# Computing Systems

## Introduction - Technology

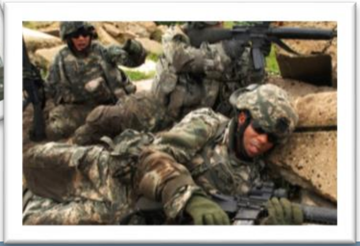
*Ver. 2.1 - 2021*
*Ver. 2.0 - 2020*
*Ver 1.6 - 2017 Aug/Sep*

# Cyber Physical & Phygital Systems

- Cyber Physical System products and byproducts
  - Smart Mobile
    - Smart card, smart mobile
  - Human Computer Interface
  - **Smart Environment**
    - **Annotating the physical world**
    - **Sensors and Sensor Networks**
    - **Micro Actuation and Sensing: MEMS**
    - **Embedded Systems**
  - Context-Aware systems
    - Spatial awareness (e.g. GIS), mobile awareness

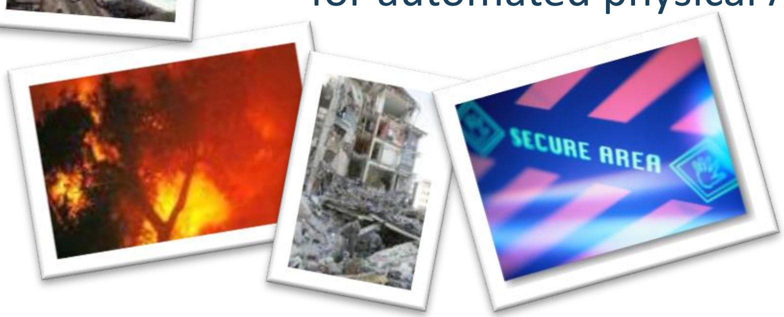
# Smart Environment

- **Smart Environments**
  - Industrial and research topics
    - **Embedded systems**: a special-purpose device designed to perform one or a few dedicated functions. It is *embedded* as part of a complete system including hardware, mechanical parts…
    - **Intelligent clothing**: an articles of clothing, footwear or accessories that feature micro-electronic sensors which gather, communicate and output usage and performance data.
    - **Wearable computing**: a computer accompanying us in our every day life and offer help as we need it.



# Smart Environment

- **Smart Environments**
  - Industrial and research topics
    - **Sensor network**: a network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, vibration, pressure, motion, at different locations
    - **Tagging, Tracking and Locating**: Use of active or passive RFID to locate items, for security, for tracking, for automated routing of physical objects, for automated physical Access…



# Smart Environment

- The design of devices for Smart Environment should include:
  - **Transform intrinsic functionalities into programmed functionalities**
    - Embedded systems
  - **Enhance existing apparatus and systems**
    - Intelligent Clothing, Wearable systems and Ambient monitoring
  - **Allowing systems to communicate each other**
  - **Simplify, reducing or eliminate the user interface**
    - iHCI : implicit Human Computer Interface

# Technological issues

- From the technological point of view, the following aspects need to be taken into account (architectural selection)
  - **Computing platform**
    - Executor (micro per embedded, microcontroller, DSP - Hardware to speed up one or more functionalities)
    - Memory (RAM, mass memory)
    - Software (BSP - board support package -, firmware, OS)
  - **Communication infrastructure**
    - Communication wireless and/or wired
  - **Interfaces**
    - Specific and application dependent, Sensors and actuators
  - **Power supply**
    - Batteries and harvesting

# Smart Environment

- Computing platform, communication infrastructure, interfaces and power supply require to face with a set of issues:
  - Energy consumption, power dissipation, energy harvesting and new technologies for batteries
    - Increase the duration of operation of the device, reducing emissions of $CO_2$ by reducing the energy consumption (limiting waste) and implementing energy scavenging methods.
  - Resistance to work in hostile environments
    - Preserve the system by using impact-resistant materials, waterproofing, vibration absorber, ... and no any critical part (if possible).
  - Dependability (e.g. Fault toleration and self checking)
    - Avoid the system crashes when not expected or allowing the system to communicate when a fault is detected.

# Smart Environment

- Energy and Power
  - Reduce processor performance in order to meet both energy and power constraints
    - At present, microprocessors for pervasive systems are around a hundreds of MHz.
  - Minimize the memory size.
    - From KB to MB instead of the tens of GB of general purpose platforms
      - Memory has to be accurately tailored to the application
      - Applications have to accurately optimized for the available memory
  - Identify a set of optimization techniques dedicated to energy saving
    - Techniques for computation and communication for energy saving and techniques for reduce energy consumption in the most critical source of dissipation (e.g. busses)

# Smart Environment

- Resistance to work in hostile environments
  - Elimination of any moving parts
    - Fans have to be removed
      - Fans elimination requires CPU with less power dissipation and, consequently, with lower performance
        - Some energy advantage for the elimination of the electric motors
      - Fans elimination requires to program the system distributing the computation on time (energy is the same, power in reduced)
        - Real-time issues
  - waterproofing, impact resistant materials, …
    - Isolation is another factor reducing power dissipation
    - Packaging

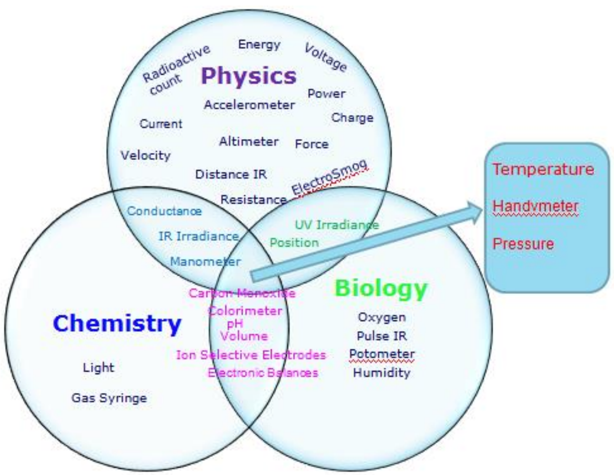
- Dependability properties (fault tolerance/self checking, reliability, availability…)
  - Redundancy
    - Adoption of architecture to tolerate or detect faults
      - e.g. triplication with voting
  - Design the system with respect to faults
    - Risk analysis and fault analysis

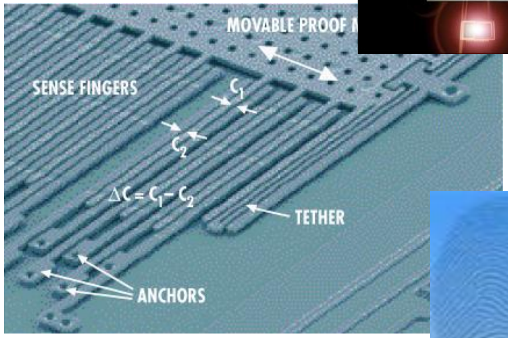
# Smart Environment

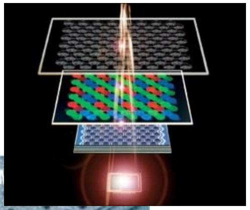
- Communication infrastructure
  - A wireless communication
    - ZigBee, Bluetooth (meters), Wi-Fi (tens of meters)
    - LoRa, Narrowband Internet of Things (NB-IoT), …
      - LPWAN (Low Power Wide Area Network): long range, low power, low cost
    - Wireless communication has some limitations with respect to wire communications like bandwidth, transmission error, energy consumption, but it has undebatable vantages in terms of flexibility, device mobility
  - A specific wired communication
    - Ethernet
    - Field bus
      - RS485, CAN, profibus, …

# Remarks

- Sensors technologies is constantly growing: sensors are the driver for all future applications.
  - Sensor for measurement and sensors for sensing
  - Active and passive sensors

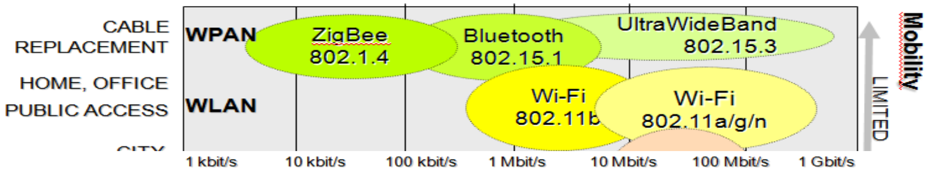


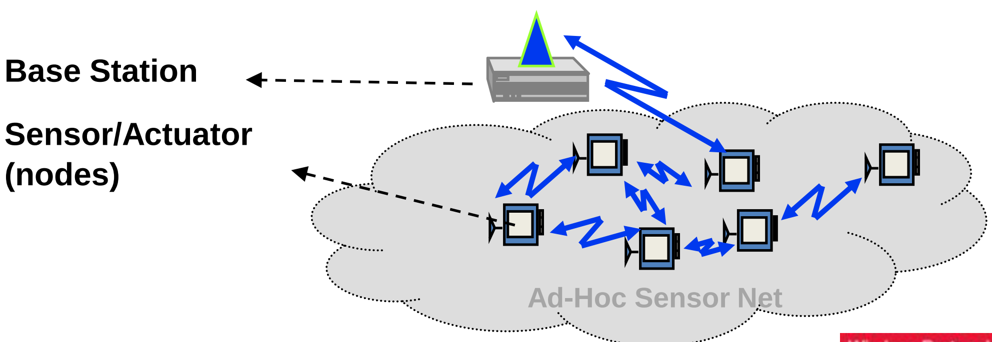



# Smart Environment

- Wireless




| OPTIONS FOR FREQUENCY ASSIGNMENTS | | | |
|---|---|---|---|
| Geographical regions | Europe | Americas | Worldwide |
| Frequency assignment | 868 to 868.6 MHz | 902 to 928 MHz | 2.4 to 2.4835 GHz |
| Number of channels | 1 | 10 | 16 |
| Channel bandwidth | 600 kHz | 2 MHz | 5 MHz |
| Symbol rate | 20 ksymbols/s | 40 ksymbols/s | 62.5 ksymbols/s |
| Data rate | 20 kbits/s | 40 kbits/s | 250 kbits/s |
| Modulation | BPSK | BPSK | Q-QPSK |

| | Wi-Fi | Zigbee | Bluetooth Low Energy |
|---|---|---|---|
| Sleep | 10 μW | 4 μW | 8 μW |
| Receive (Rx) Power | 90 mW | 84 mW | 28.5 mW |
| Transmit (Tx) Power | 350 mW | 72 mW | 26.5 mW |
| Average Power for 10 Messages Per Day | 500 μW | 414 μW | 50 μW |

Wireless Protocols Contending for Continua's V2 Guidelines

| Wireless Standard | Data Rate | Range | Nodes | Battery Life | Frequency Band |
|---|---|---|---|---|---|
| ANT | 1000 Kbps | | 65,000 + 1 | ~4 years | 2.4 GHz |
| Sensium | 50 Kbps | 3m | 8 + 1 | > 1 year | 862-870 MHz 902-928 MHz |
| Z-Wave | 9,600 Kpbs | 30–100m | 232 | > 1 year | 900 MHz |
| BodyLAN | 1000 Kbps | | | | 2.4 GHz |
| BTLE | 1000 Kbps | 5–10m | 7 + 1 | 1 year | 2.4 GHz |
| ZigBee® | 250 Kbps | 1–100m | 65,524 | > 3 years | 868 MHz 915 MHZ 2.5 GHz |

# Energy Harvesting & Wireless Power Transmission: an introduction

# Introduction

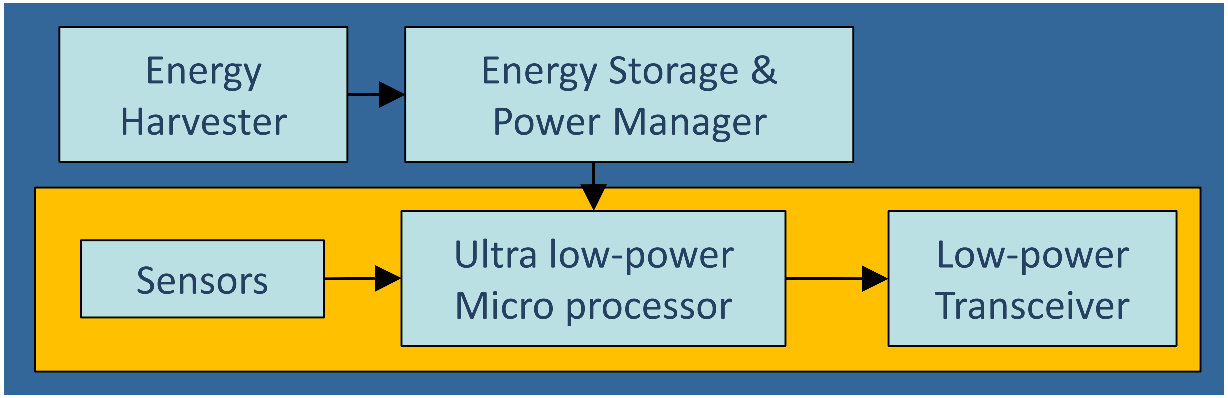
- Energy harvesting: process by which energy is derived from external sources captured, and stored.
  - Energy harvesting, power harvesting or energy scavenging are different words for the same field of study
- Possible external sources of energy are **light** (e.g. solar power), **thermal**, **wind**, **chemical** (e.g. salinity gradients), …
- Frequently Energy harvesting is associated with small, wireless and autonomous devices
  - wearable electronics and wireless sensor networks
- Note: energy harvesting enables new applications that weren't feasible given the finite lifetime and size of batteries

# Introduction

- Power (and, thus, energy) can be produced by unsuspicious sources
  - While we are sat we produce power (100 watt), while we walk, at each step, we produce 5-7 watt.
  - Temperature gradients of a combustion engine and the air moved of moving vehicles is energy that could be collected.
- Energy harvesting
  - Micro: the principle that enables small, autonomous devices to capture small energy amount  from the environment and store it.
  - Macro: the principle that enables large-scale applications to extract significant amount of energy from external sources like waterwheels, present-day wind farms or solar arrays.

# Introduction

- System architecture: an ultra-low-power system with power supply that harvests energy from the environment.
- The portion of the system that harvests energy consists of two main parts: 1) the energy harvester, 2) energy storage.



## Batteryless systems

- Few applications could run directly from the energy harvested
- Two problems:
  - A very large harvester would be required to run the application but it is not practical to have a extremely large harvester to power small applications;
  - Cost vs benefit trade off
  - The energy source would have to be present at all times when the device would be running but it is unrealistic to assume that the energy source would be constantly available.
- For this reasons the energy is typically stored first and made available for the application when needed.

# Batteryless systems

- In order to accommodate the widest possible use cases, the ideal energy buffer would have the following properties:
  - Negligible leakage, Unlimited capacity, Negligible volume, No energy conversion, Efficient energy acceptance and delivery
- Several options are available including: rechargeable batteries, super capacitors, or thin-film batteries.
  - Rechargeable batteries (various chemistries) and super capacitors are well-established technologies.
    - Capacitors are used when the application needs to provide huge energy spikes. Batteries leak less energy and are, therefore, used when the device needs to provide a steady flow of energy.
  - Thin-film batteries serve as a good alternative to super capacitors.

