming wearable that will shock you! Literally…..
- Designed to shock the user when they do a pre-programmed bad habit
  - Wasting time online
  - Going to fast food restaurants?
  - Hitting snooze button on alarm clock
- Failure waiting to happen???

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Uh Oh!!!!

- Pretty detailed approach to making your own wearable product.
  - Circuits
  - Components
    - Microcontrollers
    - Sensors
    - Actuators
    - Wireless
  - Conductive Materials
  - E-Textile Toolkits

- **However, reliability is not addressed**

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?

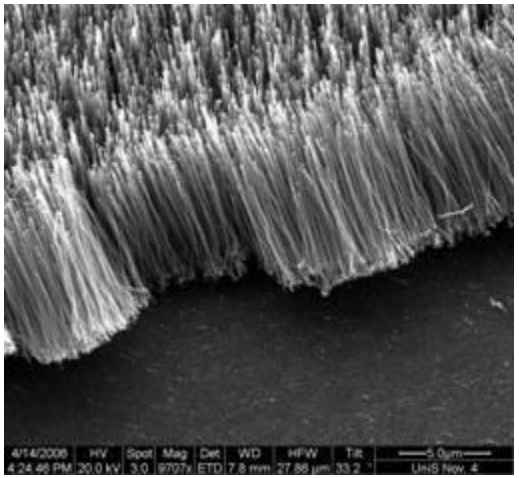
What are Wearable Electronics?

- 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

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



Carbon Nanotube Array for Tissue Regen. & Wound Repair

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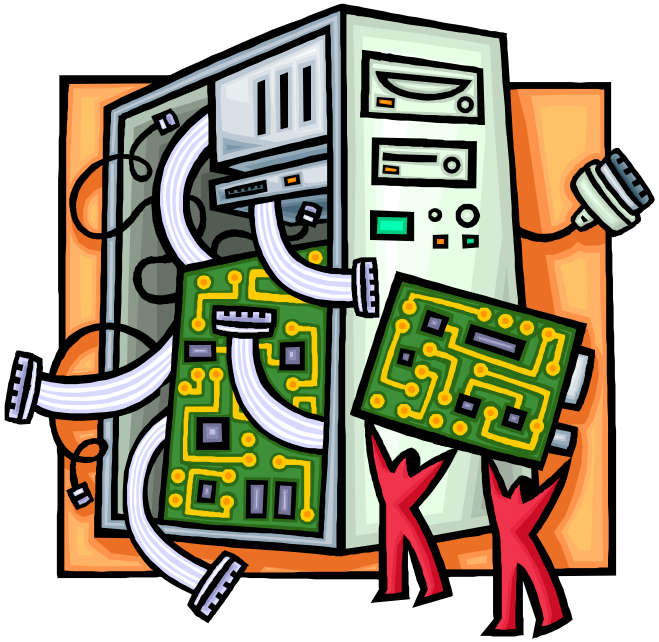
Next Generation Technology (cont.)

- 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…

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 reliability 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?



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Next Gen 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

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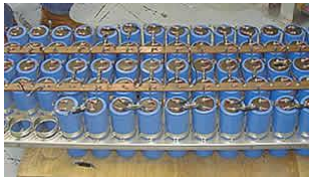
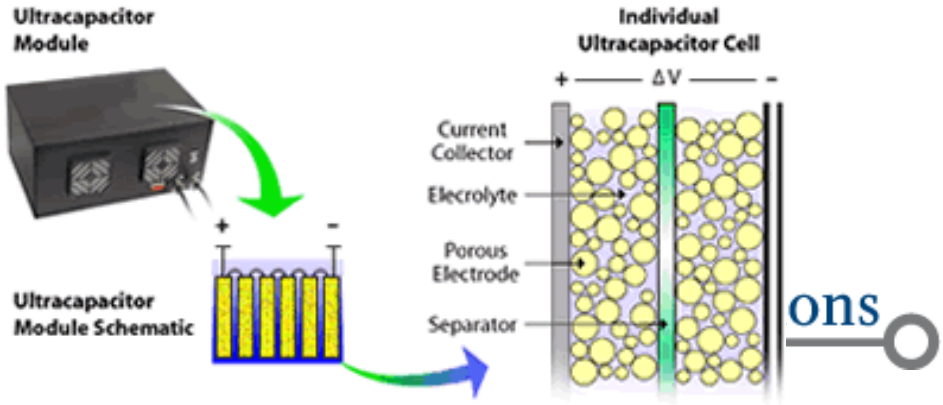
Examples of Next Gen Technologies in Wearables

