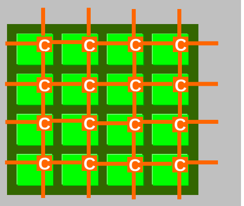
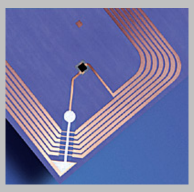
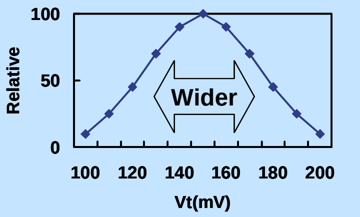

Research Focus

Semiconductor and Bus Lab

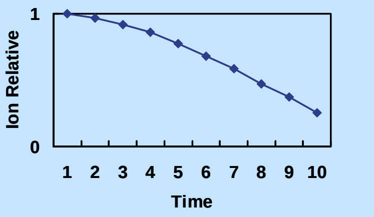
1. Embedded/ SoC Design – Autonomous Wireless Sensor Networks (WSN)
2. Energy Harvesting/ Scavenging
3. Resilient Computing – Consideration of device degradation effects at the design level





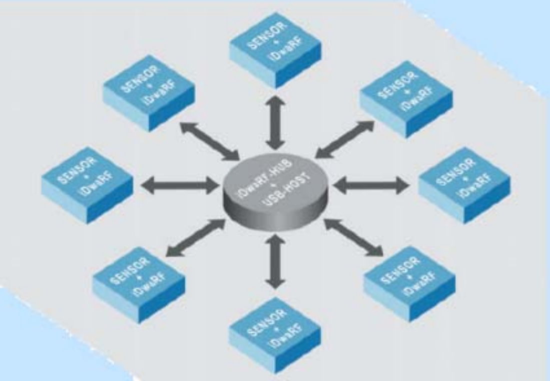


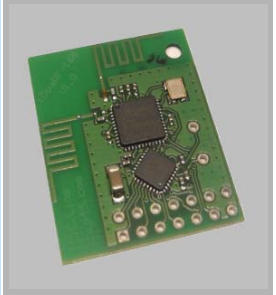
Extreme device variations



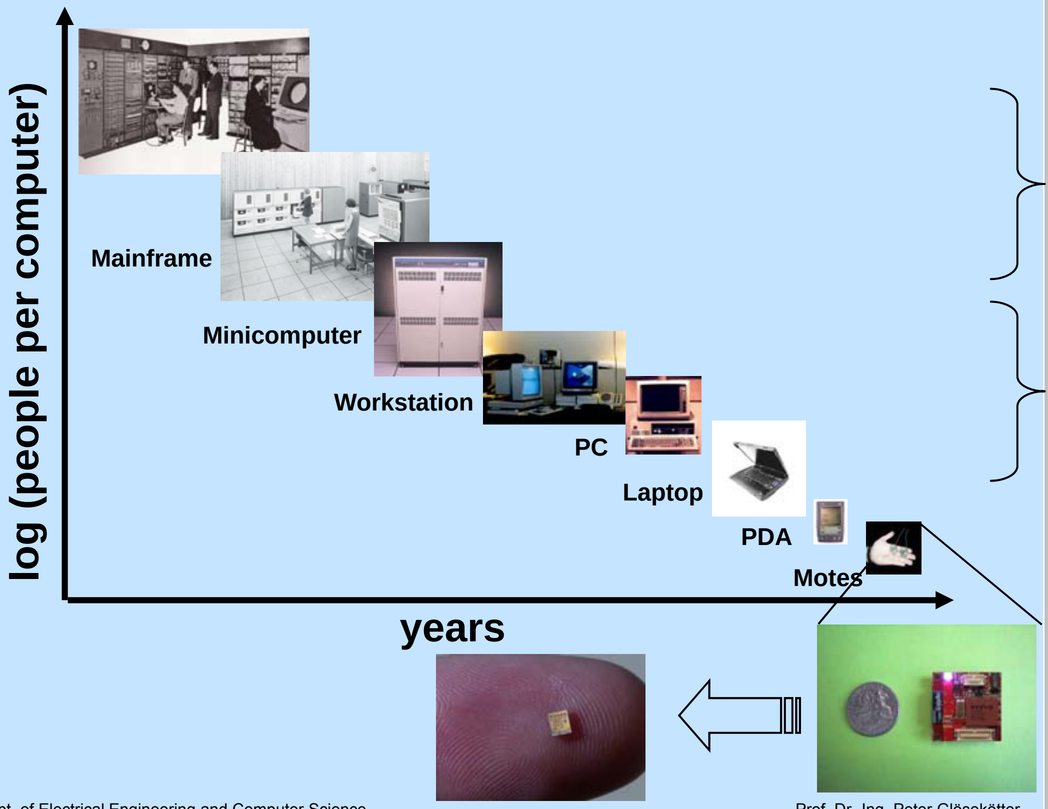
Time dependent device degradation

Wireless Sensor Networks WSN





Trends: A new class of computing (Moore's Law)