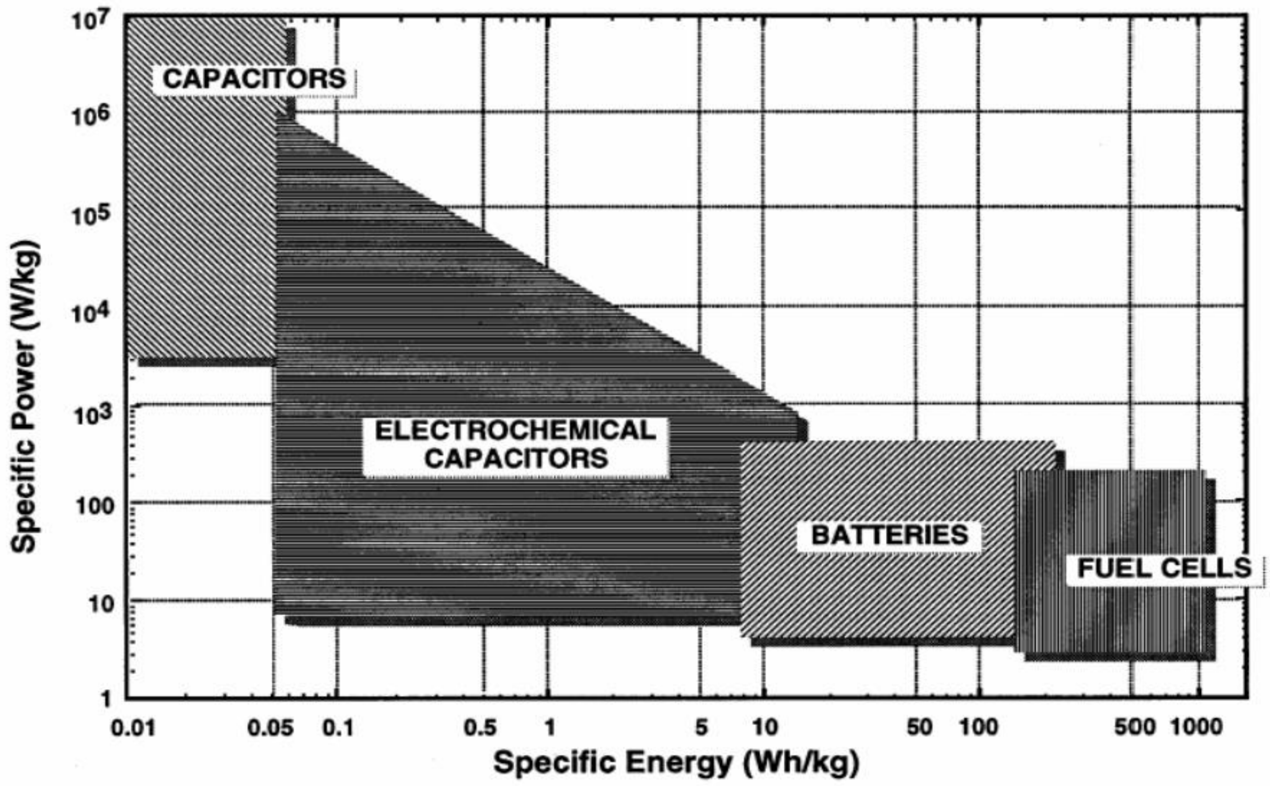
# Batteryless systems

- Key parameters of each type of storage technology

Characteristics of typical energy storage options.

| | Li-Ion battery | Thin-film battery | Super cap |
|---|---|---|---|
| Recharge cycles | Hundreds | Thousands | Millions |
| Self-discharge | Moderate | Negligible | High |
| Charge time | Hours | Minutes | Sec-minutes |
| Physical size | Large | Small | Medium |
| Capacity | 0.3–2,500 mAHr | 12–1,000 μAHr | 10–100 μAHr |
| Environmental impact | High | Minimal | Minimal |

# Batteryless systems




Super Capacitors, Prof. Zhu, University of Technology, Sydney

# Batteryless systems

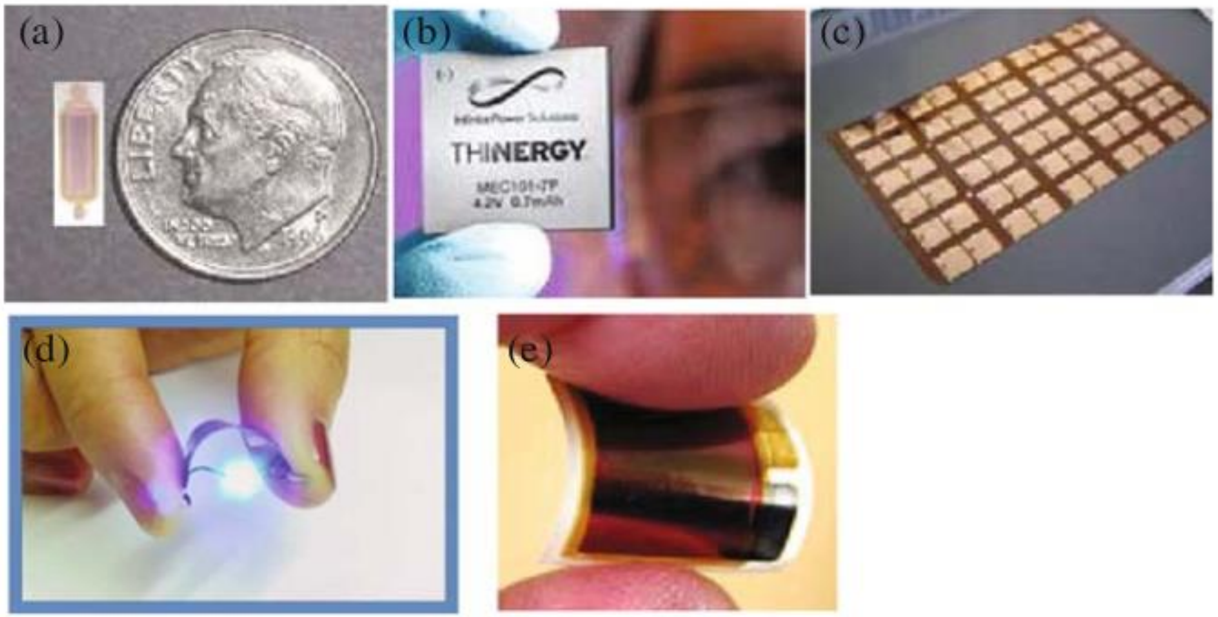



**Fig. 13.2** Examples of prototype batteries manufactured by (**a**) Oak Ridge Micro-Energy, (**b**) Infinite Power Solutions, (**c**) Excellatron, (**d**) Front Edge Technology, and (**e**) Cymbet Corporation

Priya, Shashank, and Daniel J. Inman, eds. Energy harvesting technologies. Vol. 21. New York: Springer, 2009.

# Sources of ambient energy

- The most common sources for ambient energy (micro energy harvesting) are: **Light** (Radiation), **Thermal**, **Vibration** (Kinetic), Wind (Kinetic), **Radio frequency** (Radiation), **Chemical**
- The collected energy (and power) varies by several orders of magnitude based on the technology being used, its efficiency, size, and environment.
  - Example: A one square meter solar panel would generate about 1kW in full sunlight. Currently high efficiency solar panels could generate a 400W (40%).

# Energy-harvesting

- Typical output power for real-world energy harvesting technology

http://focus.ti.com/graphics/mcu/ulp/energy_harvesting_embedded_systems_using_msp430.pdf

| Energy source | Characteristics | Efficiency | Harvested power |
|---|---|---|---|
| Light | Outdoor | 10–25% | 100 mW/cm² |
| | Indoor | | 100 μW/cm² |
| Thermal | Human | ~0.1% | 60 μW/cm² |
| | Industrial | ~3% | 10 mW/cm² |
| Vibration | ~Hz-human | 25~50% | 4 μW/cm² |
| | ~kHz-machines | | 800 μW/cm² |
| Radio frequency (RF) | GSM 900 MHz | ~50% | 0.1 μW/cm² |
| | WiFi 2.4GHz | | 0.001 μW/cm² |

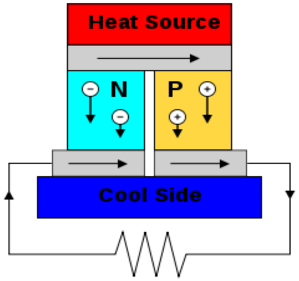
# Energy-harvesting sources

TABLE I
LISTING AND CHARACTERIZATION OF ENERGY SOURCES.

| Energy Source | Characteristics | Amount of Energy Available | Harvesting Technology | Conversion Efficiency | Amount of Energy Harvested |
|---|---|---|---|---|---|
| Solar[25], [26], [27], [28] | Ambient, Uncontrollable, Predictable | $100mW/cm^2$ | Solar Cells | 15% | $15mW/cm^2$ |
| Wind[28] | Ambient, Uncontrollable, Predictable | - | Anemometer | - | 1200mWh/day |
| Finger motion[22], [24] | Active human power, Fully controllable | 19mW | Piezoelectric | 11% | 2.1mW |
| Footfalls[22], [24] | Active human power, Fully controllable | 67W | Piezoelectric | 7.5% | 5W |
| Vibrations in indoor environments[29] | Ambient, Uncontrollable, Unpredictable | - | Electromagnetic Induction | - | $0.2mW/cm^2$ |
| Exhalation[24] | Passive human power, Uncontrollable, Unpredictable | 1W | Breath masks | 40% | 0.4W |
| Breathing[24] | Passive human power, Uncontrollable, Unpredictable | 0.83W | Ratchet-flywheel | 50% | 0.42W |
| Blood Pressure[24] | Passive human power, Uncontrollable, Unpredictable | 0.93W | Micro-generator | 40% | 0.37W |

Sudevalayam, Sujesha, and Purushottam Kulkarni. "Energy harvesting sensor nodes: Survey and implications." Communications Surveys & Tutorials, IEEE 13.3 (2011): 443-461.

# E-Harvesting tech.: Thermal




- Thermoelectric generators (TEGs)
  - Thermoelectric effect (Seebeck effect)
    - The temperature gradient in a conducting material produces a heat flow; The heat flow produces a flow of charge carriers; The flow of charge carriers (between the hot and cold regions) creates a voltage difference.
  - Objects with temperature gradients produce energy; heat can be captured from car to hot surface and body
    - E.g. Miniature thermocouples have been developed that convert body heat into electricity and generate 40µW at 3V with a 5 degree temperature gradient. Temperature gradient body/environment has an average efficiency of 5.5% and the heat emitted from the neck region can result a power of 0.3 W.
    - Thermoelectric energy conversion is a low efficiency process (less than 10%)

# E-Harvesting tech.: Thermal

- Thermoelectric generators (TEGs) … cont.
  - Peltier cell: create voltage difference using heat flux between the junction of two different types of materials

# E-Harvesting tech.: Kinetic

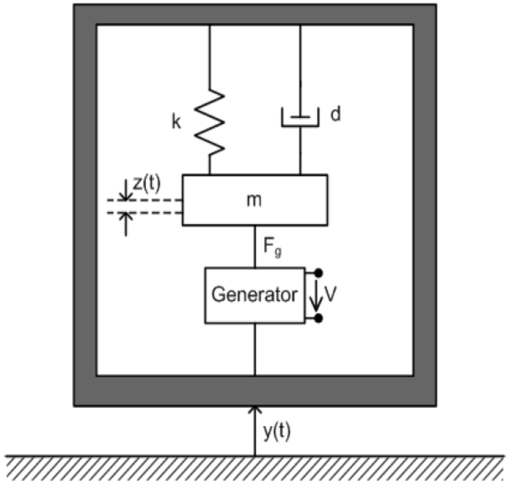
- The spectral distribution of a specific habitat or a typical average frequency is identified
  - E.g. the cadence of a person step, the frequency of vibration of the washing machine during washing and/or centrifuge, …
- The device is built in order to resonate at the desired frequency (maximum amplitude oscillation of the system)
  - Suspended masses are generally used; oscillations are translated in power using capacitance or piezoelectric transducers.
- The power generally obtained is just enough for small devices;
- It is possible to extract power from breathing (average of 0.5 W) and the movement of limbs (above Watts).

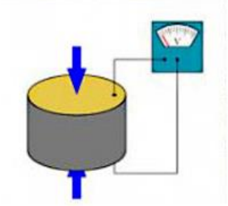
# E-Harvesting tech.: Kinetic

- Vibration Source
  - Not all vibrations could be used for energy harvesting: the source vibration must have certain characteristics for it to be usable.
- Suitable vibration source for optimal use:
  - Resonant Frequency - The source vibration object should have a known and repeatable frequency component within a range. This provides the optimal tuning frequency for the vibration harvester to work at its maximum potential (maximum mass/spring displacement).
  - Vibration Level – the level acceleration of the source vibration object will determine the power output of the Vibration Energy Harvester (VHE)

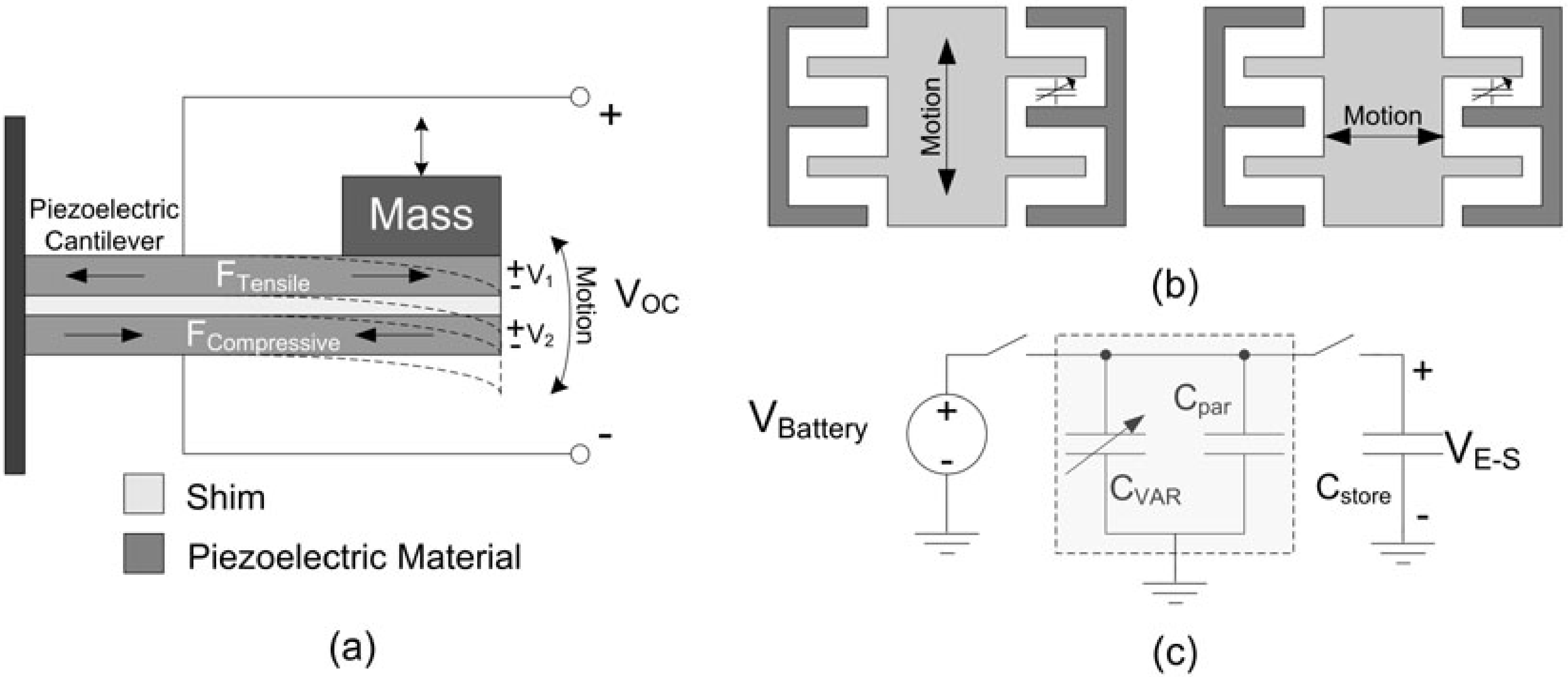
# E-Harvesting tech.: Kinetic

- Piezoelectric crystals or fibers generators (Kinetic)
  - Generate a small voltage whenever they are mechanically deformed. Vibration from engines can stimulate piezoelectric materials, as can the heel of a shoe.
  - Piezo Harvester Model



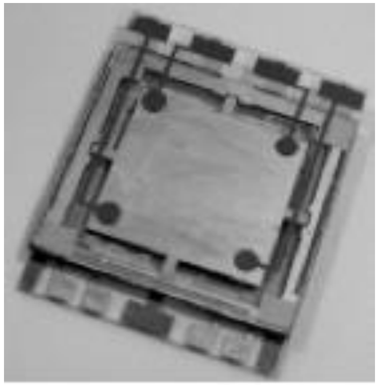
# E-Harvesting tech.: Kinetic




http://www.eetimes.com/document.asp?doc_id=1273025

# E-Harvesting tech.: Kinetic

- Electromagnetic generator (Kinetic)
  - The motion of a magnet provides a rate of change of flux, which results in some induced *emf* on the coils (according to Farday' law).
  - Example: Micro wind turbine are used to harvest wind energy available in the environment in the form of kinetic energy; such an energy is transformed in electric power using a DC motor.