- Embedded components

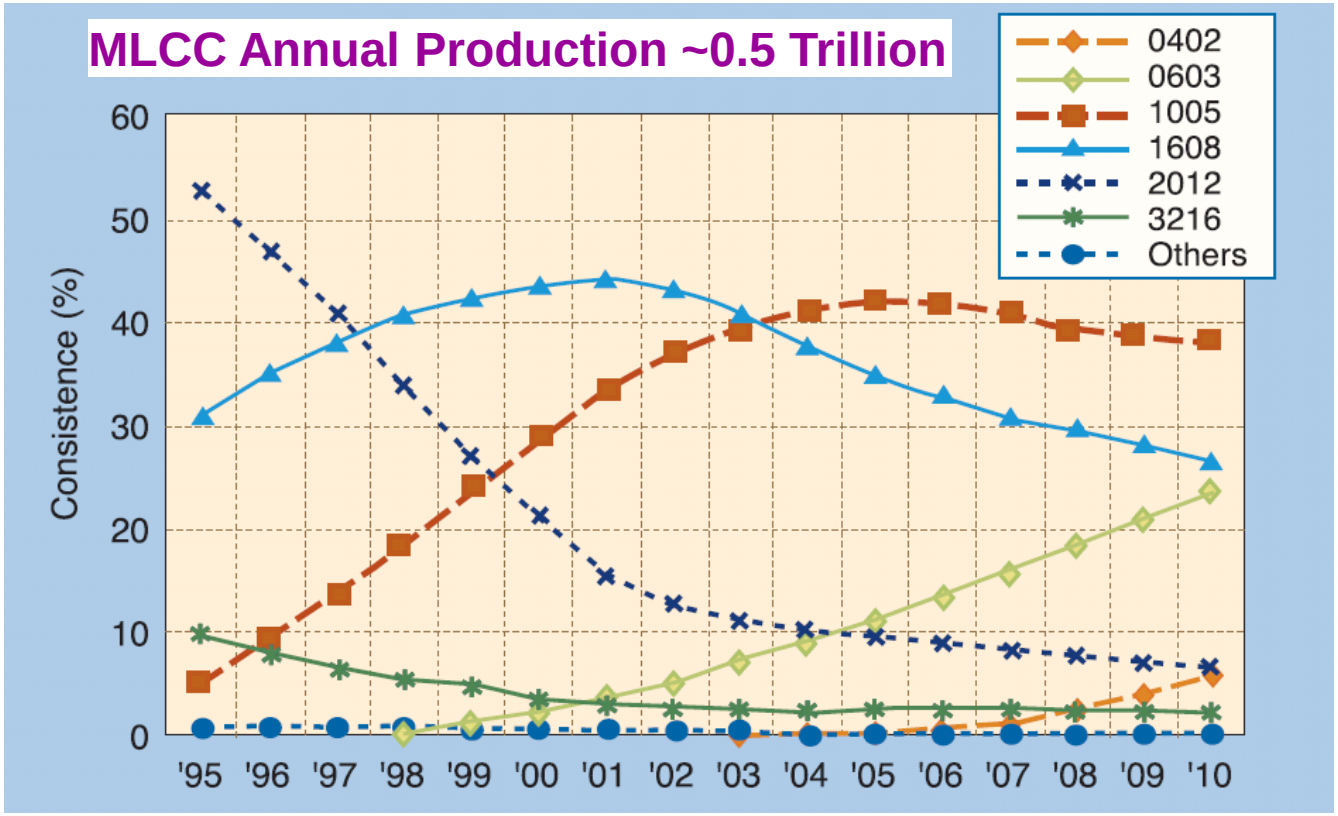


- Ultra-small components (i.e., 01005 capacitors)
- New substrate materials
  - Polyethersulfone, polyethylene terephthalate (PET), polyethylene napthalate (PEN)
  - Polyimide is not a next gen technology
- Printed connections
  - Silver inks, copper inks, nanosolders, conductive polymers
- Organic displays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