number crunching, data Storage

productivity interactive

streaming information from/to physical world

Examples of upcoming sensor network applications

- Environmental monitoring
  - Habitat monitoring
  - Precision agriculture
  - Heating Ventilation Air-Conditioning (HVAC) systems
  - Security, surveillance
- Structure and equipment monitoring
  - Structural dynamics
  - Condition-based maintenance
  - Emergency response
- Supply chain monitoring
  - Manufacturing flows, asset tracking
- Context aware computing
  - Information beacons


Home automation


Structure and earthquake monitoring


Process monitoring and control


Agriculture


Firefighting and rescue

Current Research Topic:

Power-Optimization of autonomous WSN

Consumption:	Cypress Radio	LDR	LED	CPU ATM-168	Regulator LP2989-3.3	LM75 Temp.
Active	91%	<1%	2%	4%	1%	<1%
Sleep	<1%	0%	0%	7%	90%	3%

Autonomous Power Supply Requires Optimization Of Sleep Mode!

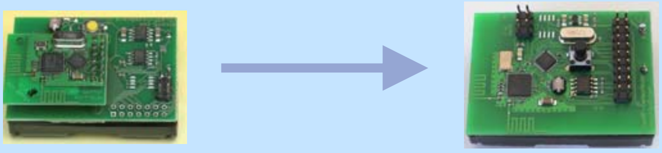
Power Consumption: Version A vs. B

Version A	Cypress Radio	LDR	LED	CPU ATM-168	Regulator LP2989-3.3	LM75 Temp.	Σ
Active	**58/ 69mA** 91%	**600μA** <1%	**1.4mA** 2%	**3.5mA** 4%	**1mA** 1%	**250μA** <1%	**75.8mA**
Sleep	**0.24μA** <1%	**0μA** 0%	**0μA** 0%	**8μA** 7%	**110μA** **90%**	**4μA** 3%	**122μA**

Version B	Cypress Radio	LDR	LED	CPU ATM-168	**Regulator** **TPS780**	LM75 Temp.	Σ
Active	**58/ 69mA** 91%	**600μA** <1%	**1.4mA** 2%	**3.5mA** 4%	**5μA** 1%	**250μA** <1%	**74.8mA**
Sleep	**0.24μA** 2%	**0μA** 0%	**0μA** 0%	**8μA** 64%	**0.5μA** **4%**	**4μA** 32%	**12.7μA**

Power Consumption: Version A vs. B

	Version A	**Version B**	**Reduction**
Active	**75.8mA**	**74.8mA**	**- 1.3 %**
Sleep	**122μA**	**12.7μA**	**- 89.6 %**



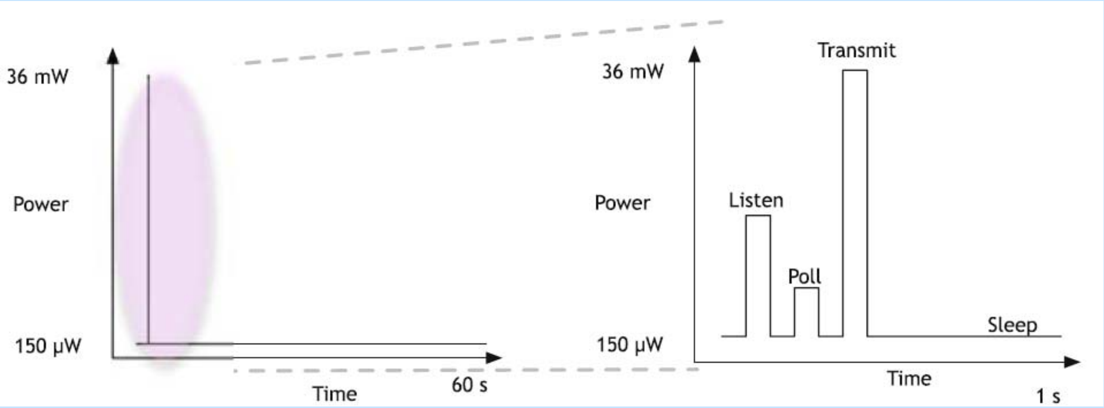
Power Demand Version B

- **3ms @ 4.5mA Exit from Sleep = 13.5µAs**
- **3ms @ 4.5mA Radio wake up = 13.5µAs**
- **4ms @ 59mA Receive/ Wait for Packet = 236µAs**
- **200µs + 128µs/byte @ 70mA Transmit mode**
  - **11-byte packets = 113µAs**
  - **17-byte packets = 166µAs**
- **→ Average charge per communication (17-byte packet): 13.5µAs + 13.5µAs + 236µAs + 166µAs = 429µAs**