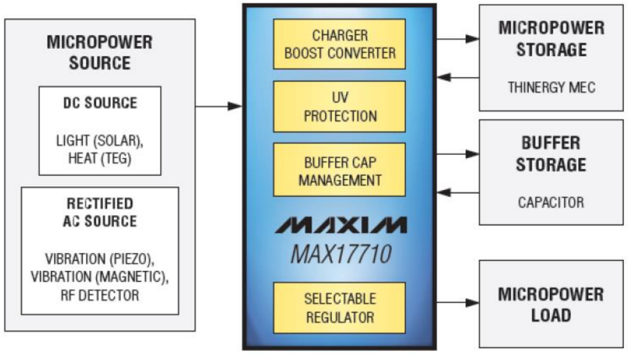
- Electrostatic generator (Kinetic)
  - Vibrations separate the plates of an initially charged variable capacitor (varactor - variable capacitor) and mechanical energy is converted into electrical energy.
  - Coulomb-damped resonant generators (CDRGs)

# E-Harvesting tech.: Radiation

- EM radiation generators (Radiation)
  - Special antennas (rectennas) can collect energy from stray radio waves or, theoretically, from light.
  - A rectenna stands for **rect**ifying ant**enna**; it is a special type of antenna that is used to directly convert microwave energy into DC electricity.
  - Note that RF radiation employed to power ID cards (RFID) by directing high power electromagnetic energy to the devices from a nearby source is not an energy harvesting systems.

# E-Harvesting: PMIC

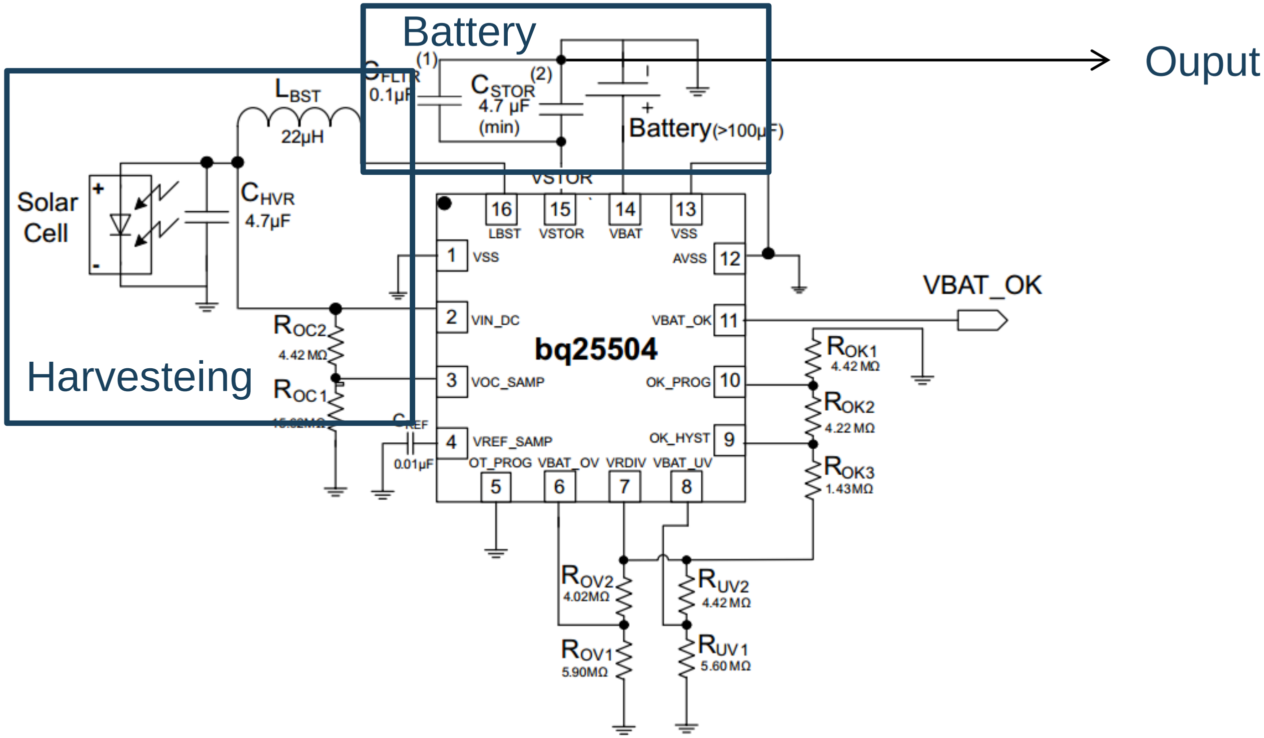
- Power Management Integrate Circuit or PMIC
  - It is possible to harvest different type of energy
  - To gather each single contribution is necessary to face with frequency, voltage and current differences; these require a specific “manager” to charge and to protect energy storage.
  - Example: MAX17710




http://www.maxim-ic.com/datasheet/index.mvp/id/7183

# Power Supply

- Example: Texas bq25504 for Solar Cell



# Applications: Light

- Traffic counters, calculators, ICT-devices using PV (photovoltaic panels)
  - Any application where:
    - The cost is acceptable
    - PV can perform reliably in the specific application and location
    - A practical size array produce sufficient energy
- The key benefit of PV is to reduce the consumption of batteries while the net energy saved is less significant and to support for social progress in rural areas and in developing countries where people are not connected to the grid

# Applications: Light

- PV powered street lamp

Western Co

- PV powered traffic light

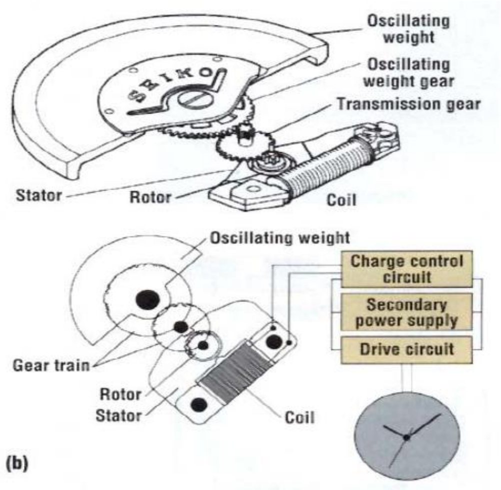
- Solar Road Stud

# Applications: Thermal

- Seiko's Thermic wristwatch 10 thermoelectric modules
  - Seiko Thermic is the first practical application of the Seebeck effect in a watch.
  - The watch absorbs body heat from the back case and dissipates it from the front of the watch to generate power with its thermal converter.
    - As the difference between the air temperature and the surface temperature increases, the power generation performance increases.

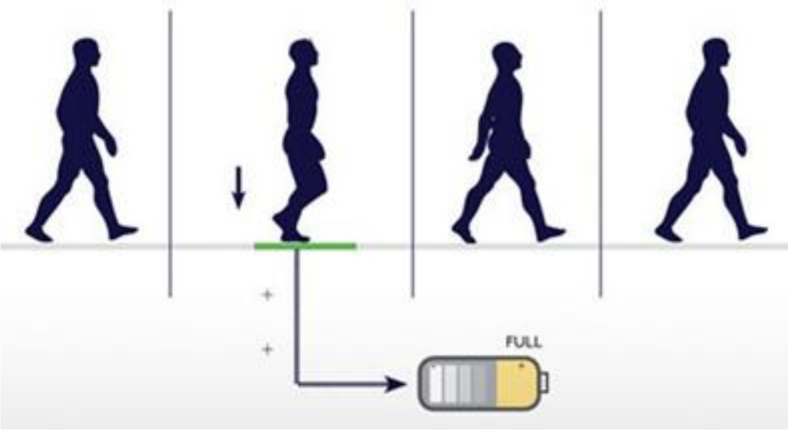
# Applications: Vibration

- Self-winding wristwatch
  - A mechanical watch, whose mainspring is wound automatically by the natural motion of the wearer's arm, to make it unnecessary to manually wind the watch.



# Applications: Vibration

- Energy Harvesting Paving systems extracts energy from the power generated by walking the passengers on paving
  - Example: London underground
- The plate moves 5mm transforming kinetic energy into electrical energy

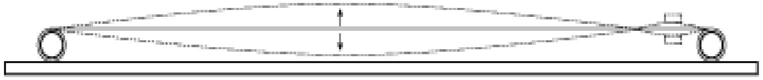




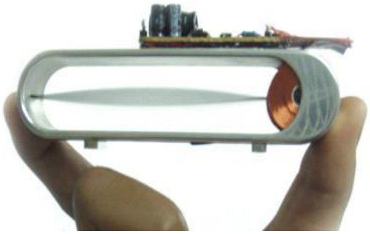
From www.pavegensystems.com

# Applications: Vibration

- Wind micro-generator.
  - power generation through wind-belt: Windbelt™ relies on an aerodynamic phenomenon known as aeroelastic flutter ('flutter').
  - The Windbelt™ uses a tensioned membrane undergoing a flutter oscillation to pull energy from the wind.
    - http://www.youtube.com/watch?v=AMojRXK14jU&feature=related



Oscillation profile of one variation of the Windbelt technology.



From http://www.humdingerwind.com/#/wi_overview/

# Applications: Vibration

- Human step energy scavenger.
  - The mechanical energy produced by humans during walking is captured and converted into electrical power.
  - “…about 20W of power is lost as heat during walking.”


http://www.instepnanopower.com/

# Products: Vibration

- Vibration Energy Harvesting Microgenerator PMG7
  - The unit can be used to power sensors, microprocessors and transmitters
  - The micro-generator converts kinetic energy from the vibration of the equipment running at mains frequency (50 or 60Hz) into electrical energy.
  - It can generate up to 5mW. It is available for optimized operation around the 50, 60, 100 or 120Hz resonant frequencies, with simple tuning via a 1Hz/turn 3mm hexagonal key. The maximum voltage generated is 3.4V.

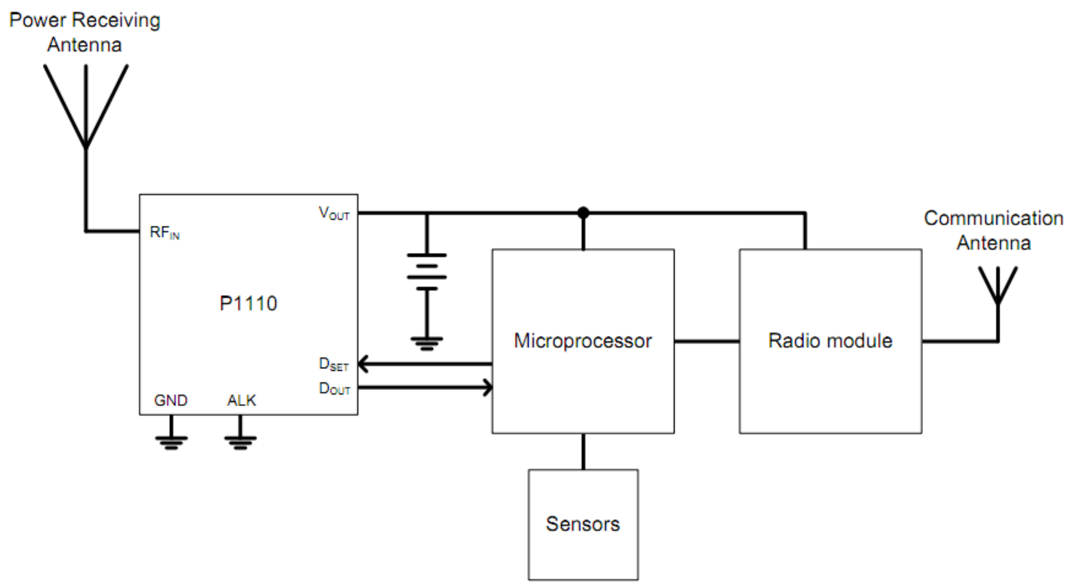
Ø55mm
H 55mm
190 gr

# Products: RF


- Converter from radio waves to DC power.
  - components for enabling wireless powered devices.
- Powercast (http://www.powercastco.com) offers several modules that have been designed for charging batteries, other energy storage devices, and for direct power applications.
- Examples: P1110 Powerharvester Receiver
  - Designed for battery charging and direct power applications using RF harvesting range from 850-950MHz. P1110 has configurable overvoltage protection up to 4.2V and RSSI and data output.

# Products: RF

- Typical Application Circuit w/Battery (from Powercast)



# Best Practice

- System characteristics:
  - Energy harvesting systems are tune for ultra-low power operation
  - Energy harvesting systems must accommodate for wide fluctuations in input power, including the possibility that the power source becomes unavailable for some period of time.
- Traditional ultra-low power design practices should be the foundation for operation.
  - E.g. A microcontroller and RF transceiver optimized for minimum power consumption such as a 16-bit MSP430 MCU (Texas - 250 µA @ 1 MHz, 2.2 V) and CC2500 2.4GHz transceiver (Texas - 1.8 : 3.6 V - Current Consumption:RX 12.8mA - TX 21.6 mA)

# Best Practice

- The microprocessors low-power standby modes should be properly used and the time spent in a higher power active mode should be minimized.
- An appropriate storage technology have to be selected to ensure that enough power will be available when the application is active and running
- If the sensor data is not needed at all times, the system could be modified to only transmit when a readily available energy source is present.

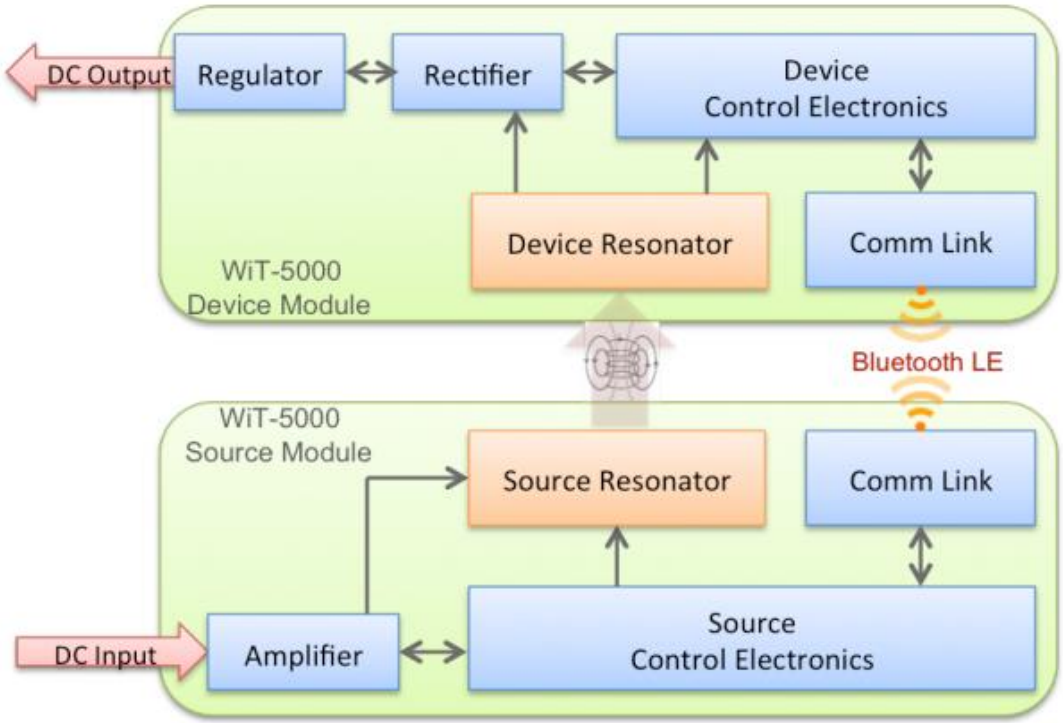
# Multi-source Energy

- Harvest energy from different sources is a way to face with the energy source availability
  - Discontinuous physical phenomena.
  - Light, kinetic, termal, … are not always available at the same time.
- Problems to solve
  - manage and harvest energy coming from different sources.
  - collect current as a single flow.
- Different possible architectures
  - E.g. RCA (Reservoir Capacitors Array)
    - Each capacitor is managed by a single and independent source, Energy is spilled in parallel, diodes block current in undesired directions

# Wireless Power Transmission

- Conventional energy transfer is using wires
  - most electrical energy transfer is through wires
- Most of the energy loss is during transmission
  - On an average, more than 30%
- WPT is the transmission of energy from one place to another without using wires
  - The wireless transmission is made possible by using various technologies
- WPT is:
  - Low maintenance cost
  - Can be used for short-range or long-range.