“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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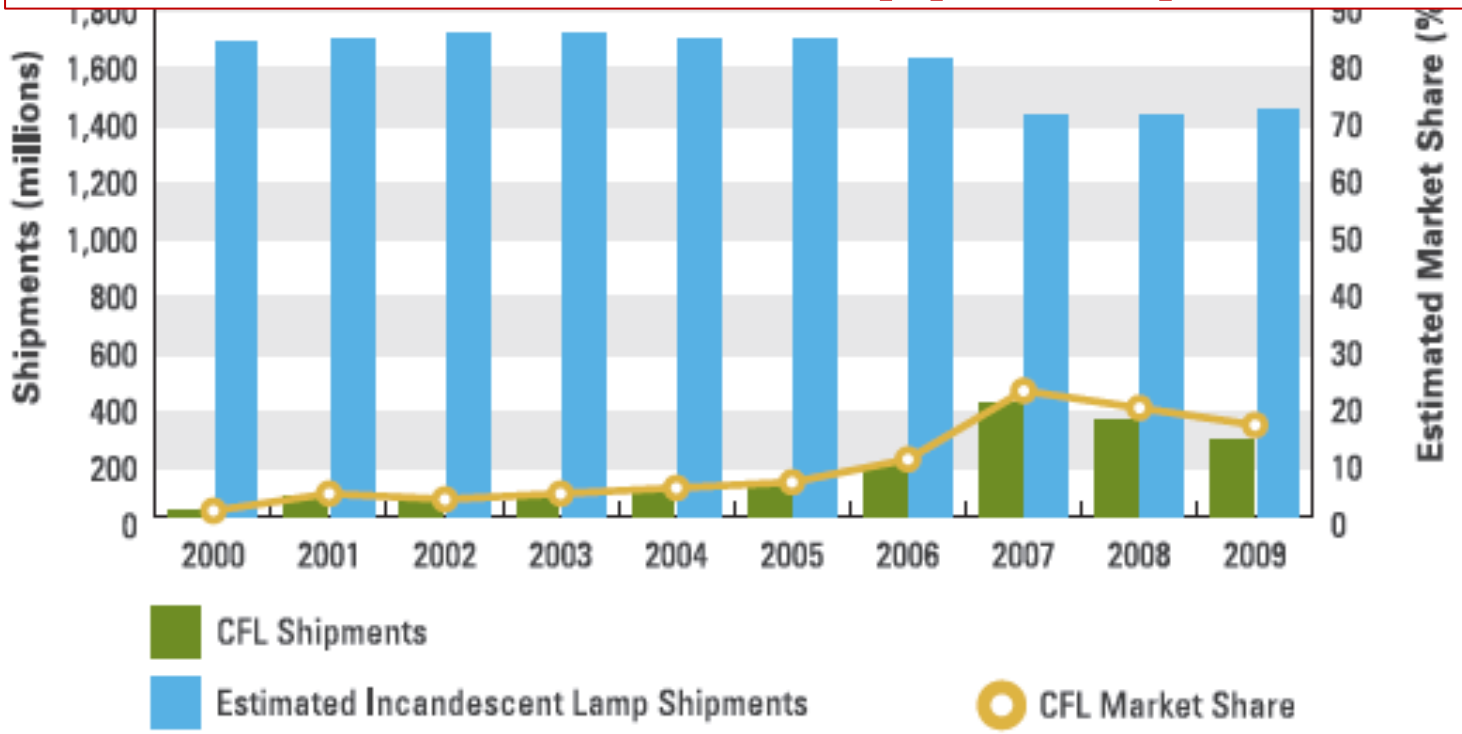
0201 Ceramic Capacitors: The Reality

- 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

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
  - Specification creation
- 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

Bringing it All Together

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

Reliability expectations

Use environment

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)

Desired Lifetime and Wearable Electronics

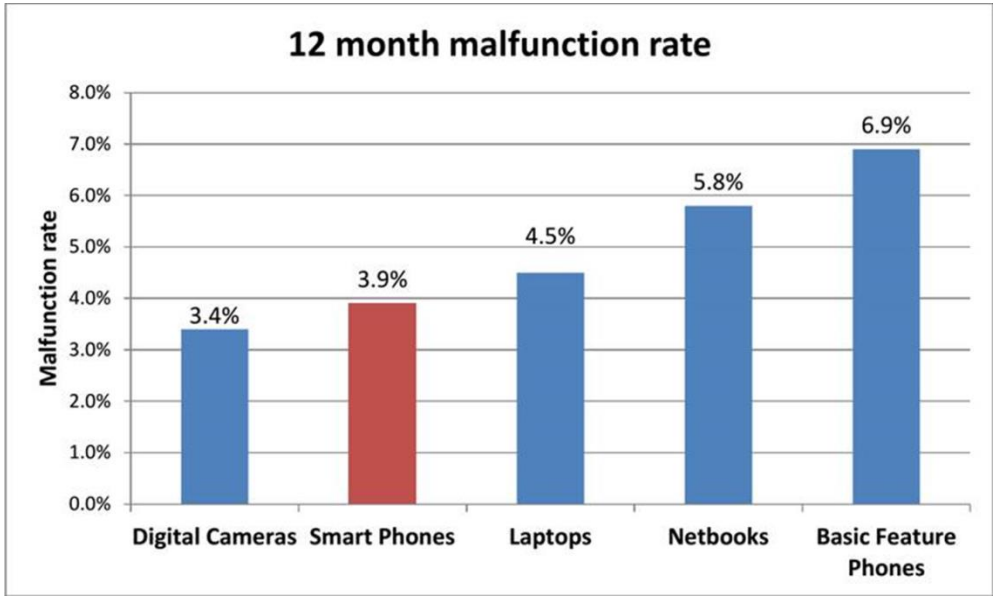
- What is the desired lifetime of wearable electronics?