Duty Cycle	10 trans/ s	1 trans/ s	0.3 trans/ s	0.1 trans/ s	2 trans/ min	1 trans/ min
AVG Current Active Sleep Sum	4.29mA 12.7µA 4.3mA	429µA 12.7µA 442µA	129µA 12.7µA 142µA	43µA 12.7µA 56µA	14µA 12.7µA 27µA	7µA 12.7µA 20µA
AVG Power ***Ver. A→B***	14.2mW ***-3%***	1.5mW ***-17%***	469µW ***-43%***	185µW ***-66%***	89µW ***-80%***	66µW ***-85%***

Power Sources for Wireless Sensor Networks

Power Trace for a Wireless Sensor Node



Batteries

Example:

- **Low-power node (sleep 80µW)**
- **Cycle of five to ten times an hour (overall average 100µW)**
- **Requires 876mWh during 1 year**
- **Lithium cell (open-circuit potential 3V) and capacity of 300mAh meets this goal (discounting self-discharge and the poor high-current pulse response)**
- **Battery weighs under 5 g, is roughly 5mm^3**

Besides costs:
1. Lifetime
2. Size
3. Environment

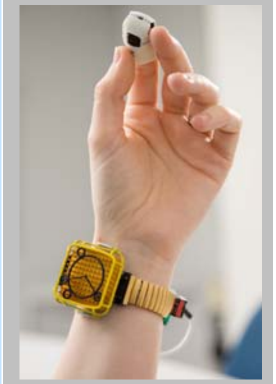
Battery Degradation

Difficult to generalize:

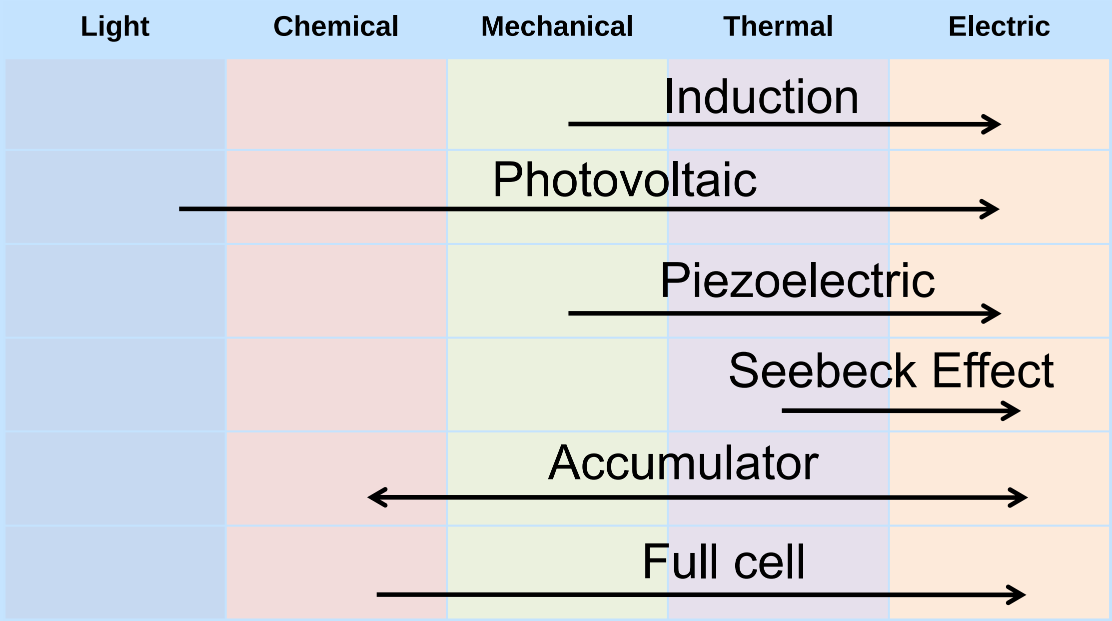
- **Lifetime and size usually balanced about the energy density of cell in short term (1–18 months)**
- **Beyond two years self-discharge of cell becomes complicating factor**
- **Environmental concerns are superimposed on top of calculation.**