# Wireless Power Transmission



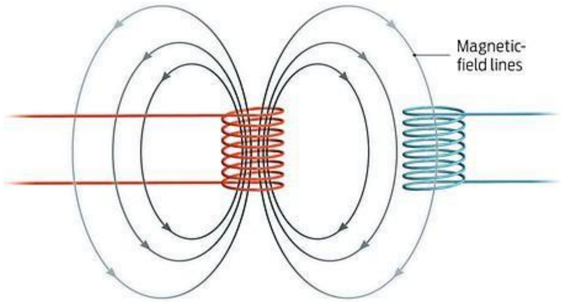

*The WiT-5000 allows OEMs to develop WiTricity-based systems*

# Types and Technologies

- Near-field techniques
  - Inductive Coupling
  - Resonant Inductive Coupling
  - Air Ionization
- Far-field techniques
  - Microwave Power Transmission (MPT)
  - LASER power transmission

# Inductive coupling

- Primary and secondary coils are not connected with wires.
- Energy transfer is due to Mutual Induction
  - Transformer is an example



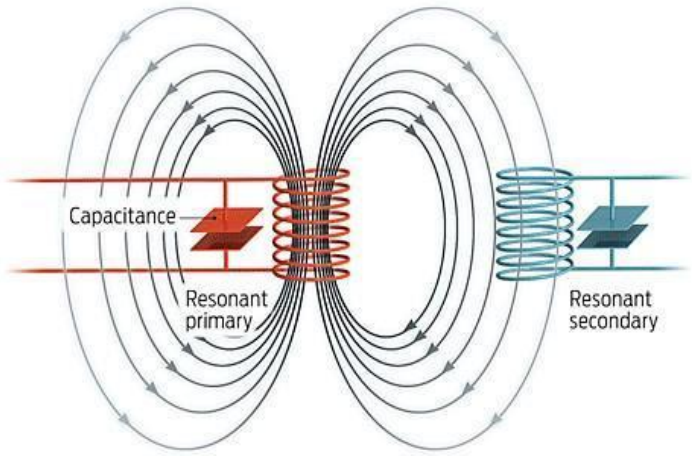

- Energy transfer devices are usually air-cored
- The charging pad (primary coil) and the device (secondary coil) have to be kept very near to each other

# Inductive coupling: examples

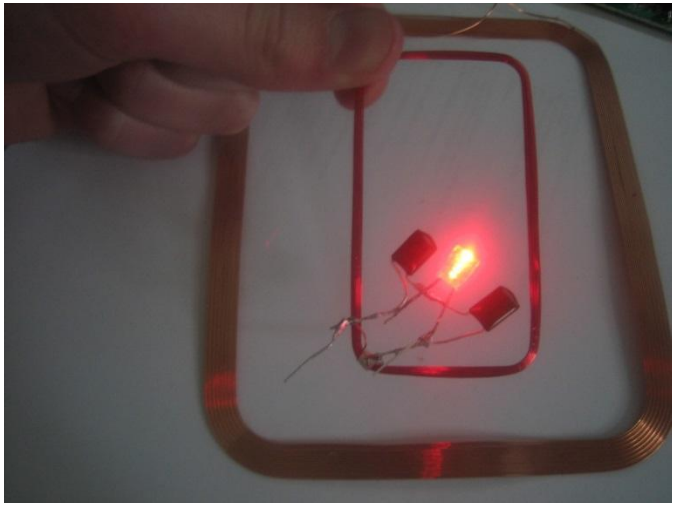
- Examples
  - Wireless Charging Pad
  - Electric Toothbrushes
  - Ultra Slim wireless receiver

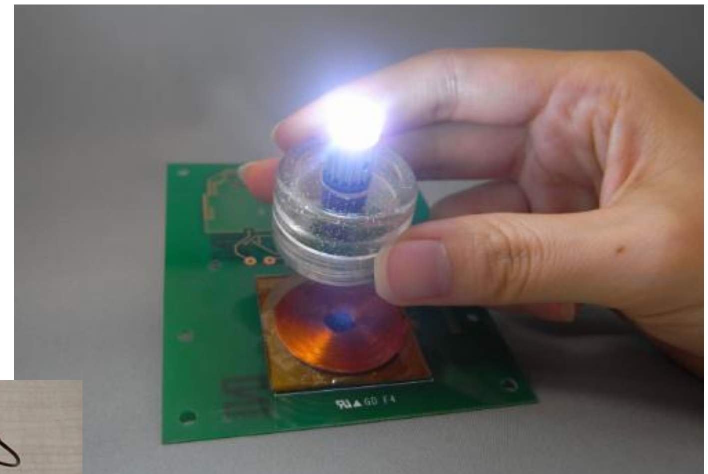
# Resonance Inductive Coupling

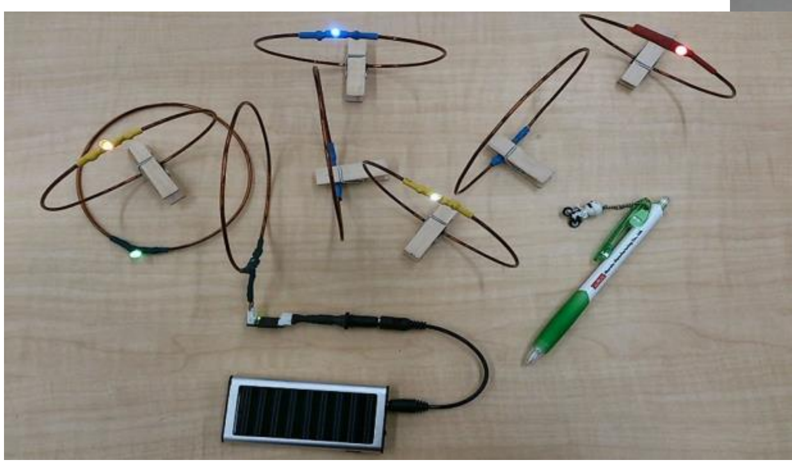
- Combination of inductive coupling and resonance
- Resonance makes two objects interact very strongly
- Inductance induces current



# Examples







# RIC vs. inductive coupling

- RIC vs. inductive coupling :
  - RIC (Resonance Inductive Coupling) is highly efficient
  - RIC has much greater range than inductive coupling
  - RIC is directional when compared to inductive coupling
  - RIC can be one-to-many. But usually inductive coupling is one-to-one
  - Devices using RIC technique are highly portable
- CONS of RIC/inductive coupling :
  - Distance constraint
  - Field strengths have to be under safety levels
  - In RIC, tuning is difficult
  - High frequency signals must be the supply

# Applications

- Near-field energy transfer
  - Electric automobile charging
    - Static and moving
  - Consumer electronics
  - Industrial purposes
  - Harsh environment
- Far-field energy transfer
  - Solar Power Satellites
  - Energy to remote areas
  - Can broadcast energy globally (in future)

# Dependable Pervasive Systems
# Introduction, Basic Concepts & Terminology: an introduction

# Critical systems

- A critical system is any system whose failure could threaten human life or the system's environment
- Main critical systems
  - **Safety**-critical systems
    - A system whose failure may result in the loss of human life, injury or major environmental damage
      - Embedded control systems medical devices, Command and control systems for disaster management systems, …
  - **Mission**-critical systems
    - A system whose failure may result in the consequent failure of a goal-directed activity
      - Communication systems for telephone switching systems, aircraft radio systems, …

# Critical systems

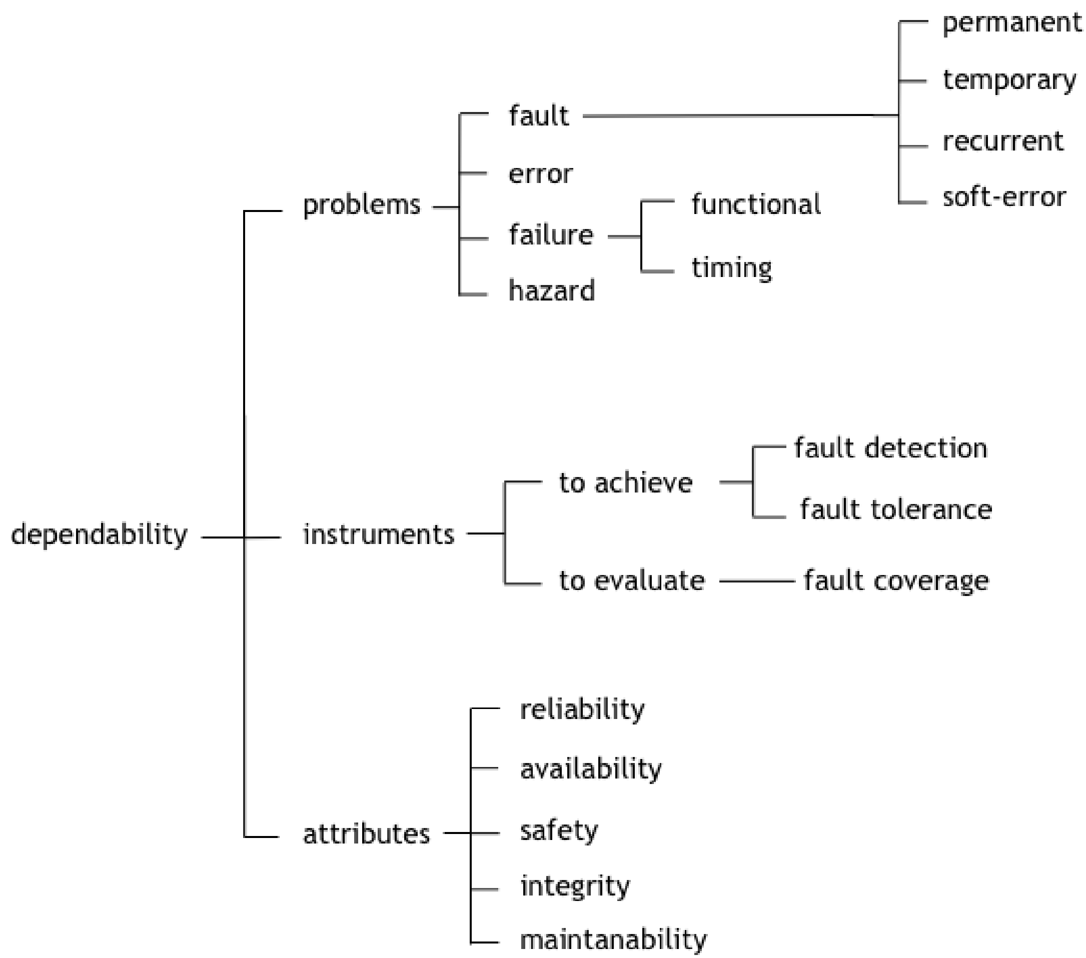
- The cost of failure in a critical system is likely to exceed the cost of the system itself
  - Direct costs: fault location, repair, …
  - Indirect costs: these are usually be significantly higher than the direct costs and they are due to the effects of the failure on the *environment*
- Development of critical systems
  - Critical systems attributes are not independent
    - Attributes: Reliability, Availability, Safety, Integrity, Maintainability
    - Other: Testability
  - The development process of critical systems must be organized so that all the attributes are satisfied at least to **some minimum** level

"*Dependability is that property of a computer system such that reliance (trustiness) can justifiably be placed on the service it delivers.*"
J. C. Laprie

# Dependability

- The dependability reflects the extent of the user's confidence that **the system will operate as users expect and that it will not fail in normal use**
  - Dependability encapsulates the concepts of Reliability, Availability, Safety, Integrity, Maintainability
  - For critical systems, often the most important system property is the dependability of the system
- Dependability attributes are **non-functional properties** since they do not relate to any specific functionality of the system
  - System specification and requirements phases need to identify which properties are desirable and which are mandatory

# Dependability



# Fault

- Fault: In hardware structure or in software modules, faults could arise form defect, imperfections or interaction with external environment.
- Categories:
  - Permanent:  Remain for indefinite period
  - Temporary (or Transient) : Appear and disappear
  - Recurrent  (or Intermittent) :  Appear, disappear and then reappear and are often early indicator of imminent permanent fault
  - Soft-error: bit-switch due to high energy particle

# Fault

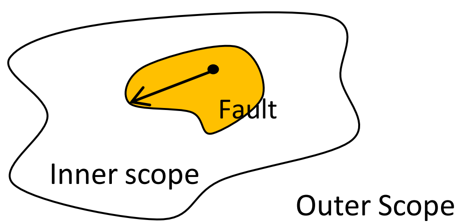
- Faults can occur in any abstraction layer of the system

| Layer | |
|---|---|
| User application | Software bugs are faults arising in application OS or firmware |
| OS | |
| Firmware | |
| Architecture | Design faults can arise in architecture or circuit |
| Circuit | |
| Process Technology | Defects, imperfection, bit-flip … |

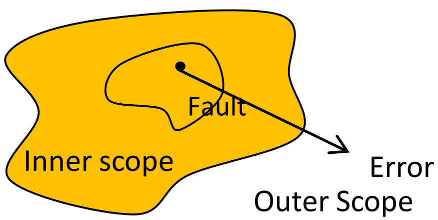
- A fault in a particular layer may not show-up as a visible error
  - First, a fault may be masked in a intermediate layer
  - Second, a layers may be partially or fully designed to tolerate faults

# Error - Failure

- Error: an error is a manifestation of a fault
  - Non visible faults are masked faults
    - Involuntary: masking effects
    - Voluntary: fault toleration mechanism




Fault not visible outside the inner scope

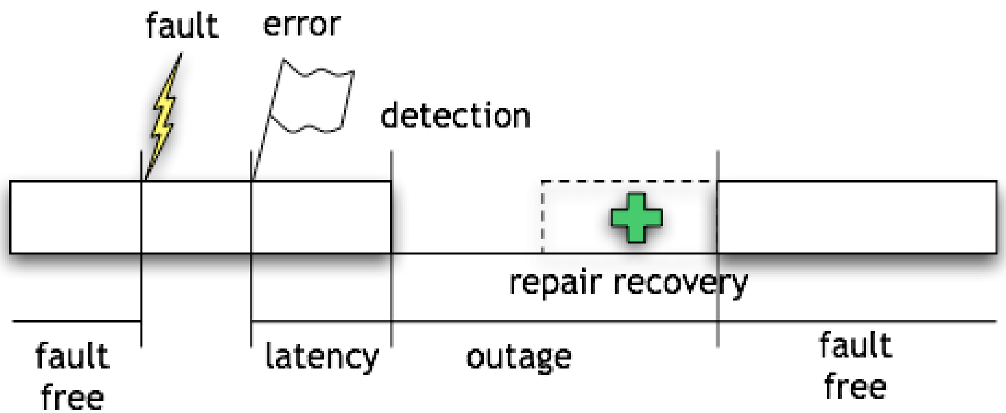


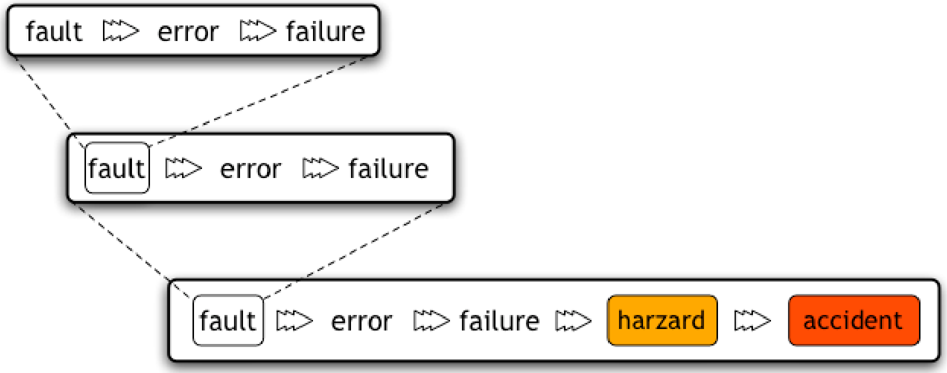

Fault propagated outside the outer scope and visible as an error

- Failure
  - A system malfunction that causes the system to not meet its correctness, performance or other guarantees

| Term | Description |
|---|---|
| Fault | A defect within the system |
| Error | A deviation from the required operation of the system or subsystem |
| Failure | The system fails to perform its required function |