- 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

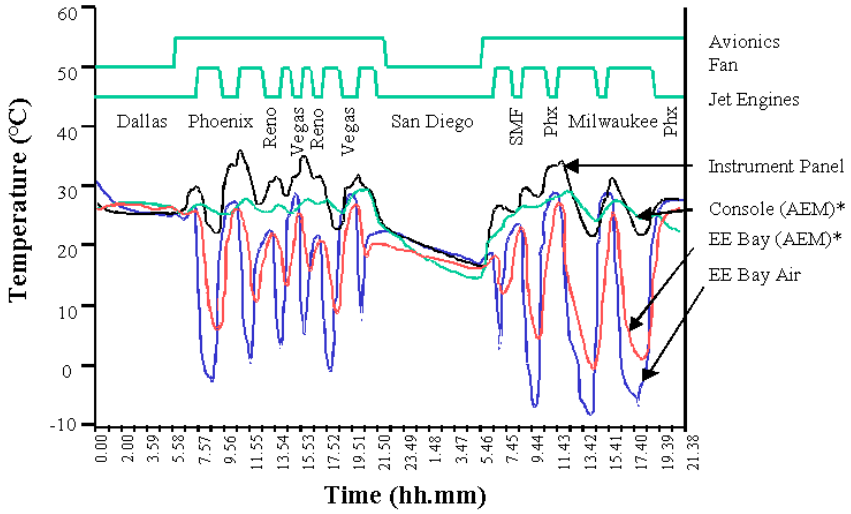
Product Performance: Warranty Returns

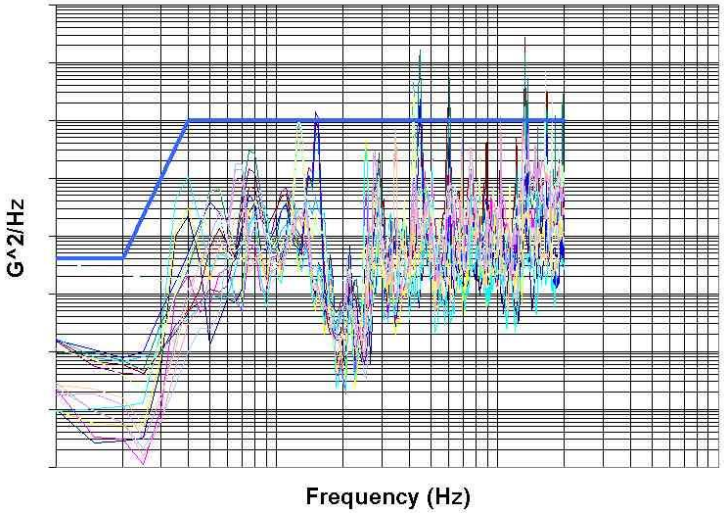
- **Consumer Electronics**
  - 5-25%
- **Low Volume, Non Hi-Reliability**
  - 1 to 2%
- **Industrial Controls**
  - 500 to 2000 ppm (1st Year)
- **Automotive**
  - 1 to 5% (Electrical, 1st Year)
  - Can also be reported as problems per 100 vehicles