# Fault, error and failure



# Metrics and models

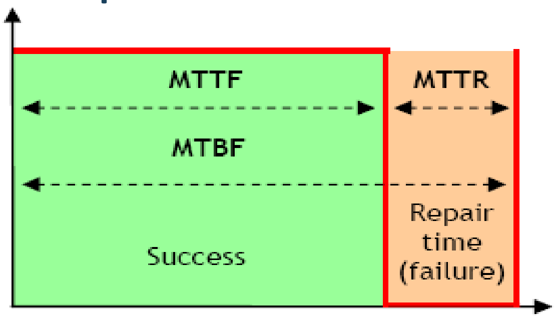
- MTBF: mean time between two failures
  - Express the mean time elapsed between two failures
- MTTF (MeTTF): mean (median) time to failure
  - Express failure rate in term of years
  - Under certain assumption (i.e. exponential failure law) the MTTF of a system is a combination of MTTF of its component

$$MTTF_{system} = 1/\Sigma(1/MTTF_i)$$

  - Exemple: a system is composed by 2 component where $MTTF_1 = 6$ years and $MTTF_2 = 1$ year.
    $MTTF_{system}=1/(1/6+1) = 6/7 = 0.85$ year

# Metrics and models

- MTTR: mean time to repair




- FIT: Failure in time
  - Express the number of failure in a billion hours ($10^9$ hours)
  - FIT is additive
    - Example: a system is composed by two components. C1 has 10 FIT while C2 has 20 FIT. The system has 30 FIT.
  - FIT and MTTF are related

$$MTTF_{system} = 10^9/(FIT * 24 * 365) \cong 1.141*10^6/FIT \text{ [years]}$$

# Metrics and models

- R(t): Reliability
  - Probability that the system does not experience a user-visible error in the interval (0,t]
- A: availability
  - Probability that a system is functioning correctly at a particular instant of time

$$A = MTTF / (MTTF+MTTR) = MTTF / MTBF$$

$$A = E[uptime]/(E[uptime]+E[downtime])$$

  - A increases increasing MTTF and/or decreasing MTTR
    - The term *five 9s* (99,999% - downtime of 5 min per year) or *six 9s* (99,9999% - downtime of 32 sec per year) is used to describe the availability of a system

# Attributes: Availability

- Numbers
  - A = 99% - Downtime per Year = ~5000 min – System: Web site
  - A = 99,99% - Downtime per Year = ~50 min – System: Enterprise Server
  - A = 99,999% - Downtime per Year = ~30 sec – System: Phone  Switchs
- Example:
  - Equipment  with MTTF of 20 years and MTTR of 1 hour:
    - MTTF in hours = 20 × 365 × 24 = 175200 hours
  - A =175200/(175200+1)=713940/713941 → 99,99942922 %
- Two different points of view:  "**reliability**: does not break down …" and "**availability**: even if it breaks down, it is working when needed …"

# Attributes: Risk

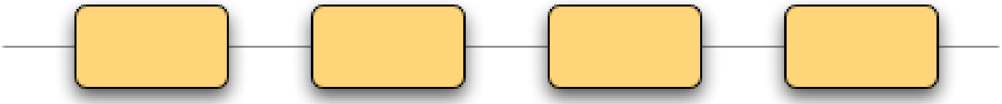
- Risk
  - Risk is the expected loss per unit time
    - Risk = Damage + Uncertainty

$$Risk(accident) = P\,(accident) * cost\,(accident)$$

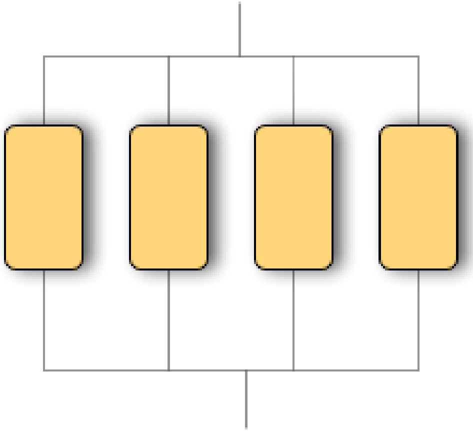
  - Example: FAA (Federal Aviation Administration) Safety and reliability categories (for Airports)

| Category | Meaning | hazard rate ($\lambda$) |
|---|---|---|
| Catastrophic | All failure conditions precluding continued safe flight and landing | $10^{-9}$ |
| Hazardous/ Severe-major | Large reduction in safety margins<br>Crew can't perform task<br>Adverse impact upon occupants | $10^{-7}$ |
| Major | Significant reduction in safety<br>Increase workload crew is inefficient<br>Discomfort to occupants | $10^{-5}$ |
| Minor | Slight reduction in safety<br>Slight increase in crew workload<br>Inconvenience to occupants | $10^{-3}$ |
| No effect | No effects on operation of the aircraft | |

# Attributes: Reliability



- Series systems
  - $R(t) = R_1(t)\ R_2(t)\ \dots\ R_N(t)$
  - Unreliability $Q(t) = 1 - R(t)$



- Parallel systems
  - $Q(t) = [1-R_1(t)]\ [1-R_2(t)] \dots\ [1-R_N(t)]$
  - $R(t) = 1-Q(t)$

# Attributes: Safety

- Safety: the absence of catastrophic consequences on the users or the environment
- Safety-critical system is a system whose failure or malfunction may result in **death or serious injury to people, or loss or severe damage to equipment or environmental harm**.
- Reliability regimes for life-critical systems:
  - **Fail-operational systems** continue to operate when they fail.
  - **Fail-safe systems** become safe when they cannot operate
  - **Fail-secure systems** maintain maximum security when they can not operate.
  - **Fault-tolerant systems** avoid service failure when faults are introduced to the system.

# SIL: Safety Integrity Levels

- SFF (safe failure fraction): the fraction of the overall failure rate of the device that results in either safe faults or detected dangerous faults

| | Hardware Fault Tolerance | | |
|---|---|---|---|
| Safe Failure Fraction | 0 | 1 | 2 |
| < 60% | NA | SIL1 | SIL2 |
| 60% - < 90% | SIL1 | SIL2 | SIL3 |
| 90% - < 99% | SIL2 | SIL3 | SIL4 |
| ≥ 99% | SIL3 | SIL4 | SIL4 |

The Safe Failure Fraction (SFF) is the ratio of Safe Failures to Total Failures

$$\mathrm{SFF} = \frac{[\,\lambda^{S} + \lambda^{DD}\,]}{[\,\lambda^{S} + \lambda^{DD} + \lambda^{DU}\,]}$$

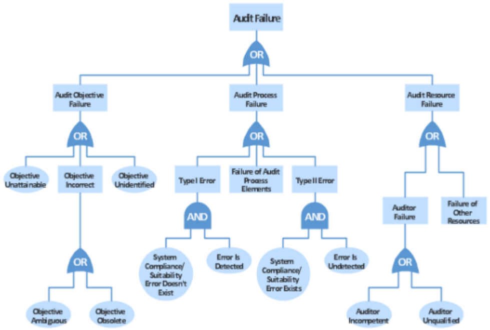

- SIL2: Anti-Blocking System (ABS)
- SIL3: active safety systems (x-by-wire, stability control, …)

## SIL: Safety Integrity Levels

- For functions with a **low demand rate** (e.g ABS), the accident rate is a combination of two parameters :
  - The frequency of demands, and
  - The Probability the **function fails on demand** (PFD).
  - In this case, therefore, the appropriate measure of performance of the function is **PFD**, or its reciprocal, **Risk Reduction Factor** (RRF).
- For functions with a **high demand rate** (e.g. braking) or operate continuously, the accident rate is the failure rate ($\lambda$) which is the appropriate measure of performance.
  - An alternative measure is Mean Time To Failure (MTTF) of the function.

# Safety analysis: methods

- FMEA (Failure mode and effects analysis)
  - bottom-up method (inductive analytical method)
  - Method
    - details and identifies systematically, for each component, all possible ways of system malfunction and their effects.
- Fault Tree Analysis
  - Top-down method (deductive analytical method)
  - Method
    - Iterate until the required details are reached
      1. select the malfunction of the system
      2. identify the events that directly contribute to the malfunction
      3. correlate the events through logic functions



# Attributes: others

- Maintainability
  - Ability to undergo repairs and modifications
  - Ease of repairing the system after a failure has been discovered or changing the system to include new features
- Survivability
  - The ability of a system to continue to deliver its services to users in the face of deliberate or accidental attack
    - Survivability subsumes the notion of resilience (the ability of a system to continue in operation despite of component failures)
- Testability
  - Ability to test for certain attributes within a system
    - Related to maintainability: importance of minimizing time required to identify and locate specific problems

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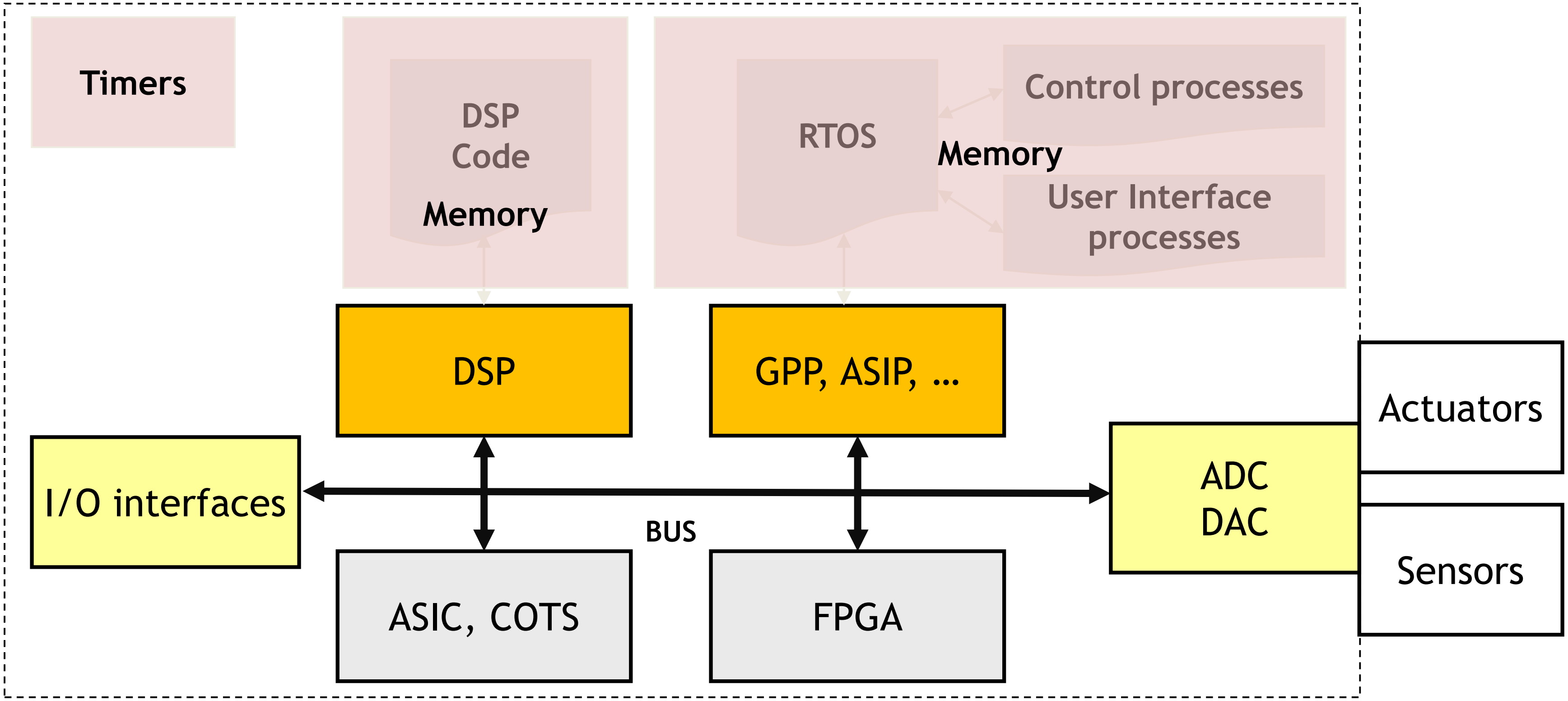
# Special Purpose Processors & Microcontrollers: an introduction

- Generic schema of a Digital System

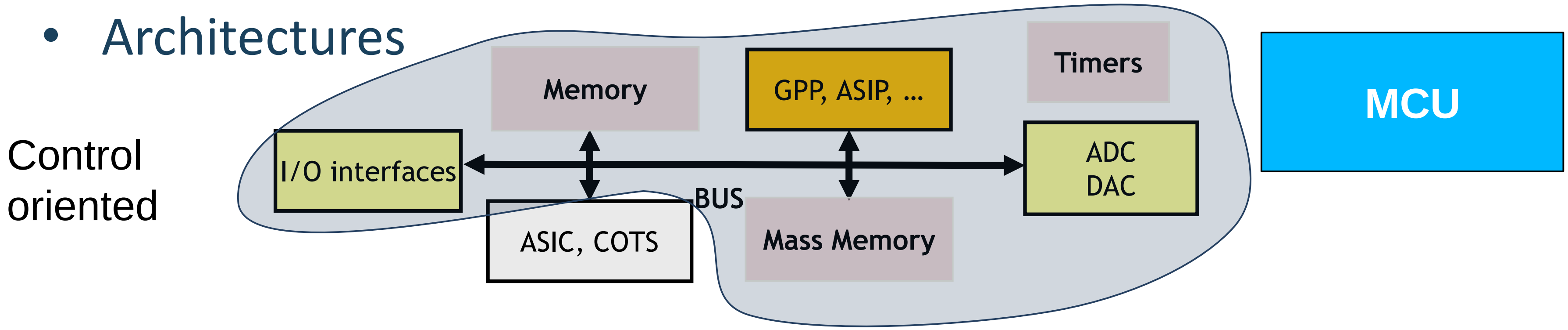


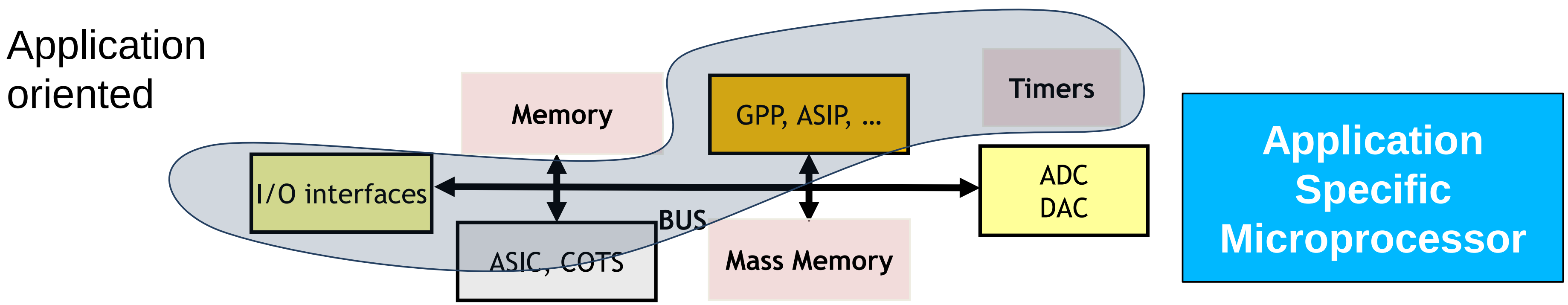
# Introduction

- Processors differ in term of
  - Technology
  - Architecture
  - Application environment
    - General purpose applications
    - General purpose application with some specific feature
      - DSP and GPU (Graphic Processor Unit)
    - Special purpose or specific applications
    - Control applications
- Application environment roughly classifies processors in three categories
  - General purpose processor (or GPP)
  - Special purpose (application specific) processor (or SPP)
  - Microcontrollers (or MCU)

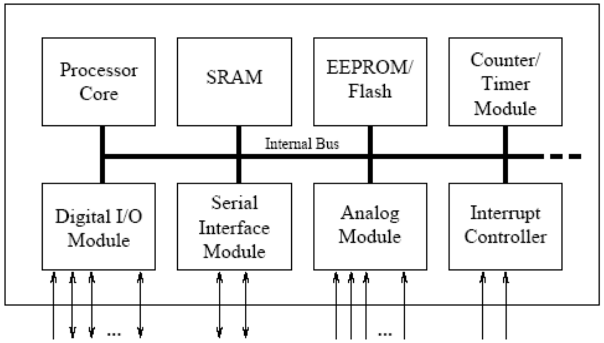
# MicroController Unit (MCU) and Special Purpose Processor (SPP)