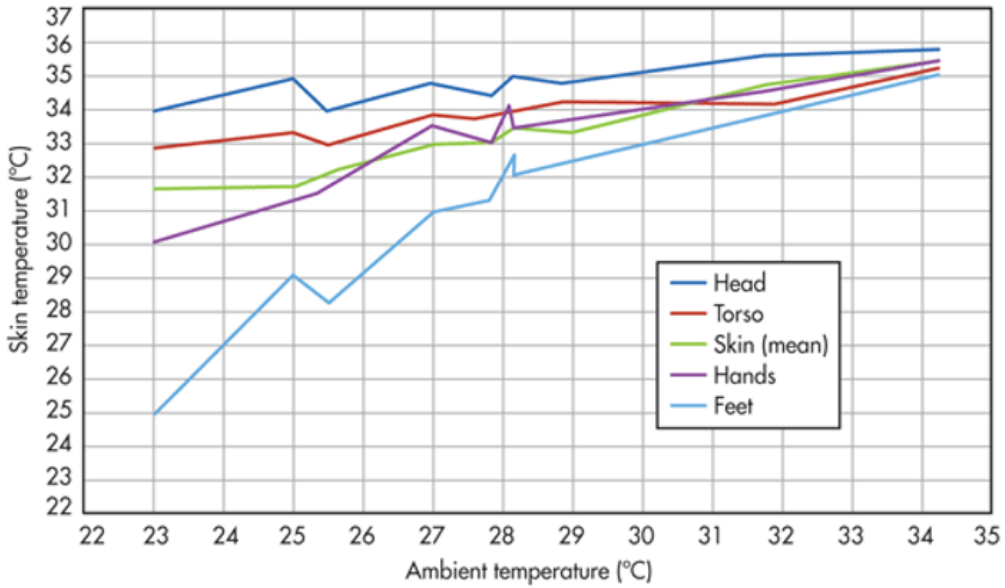
Identify and Quantify Failure Inducing Loads

- 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





Field Environment: Body & Outdoor Temperatures



- 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)

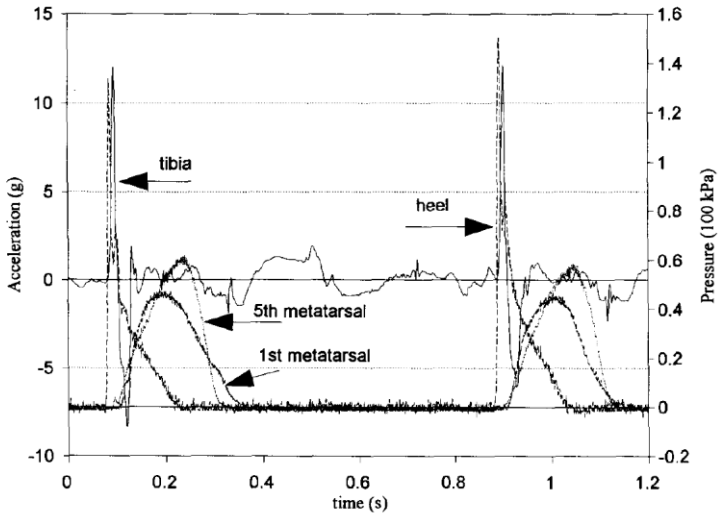


Fig. 7. Typical acceleration and pressure patterns recorded while subject was running.

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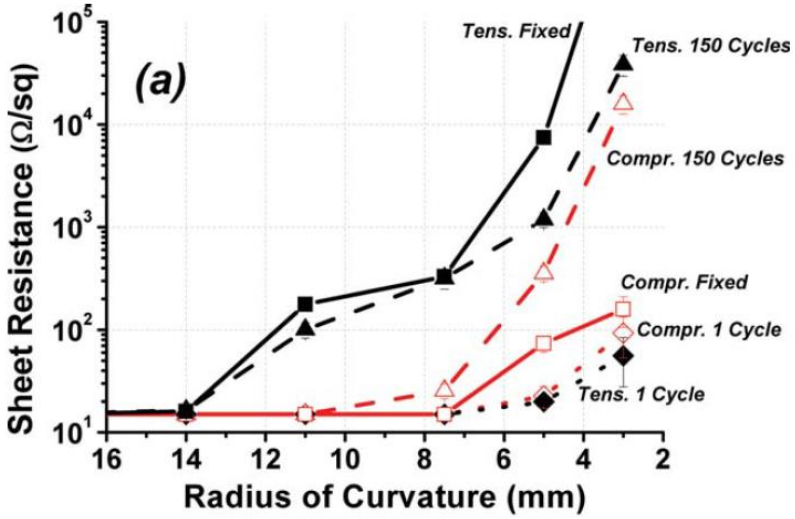
Field Environment: Mechanical (cont.)

- 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
  - Some next-gen substrate materials experience a change in electrical properties after exposure to bending
  - Aggravated by elevated temperature



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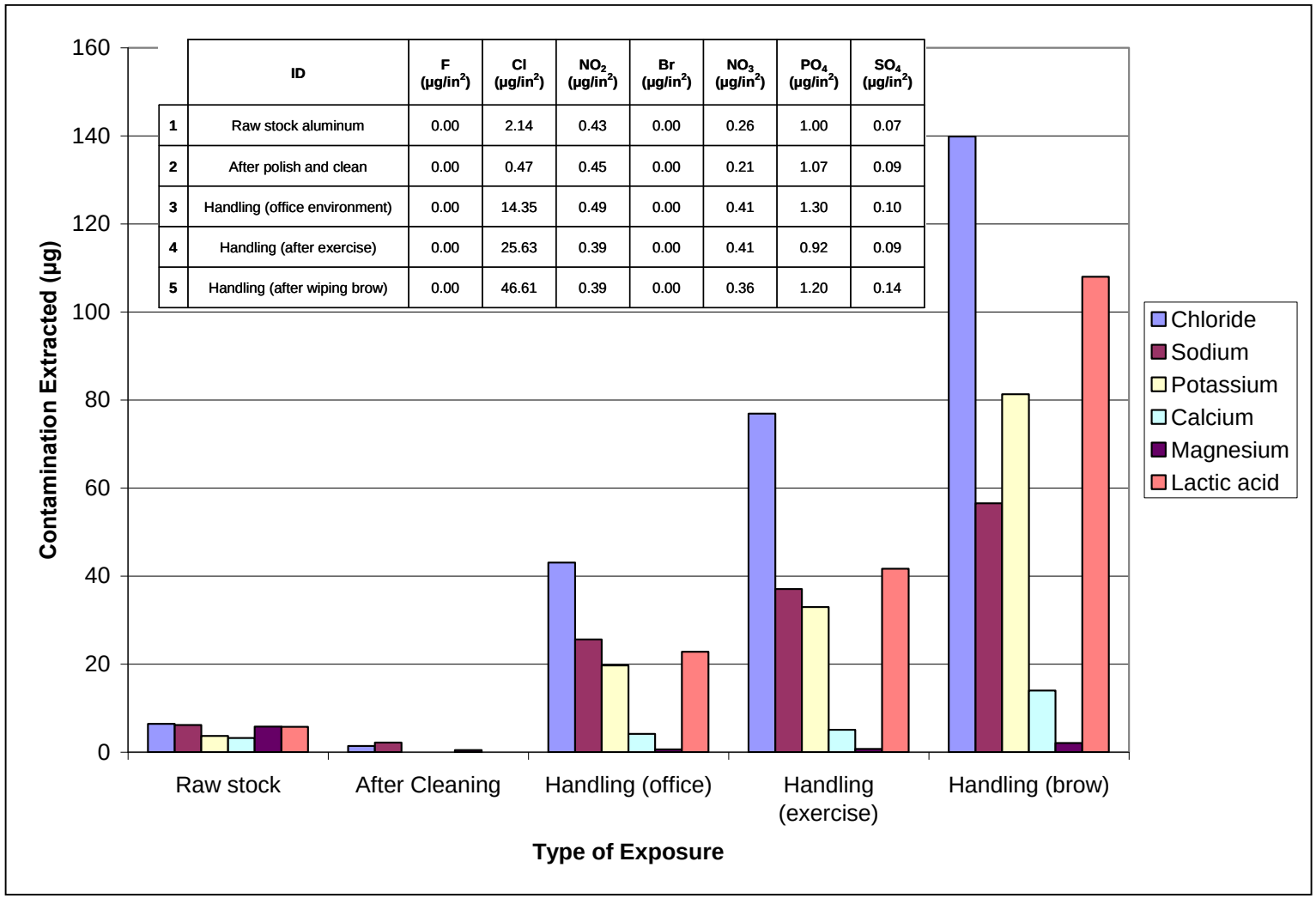
Corrosion: Handling / Sweat

- 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
  - Iron, copper, urocanate, and other metals, proteins, and enzymes are also present
- Main concern regarding sweat is as a source of *chloride*

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



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Rain & Water Immersion Challenges

- 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

Corrosion: UV Exposure

- Ultraviolet (UV) exposure 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
- Stress corrosion cracking has been caused by sunscreens