- Architectures



# Microcontrollers

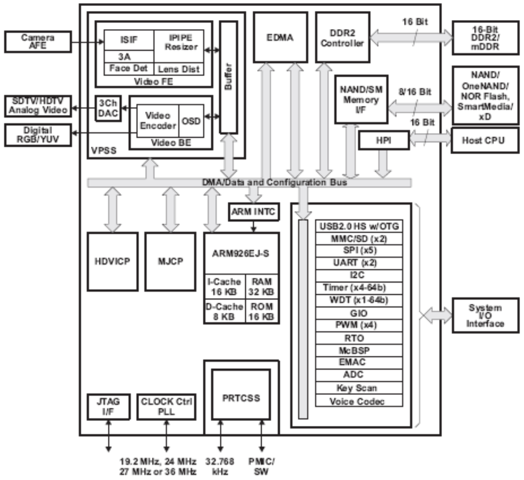



- Microcontrollers (MCU)
  - Single chip with
    - General purpose microprocessor
    - Timers and counters
    - I/O ports specialized (ADC e DAC)
    - Memory ROM and RAM, EEPROM, FLASH (KB)
    - Clock generator
    - …
  - MCU does not require auxiliary hardware
    - Just  a minimal set of hardware

# Microcontrollers

- From a high level point of view, MCU are characterized by:
  - Low performance architecture
    - Sometimes without cache
  - Low frequency
    - From 1MHz to 100MHz (500MHz)
  - Low power dissipation/low energy consumption
    - From 0,01W to 1W
  - Low cost
    - From 0,1$ to 10$

# Special purpose processor



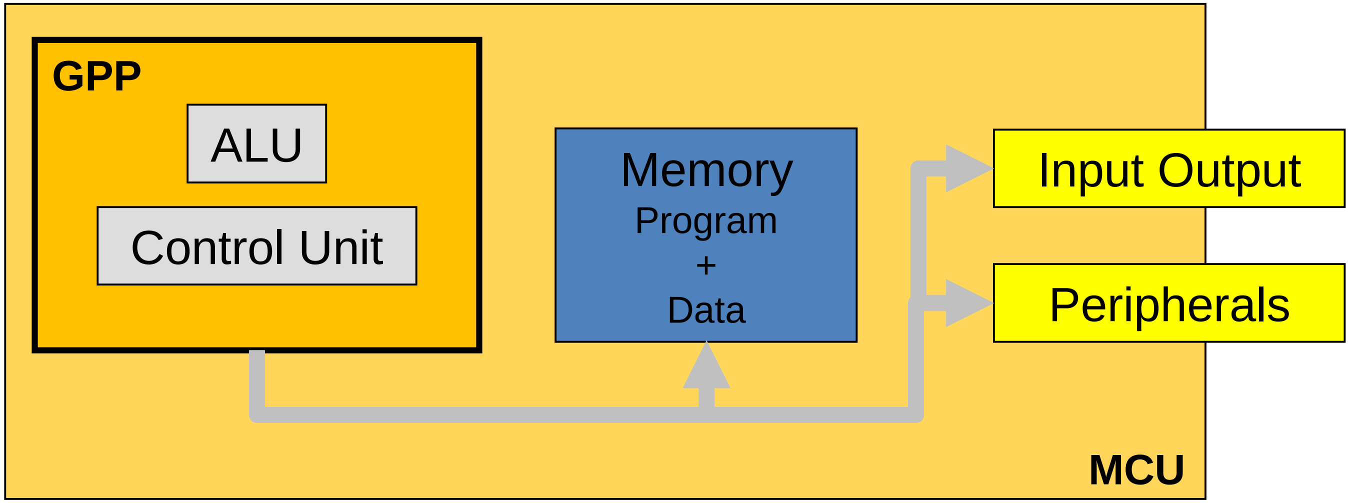

- Special purpose processor (SPP)
  - Single chip with
    - General purpose microprocessor
    - A set of complex functionalities
      - Functionalities on the chip (typically only digital)
        - E.g. (Intel PXA270): Advanced Camera Interface, Enhanced LCD Controller, USB Host/Client, UART, real-time clock, MMC/SDCard, Memory Stick, …
  - Require auxiliary hardware to implement the platform (a minimal set of hardware blocks)
- NOTE: Special purpose processor is also named Embedded Processor. This processors has been extensively used in a embedded applications (application specific applications)

# Special purpose processor

- From a high level point of view, SPP are characterized by:
  - Medium/high performance architecture
    - Cache
    - Pipeline
  - Medium frequency
    - From 100 MHz to 1.5GHz
  - Low/medium power dissipation-low/medium energy consumption
    - From 0,1W to 10W
  - Low/medium cost
    - From 1$ to 100$

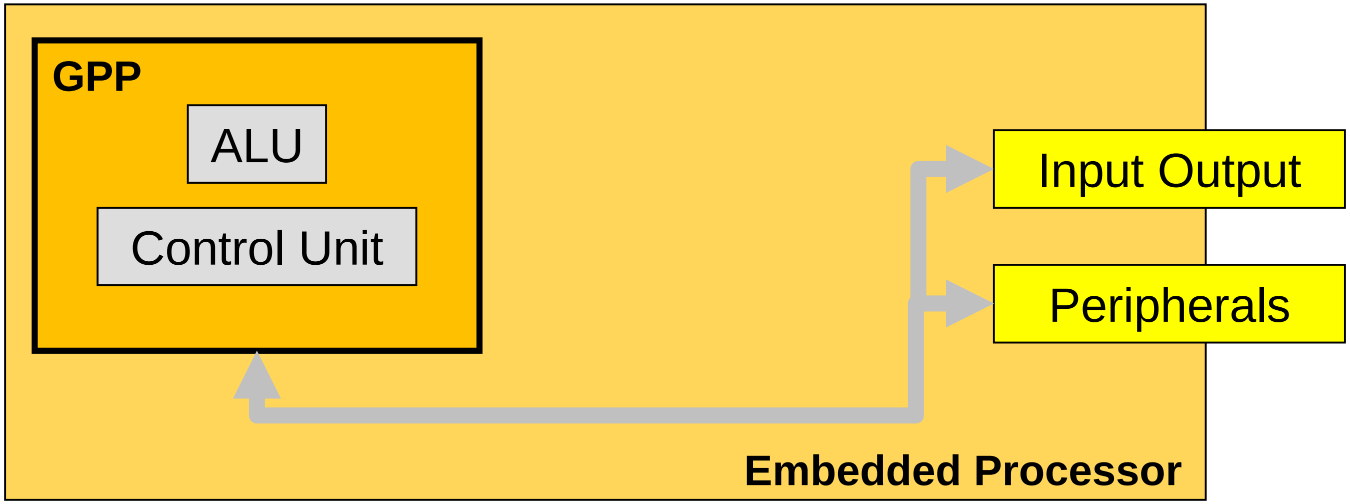
# Microcontrollers

- Architectural differences between GPP and MCU: a MCU is a GPP (low end category) with memory, I/O and converters, registers, serial interfaces, timers… on the same chip



# Special purpose processor

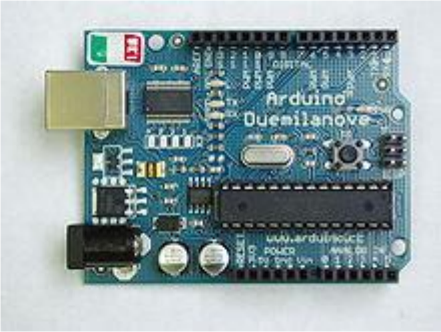
- Architectural differences between GPP and SPP: a SPP is a GPP with specialized functionalities for managing peripheral devices (or peripheral devices) on the same chip.



# MCU: Example

- ARDUINO is an MCU based platform (Atmel ATmega) :

| Arduino | Diecimila | Duemilanove | Uno | Mega | Mega2560 |
|---|---|---|---|---|---|
| Processor (Amtel) AVR | ATmega168 | ATmega328 | ATmega328 | ATmega1280 | ATmega2560 |
| KB Flash | 16 | 32 | 32 | 128 | 256 |
| KB EEPROM | 0.5 | 1 | 1 | 4 | 4 |
| KB SRAM | 1 | 2 | 2 | 8 | 8 |
| Digital I/O Pins (40 mA) | 14 | 14 | 14 | 54 | 54 |
| of which PWM output | 6 | 6 | 6 | 14 | 14 |
| Analog Input Pins | 6 | 6 | 6 | 16 | 16 |




- ATmega328:
  - 32KB self-programming Flash Program Memory, 2KB SRAM, 1KB EEPROM, 8 Channel 10-bit A/D-converter(TQFP/MLF).
  - Up to 20 MIPS throughput at 20 MHz. Operating Voltage: 1,8V - 5.5V
  - Some routine for basic operation on the Atmel site.
    - http://www.atmel.com/dyn/products/product_card.asp?PN=ATmega328

# GPP, MCU and SPP

- Special Purpose Processor vs. General Purpose Processor
  - SPP uses less energy and has lower performance
  - SPP cost less
  - SPP has integrated peripherals
    - PIO, SIO, Controllers, video, …
  - SPP is more *predictable*
- Special Purpose Processor vs. Microcontroller
  - SPP uses more energy, is more costly and has more performance with respect to MCU
  - SPP has more specialized integrated functionalities
    - Functionalities for a specific application class
      - LCD controller, PCMCIA, USB, Audio, IrDa, CAN, …
  - SPP has no internal RAM and/or EEPROM and has no analog digital interfaces

# GPP, MCU and SPP

- Example

| | Pentium 4 | PXA255 | MCS 8051 |
|---|---|---|---|
| **Freq max (MHz)** | ~3500+ | 400 | ~20 |
| **Cache L3-L2 (Kb)** | 512-1000 | no - 64 | no - no |
| **Bus (MHz)** | ~800+ | 600 | |
| **Data (bit)** | 32-64 | 32 | 8 |
| **Internal memory** | no | no | 128 bytes RAM 4 Kbytes EPROM |
| **Power (W)** | ~100 | 2,5 | 1,5 |

# GPP, MCU and SPP

- The difference between GPP and SPP consists mainly on the number and type of integrated functionalities
- An embedded processor (SPP) represents a tradeoff between the specialization of MCU and the microprocessor generality
  - The integrated functionalities represent a cost benefit in term of design time (e.g. PCB), component selection time, components…
- From general-purpose to application-specific
  - Microprocessor
  - Embedded processors
  - Microcontroller (MCU)

Increasing application specificity

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# Beacon Technology: an introduction


# What is Beacon?

- Beacons are **radio** hardware devices that **periodically emit signals** with data than can be **used to trigger a context-aware personalized behavior** of a mobile device application.
- Their basically **one-way communication**
- Beacons are
  - small (and usually deployed to be out of sight/reach, hidden, the characteristic of **ubiquitous computing** merging and fading out in reality)
  - low-cost
  - low-power (being battery-powered)

Short History
- Bluetooth wireless technology, 1994, Ericsson
- Nokia, Ericsson, Intel, IBM, Toshiba, formed Bluetooth Special Interest Group in 1998
- Nokia efforts in 2001 for a low-power short-range radio leading to Wibree standard
- Bluetooth Special Interest Group in 2007 with Wibree as starting point
- Bluetooth Low Energy Specifications released in June 2010.

# BLE

- Beacon radio relies on Bluetooth Low Energy protocol
  - BLE, Bluetooth 4.0 or Bluetooth Smart
    - Dual mode chips, supporting both Bluetooth standard and Bluetooth Smart are begin implemented in devices since 2010.
  - BLE enables very low-power battery-operated applications running for months/years.
- BLE operates in 2.4GHz
- BLE is designed to be implemented as an extension to the standard Bluetooth chips in mobile phone with the same radio and modified protocol stack.

# Beacon Features

http://www.gsma.com/digitalcommerce/wp-content/uploads/2013/10/A-guide-to-BLE-beacons-FINAL-18-Sept-14.pdf

- Battery life depends on
  - Tx Interval
  - Tx power (form  5 m to 100 m)
- Sensors
  - Beacons could have extra capabilities like inertial sensors, light or movement sensors

| Interval | Tx Power | Expected Range | Expected Battery Life * |
|---|---|---|---|
| 100ms | 3 (-12 dBm) | 35 m (115') | Up to 7 months |
| 300ms (default) | 3 (-12 dBm) | 35 m (115') | Up to 2 years |
| 1000ms or 1s | 3 (-12 dBm) | 35 m (115') | Up to 4 years |

| Strengths | Considerations |
|---|---|
| Beacons can be easy to install, as most don't need connectivity | Consumers' smartphones must have Bluetooth 4.0 or BLE to receive information from beacons |
| Beacons provide accurate proximity information, even indoors | The consumer smartphone operating system must support BLE |
| Beacon hardware is inexpensive | Bluetooth must often be enabled manually on the smartphone |
| Beacons can run on batteries for several months to several years, depending on the configuration | Apps must be beacon-enabled by the developer and security/set-up management |
| Beacons can be very small and discreet | Apps need to be designed to avoid excessive notifications |
| Some smartphones and tablets can be configured to act as beacons | If apps are badly coded, beacons could drain the handset battery |

# iBeacon packet

- Broadcast Info
  - UUID Universally Unique Identifier (128 bit)
    - owner/deployer of the beacon
      - E.g. f7826da6-4fa2-4e98-8024-bc5b71e0893e (5 groups – 8/4/4/4/12)
  - Major (16 bit - 2 byte int)
    - to identify and distinguish a group
  - Minor (16 bit 2 byte int)
    - to identify and distinguish an individual within a group
  - Power and Calibration Data
    - the output power and expected power at a pre-defined range

# iBeacon: an example

https://support.kontakt.io/hc/en-gb/articles/201620741-iBeacon-Parameters-UUID-Major-and-Minor

- Museum with 1000 iBeacons
  - **All 1000 beacons use the same UUID** which tells to the end-users that these beacons are owned by the Museum.
- This museum has 5 exhibitions running (5 groups), so the museum assigns a **Major value of 1 through 5 to identify beacons assigned to a particular exhibit.**
- Now let's say there are 200 paintings and sculptures within each exhibition. A **Minor value** is used and each beacon **is assigned a minor value of 1 through 200**.
- Note: *… you do not have to assign these values at all (although they are all required as part of the Apple's iBeacon standard). There may however be applications, where using only the UUID is a useful feature…*

# Applications

- **Tracking**: attaching beacons to goods.
- **Navigation**: using beacons to tell you where you are and where you're going.
- **Interaction**: using beacons to make automated reaction or to trigger events.
- **Security**: using beacons to identify safe/unsafe situation (e.g. to implement virtual-fencing).
- **Analysis**: beacons help generate data on where customers are going or where common problems occur on an assembly line.

# Comparison


http://www.gsma.com/digitalcommerce/wp-content/uploads/2013/10/A-guide-to-BLE-beacons-FINAL-18-Sept-14.pdf

# Ideas for Assistive Technology

- How can we use RFID/beacons as an assistive technology?
  - For the elderly, ambient assisted living…
  - For the disabled, mobility and navigation assistance…
  - For elderly with mild cognitive impairment (early Alzhiemer's)…

  - Present an idea for an assistive application and
  - motivate your choice of technology!