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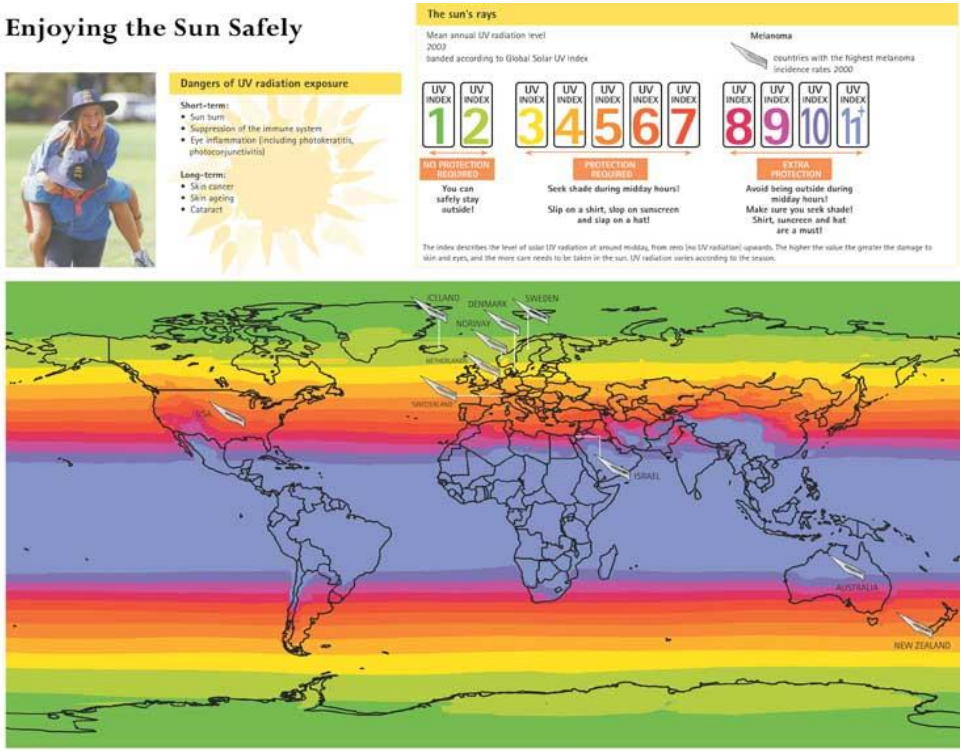
UV Exposure

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.

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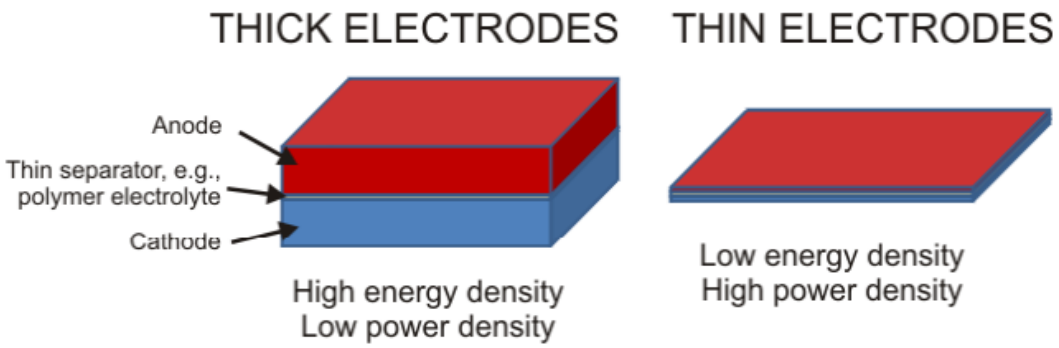
Other Challenging Environments for Wearables

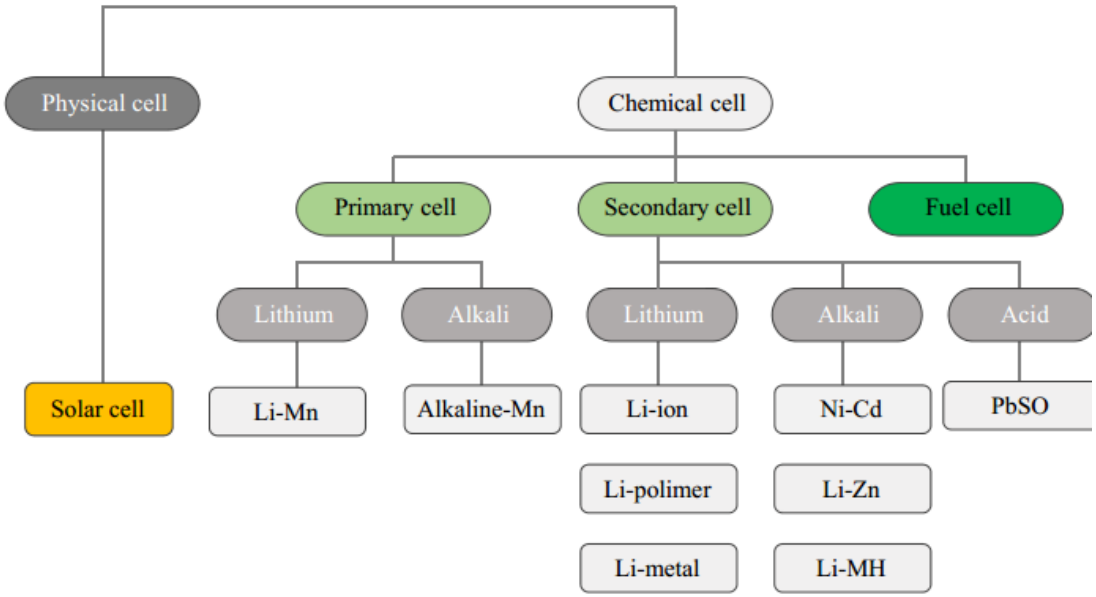
- Washer / Dryer
- Cleaning fluids
- Mud / Dust / Water

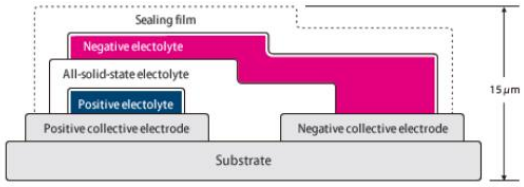
Battery Technology

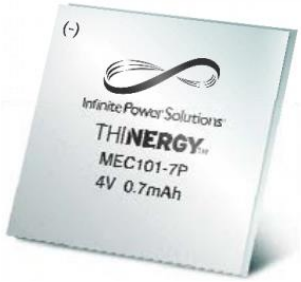


- Batteries for wearables will implement different materials
- Will have either physical cell or chemical cell configurations
- Will take on multiple form factors
  - Cylindrical
  - Pouch
  - Prismatic
  - Thin Film

Battery category types







"Wearable Energy Sources," Materials and System Inc, IEEE Wearable Technology Seminar

DfR Solutions

Flexible Chips

Flexible Chips

FleX™ Properties & Benefits

Flexible thin high performance chips

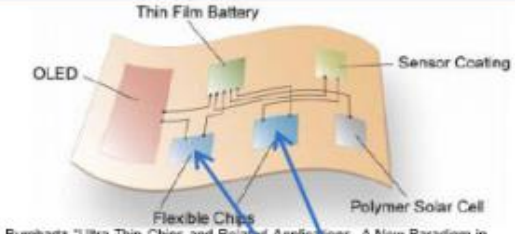
Processors, wireless communication

Flexibility.
For integration into flexible systems or conformal on mounting of non-flat surfaces.

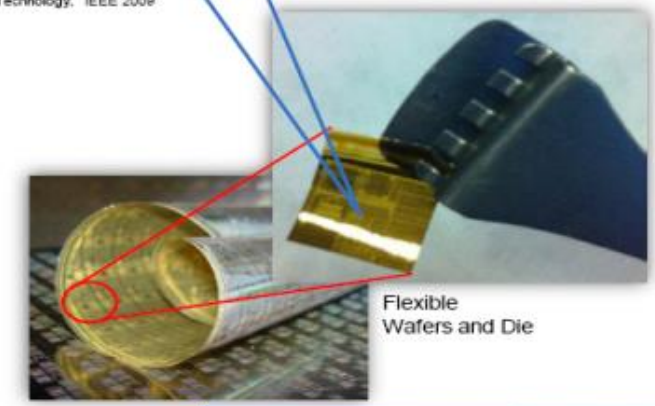
Durability.
No silicon substrate improves tolerance to both mechanical and thermal shock.

Size.
Ultra thin form factor is useful in multi-chip packages and 3DIC.

Performance.
Transistors run 50%-100% faster on FleX wafers than on full thickness wafers.



Burghartz "Ultra-Thin Chips and Related Applications, A New Paradigm in Silicon Technology," IEEE 2009



Flexible Wafers and Die

2012FLEX Feb. 6-9

American Semiconductor Inc.

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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

DfR's Wearables Center of Excellence

- DfR can assist you with the design and development of wearable electronics with:
  - Proper test plan development-selection of appropriate test methods to assess reliability
  - Material selection and compatibility
  - Testing to ascertain reliability
    - Drop Shock
    - Exposure to sweat
    - UV exposure
    - Sherlock ADA assessment
  - Root cause failure analysis to obviate issues

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Conclusions

- Wearable electronics are an exciting revolution in our engagement with ourselves and the world around us
- However, there are clear risks
  - Wearables use new technology that hasn't been fully characterized
  - They'll be placed in environments not fully considered by the designers
- Results if wearable manufacturers don't use industry best practices &physics of failure to qualify their technology:
  - Unexpected failures
  - Delays in product launch
  - Advisory notices (medical tech)

Thanks!!

Greg Caswell

Sr. Member of the Technical Staff

DfR Solutions

301-640-5825 (office)

443-834-9284 (cell)

gcaswell@dfrsolutions.com