# RF and distances

- Friis Transmission Equation
  - $P_r=P_t*(G_T*G_R)*c^2/(4\pi Rf)^2$
    - $P_r$: Power received
    - $P_t$: Power transmitted
    - Gains: directivity and electrical efficiency of antennas
      - $G_T$ : transmitting antenna gain
      - $G_R$: receiving antenna gain
        - effective aperture of any antenna can be expressed by $A_{eR}=\lambda^2*G_R/(4\pi)$
    - f: frequency
    - c : speed of the light

# RF and distances: introduction

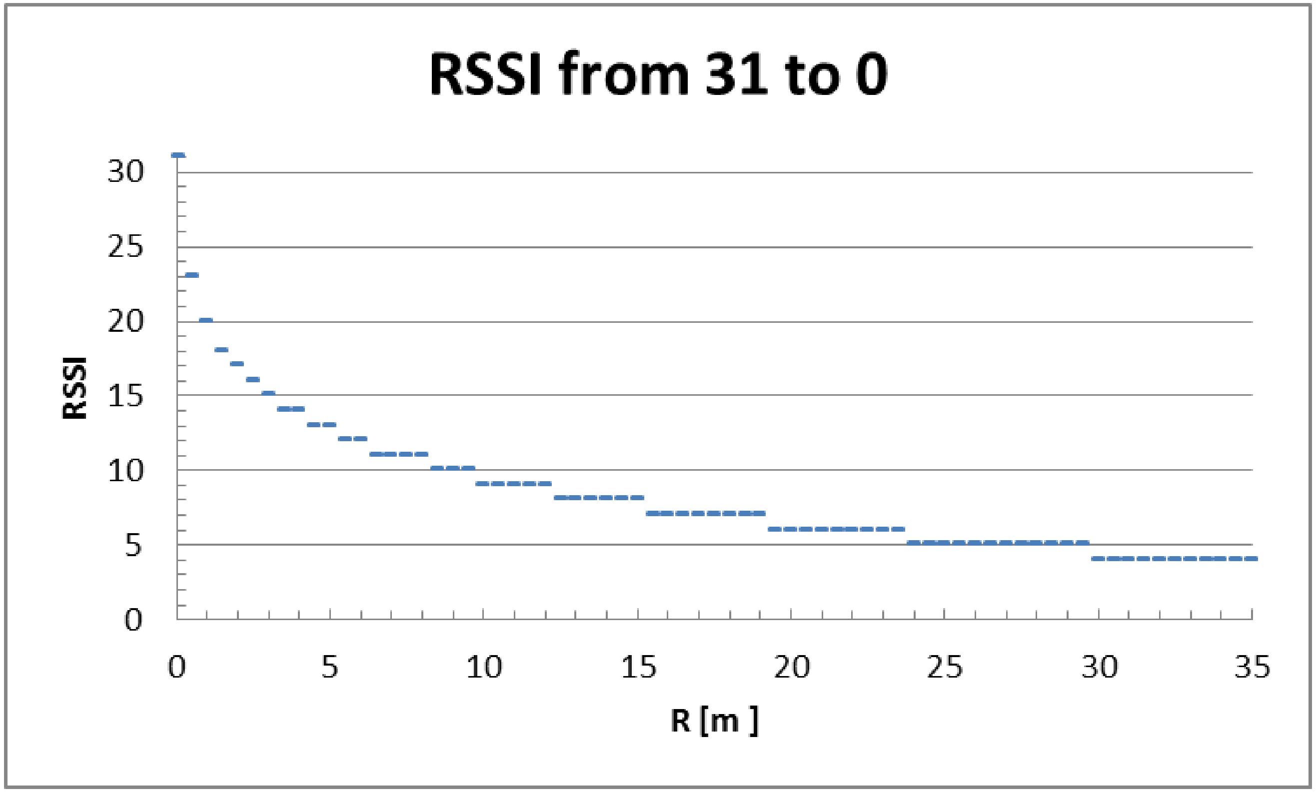
- Friis Transmission Equation (cont. )
  - At 2.4 GHz
  - $P_r=P_t*(G_T*G_R)*9,89*10^{-5}/R^2$
- Transformation in dBm
  - A power level of 0 dBm corresponds to a power of 1 milliwatt
  - $10 \log(P_r / 10^{-3}) = 10 \log ((P_t / 10^{-3})*(G_T*G_R)*9,89*10^{-5}/R^2)$ [dBm]
  - $10\log(P_{r\_mw}) = 10\log (mP_{t\_mw}) + 10 \log(G_T*G_R) - 40,045 - 20 \log(R)$
- RSSI: Received Signal Strength Indication
  - RSSI is the relative received signal strength (arbitrary unit)
    - In a positive form, the higher the value the stronger the signal
  - RSSI is an indication of the power level received

# RF and distances: introduction

- Cont.
  - $10\log(P_{r\_mw}) = 10\log(mP_{t\_mw}) + 10\log(G_T * G_R) – 40{,}045 – 20\log(R)$
  - 3 dBm <-> 2mW ; -12 dBm <-> 0,06 mw
- Calibration
  - At R=1m, its contribution is 0; in this way, the power transmitted in dBm (calibration) is $P_{t\_mw}$ [dBm] = $P_{r\_mw}$ [dBm] + 40 - 10 $\log(G_T * G_R)$
    - G=kD where $0 \leq k \leq 1$ and D is the directivity of the antenna
      - isotropic antenna radiates equally in all the directions (ideal antenna) D=1; this is the lowest possible directivity; All actual antennas have D greater than 1
    - $G_T * G_R$ depends on their relative coupling
      - +1 of - 10 $\log(G_T * G_R)$ means $G_T * G_R \cong 0{,}75$

# RF and distances: introduction

- Example



POLITECNICO MILANO 1863

# RFID Technology: an introduction

# Automatic Object Identification

## Barcode

- Low cost
- Broad Utilization
- Human Readable
- Integrated in printed material

- Data transfer requires line of sight
- Data storage is limited
- Environmentally sensitive

*http://blog.barcoding.com*

## Radio Frequency IDentification

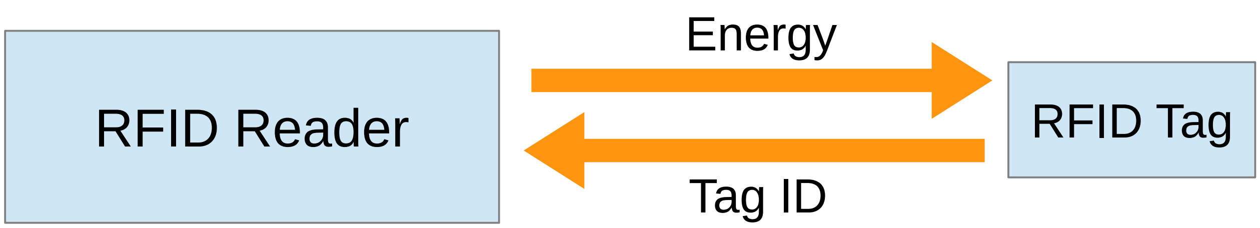

- No line of sight
- Large memory – data moves with product / asset
- Dynamic data reads

- Higher costs
- Read sensitive to product attributes (metal, H2O)
- Limited adoption

*http://www.iff.fraunhofer.de*

# What is RFID?

- A Contactless Automatic Identification Technology
- Wireless Communication Technology
  - working in Radio Frequency part of the electromagnetic spectrum
- Components
  - Tag
  - Reader

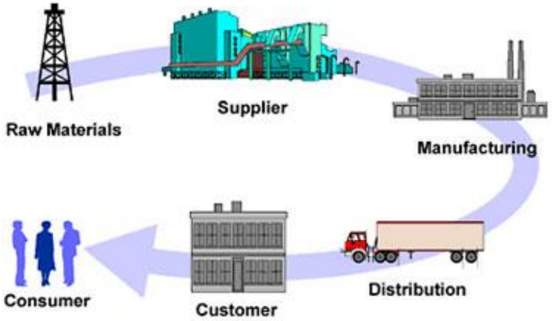


# RFID Applications

- Supply chain visibility
- Authenticity of the products (product security)
- Patient Identification in hospitals
- Moveable asset tracking
- Access control for people/vehicles
- Animal Identification
- Ticketing Systems

www.pdchealthcare.com

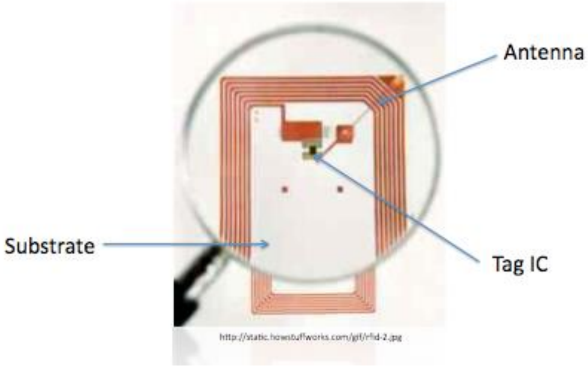
www.rfid-ready.de



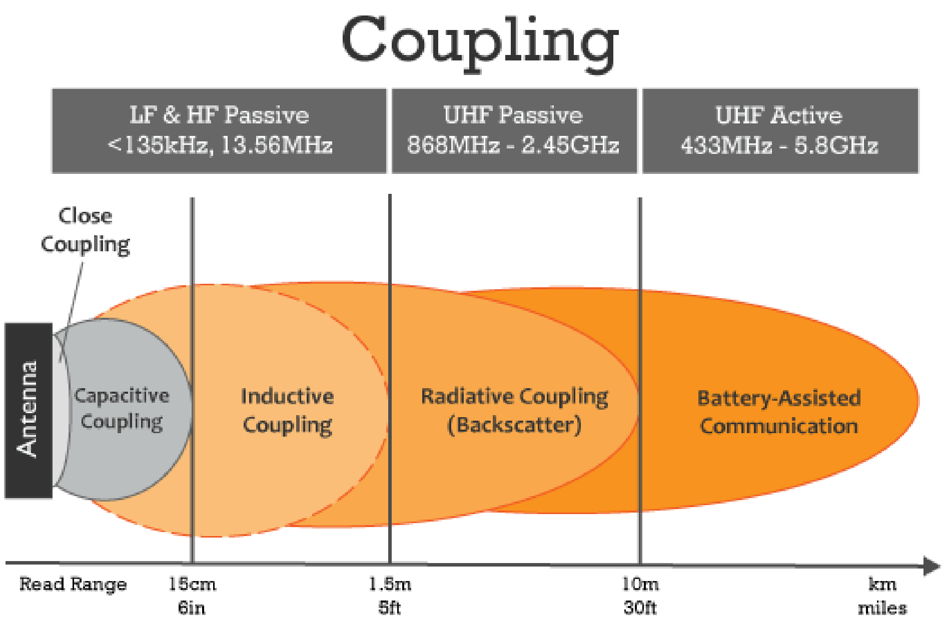

http://www.electronicseals.net

# RFID Tags

- Tag (or Transponder) is part of the RFID system which stores at least a unique ID which is transferred when interrogated by an RFID Reader.
- Types of RFID Tags
  - Active Tags: an active tag requires energy ( e.g. battery )
  - Passive Tags
- Anatomy of an RFID Tag (passive)
  - Antenna – two tasks:
    - receive energy from reader,  transfer tag ID
  - Semi-conductor Chip
  - Encapsulation protection, tag integrity, final packaging

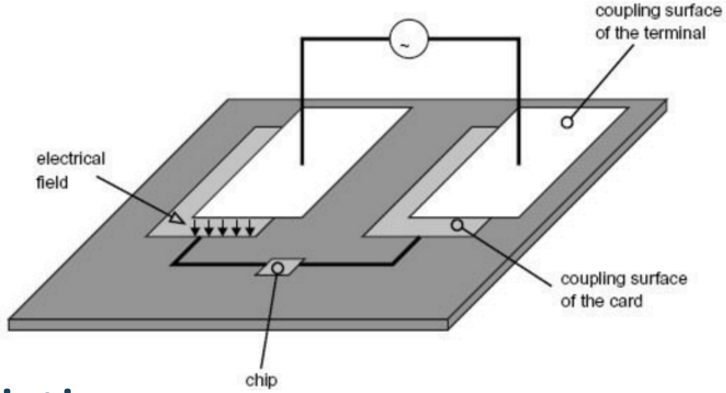


# RFID tags




- Close coupling: ~1 centimeter
  → capacitive and inductive coupling, freq, ≤ 30 MHz
- Remote coupling: up to 1 meter
  → inductive coupling, ~135 kHz, 13.56 Mhz, 27.12 MHz
- Long-range: more then 1 meter
  → backscatter: ~900 MHz, 2.4 GHz, 5.8 GHz

| Frequency | Read Range (Passive tag) [m] | Data transfer rate [Kbits/sec] | Environmental sensitivity (metal & water) | Directional |
|---|---|---|---|---|
| 125-134 kHz (LF) Induction | < 1 | 2 - 4 | Low | Not |
| 13.56 MHz (HF) Induction | < 1.5 | 10 - 20 | Limited | Hardly |
| 868 – 870 MHz 902 – 928 MHz (UHF) Backscatter | 2 – 4 | 20 – 150 | High | More |
| 2.45 GHz (UHF – µW) Backscatter | ± 1 | ➢ 100 | High | Very |




# Near-Field RFID

- Characteristics:
  - Based on capacitive coupling
    - system uses a capacitive effects to provide the coupling between the tag and the reader
    - RFID capacitive coupling operates best when items like smart cards are inserted into a reader; in this way the card is in very close proximity to the reader.
  - Standards: ISO 10536

# Near-Field RFID

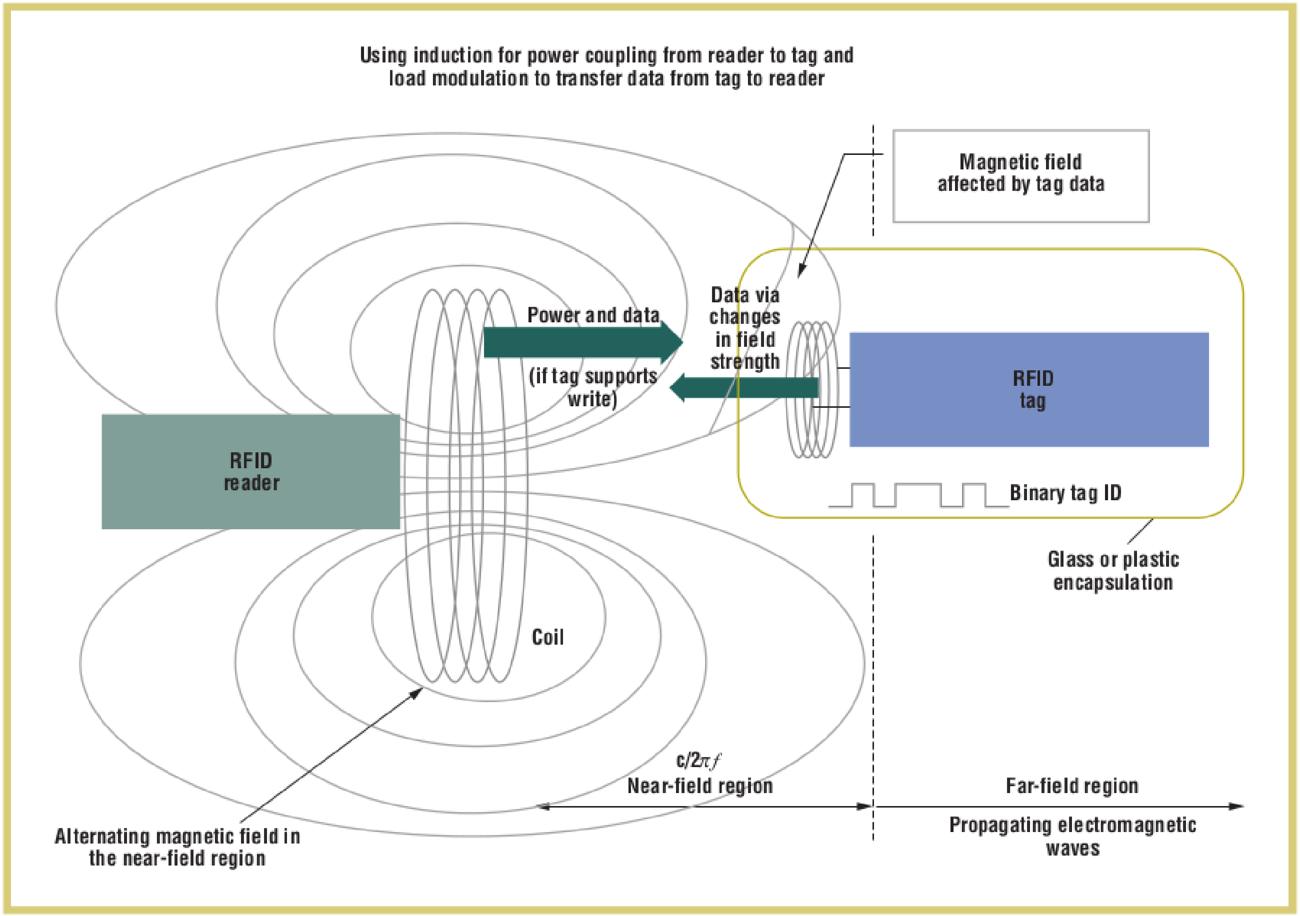



Figure 3. Near-field power/communication mechanism for RFID tags operating at less than 100 MHz.

# Far-Field RFID

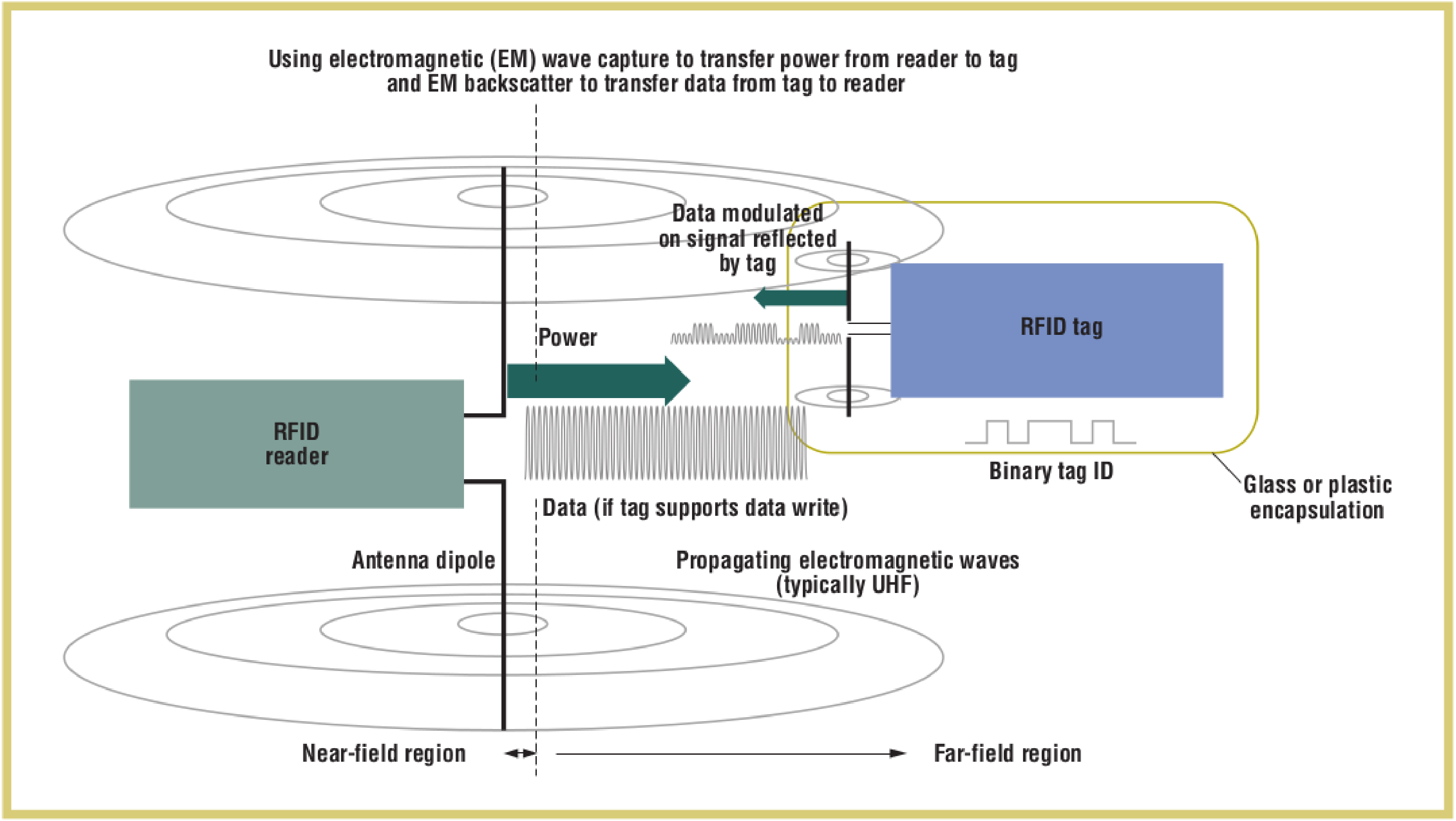
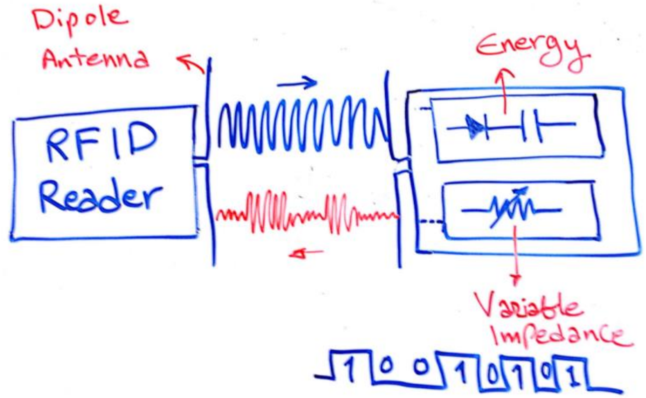


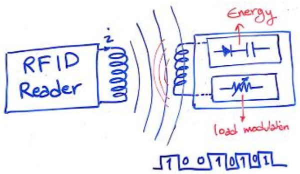

Figure 5. Far-field power/communication mechanism for RFID tags operating at greater than 100 MHz.

# Far-Field RFID

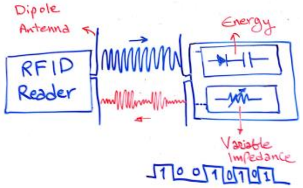



- Characteristics:
  - Based on electromagnetic
    - uses the RF power transmitter by the tag reader to energies the tag; they "reflect" back some of the power transmitted by the reader, but change some of the properties, and in this way send back information to the reader.
  - Frequencies more than 100 MHz (Microwave, e.g. UHF 2.45 GHz)
  - ID encoding through back scattering (reflection/impedance mismatch)
  - Typical range is 1,5 - 6 meters(for passive tags)
  - Range can reach to more than 100m for active tags
  - 96-bit tag

# Near-Field RFID

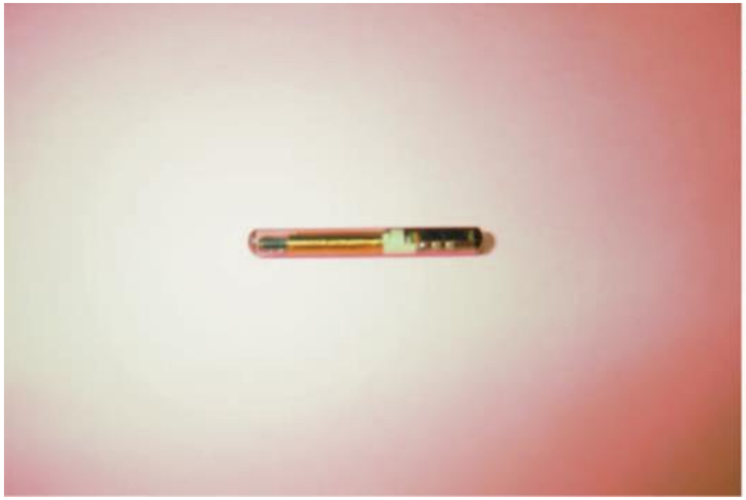
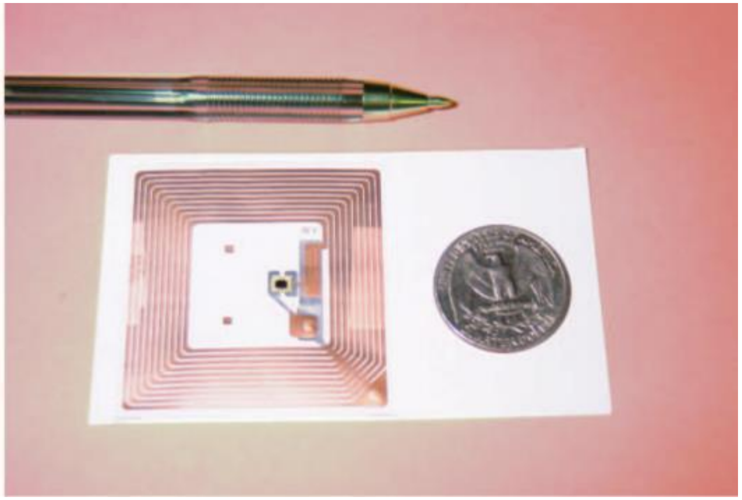
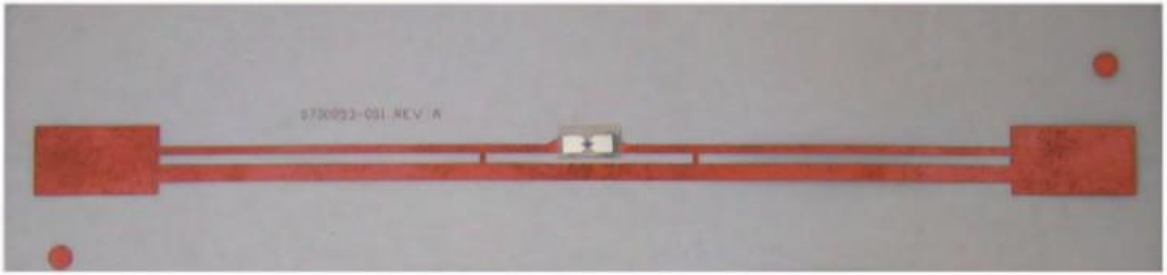



- Characteristics:
  - Inductive coupling
    - inductive coupling is the transfer of energy from one circuit to another via the mutual inductance between the two circuits
    - Frequencies less than 100 MHz
    - Typical range less than 1m




  - Electromagnetic
    - uses the RF power transmitter by the tag reader to energies the tag; they "reflect" back some of the power transmitted by the reader.
    - Frequencies more than 100 MHz (Microwave, e.g. UHF 2.45 GHz)
    - Typical range is 1,5 - 6 meters for passive tags

# Near-Field/Far-Field Tags


# Frequency/Range/Application

| Range and Coupling Technique | Frequency | Applications | Reading Range |
|---|---|---|---|
| Low Frequency (LF)<br>Inductive Coupling<br>**Near-Field** | 125 to 145 kHz | Animal Identification<br>Industrial Production<br>Automation<br>Vehicle Immobilizers<br>Access Control | A few centimeters up to 1 meter |
| High Frequency (HF)<br>Inductive Coupling<br>**Near-Field** | 13.56 MHz | Ticketing<br>Access Control<br>NFC Security Features Added<br>Government(ePassports)<br>Assest Tracking<br>Item-Level Tracking<br>Library Management<br>Pharmaceuticals | A few centimeters up to 1.7 meters |
| Ultra-High Frequency (UHF)<br>Backscatter Coupling<br>**Far-Field** | 890 to 960 MHz<br><br>2.45 GHz | Pallet Identification<br>Box Identification<br>Item-Level Tagging(Clothing)<br>Industrial Production Control | Up to 6 meters(passive)<br>More than 100 meters(active) |



*http://www.mouser.it/applications/rfid-gains-traction/*

# RFID Component Cost

Passive Tag < Active Tag < Reader

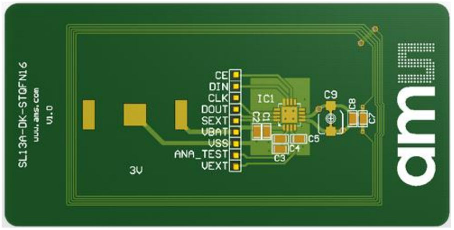
| cents | Tens of dollars | Hundreds of dollars |
|---|---|---|

**TI RI-I03-114A-01 RFID TRANSPONDER**

- ISO/IEC 15693-2, -3; ISO/IEC 18000-3 Compliant
- 13.56-MHz Operating Frequency
- 256-Bit User Memory in 8 blocks × 32-Bit
- Application Family Identifier (AFI)
- Fast Simultaneous Identification (Anti-Collision)

**Price for 50-99: £0.50***

*Price from farnell*




**Ams SL13a semi-active tag 13.56 MHz**

**Price: $4.61***

*Price from mouser*

**TI READER S251B LF: 134.2 KHz**

**Price: £577***

*Price from farnell*



** Prices on Nov 2014*

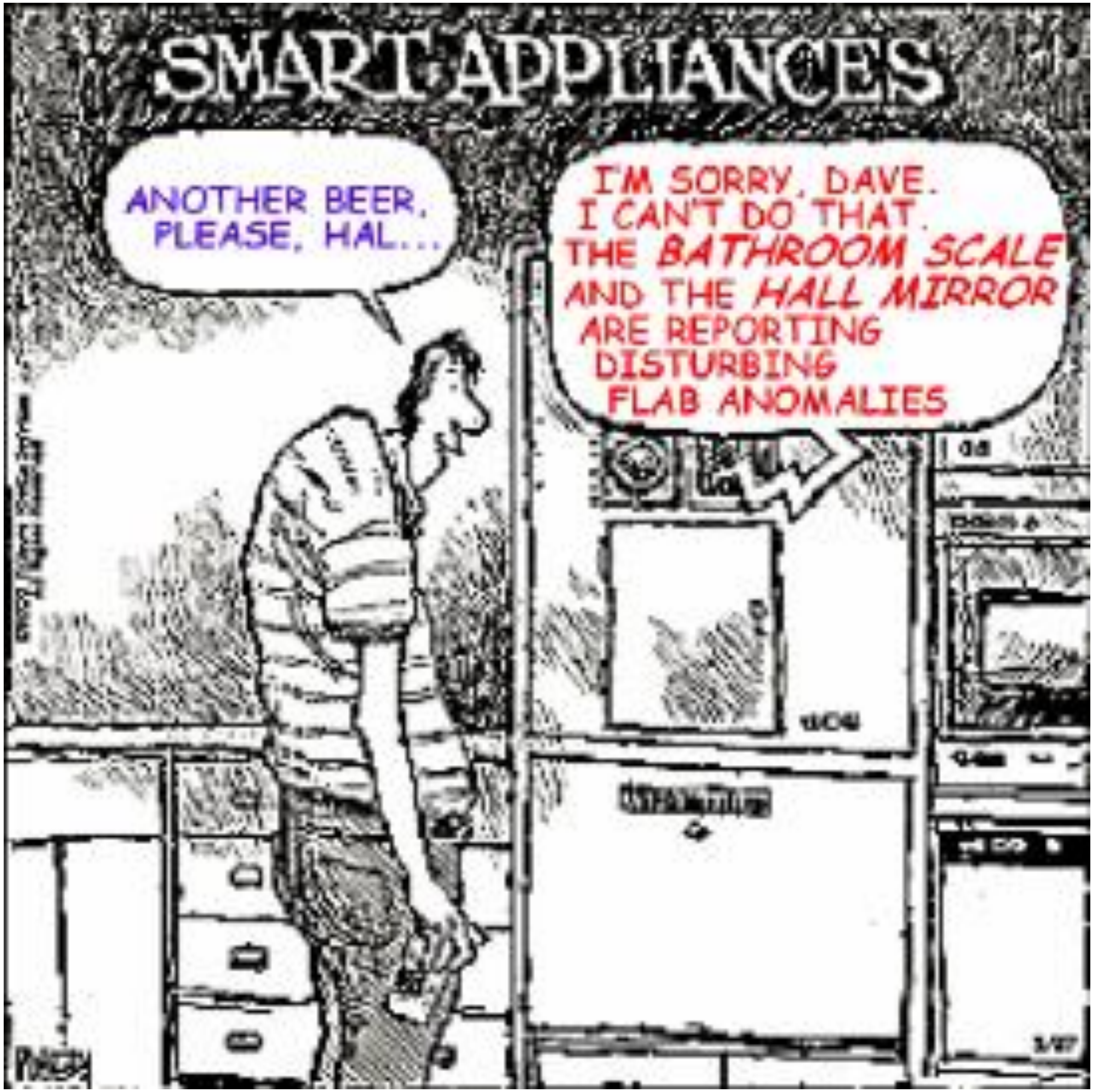
# RFID Selection Criteria

- Scenarios:
  - Frequency
    - 100KHz-20MHz - inductive coupling
      - better penetration of objects
      - Sensitive to electromagnetic fields (interference)
    - 2.45-5.8GHz - microwave systems
      - Higher range
      - Higher memory (up to 32KBytes)
      - Directional beam
  - Range
    - Positional accuracy of transponders
    - Minimum distance between transponders
    - Speed of transponder with respect to reader

# RFID Selection Criteria

Cont. Scenarios:

- Security
  - Encryption, authentication, risk assessment
- Memory
  - Chip size, price class
  - Memory type
    - EEPROM for inductive (16bytes - 8Kbyes)
    - SRAM battery microwave (256B - 64KBytes)


SMART APPLIANCES
ANOTHER BEER, PLEASE, HAL...
I'M SORRY, DAVE. I CAN'T DO THAT. THE BATHROOM SCALE AND THE HALL MIRROR ARE REPORTING DISTURBING FLAB ANOMALIES