Energy Harvesting

- **Industrial installations:**
  - **harsh environments**
  - **lifetime expectancies exceed 10 years**
- **Biomedical devices:**
  - **defibrillators and pacemakers that require routine invasive surgeries**
  - **simply to replace power source could be run “indefinitely” from a device that converted small fraction of the body’s 120W**
- **Environmental sensors for regulatory purposes:**
  - **the use of smart dust in forests**
  - **prevent forest fires and pollution**



Energy Conversion



Light **Chemical** **Mechanical** **Thermal** **Electric**

Induction

Photovoltaic

Piezoelectric

Seebeck Effect

Accumulator

Full cell

Energy Harvesting vs. Energy Scavenging

- **Energy scavenging refers to environments where the ambient sources are unknown or highly irregular,**
- **Energy harvesting refers to situations where the ambient energy sources are well characterized and regular.**

Photonic Methods

Power available for a variety of lighting conditions (Roundy et al. 2003)

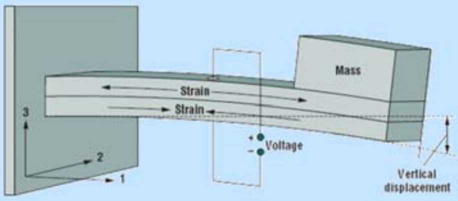
Condition	Power incident (mW/cm^2)
Mid-day, no clouds	100
Outdoors, overcast	5
1m from an incandescent bulb	10
1m from a low-energy light-bulb (compact fluorescent lamp (CFL))	1

Photonic Methods

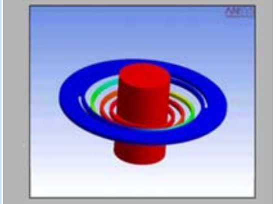
Photovoltaic technologies and reported maximum conversion efficiencies (Green et al. 2005)

Technology	Best reported efficiency (%)
a-Si	11
p-Si	18
SC-Si (single crystalline silicon)	25
Dye-sensitized (thin-film solar cell)	11
Organic	5
CdTe (Cadmium telluride)	15
CIGS (copper indium gallium selenide)	19
Multi-gap	35

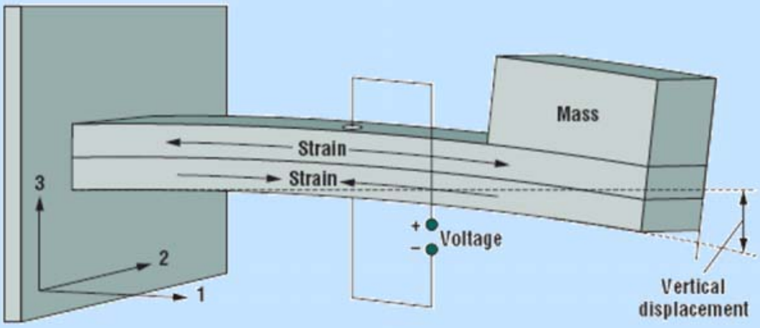
Vibrational Methods



- **Piezoelectric materials: mechanical strains across material layer generate surface charge, when oscillating load is placed on structure an AC power source results**
- **Inductive systems: magnet moving through wound coil induces current through coil**
- **Capacitive systems: charge on a capacitor is "pumped" by varying distance between plates of the capacitor, harvester always requires voltage source from which to pump**



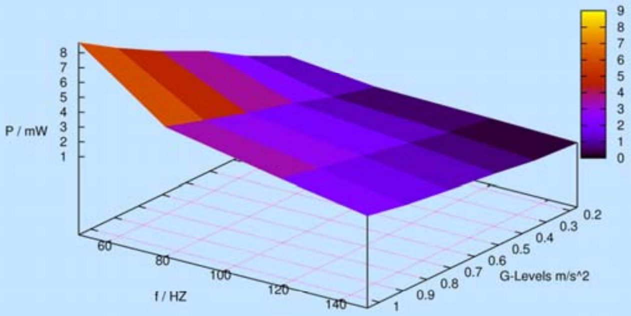
Vibrational Methods

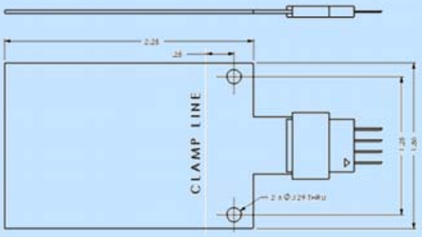


first-order approximation

$$P = \frac{m\zeta_e a^2}{4\omega\left(\zeta_e + \zeta_m\right)^2}$$

Piezoelectric Power Harvester





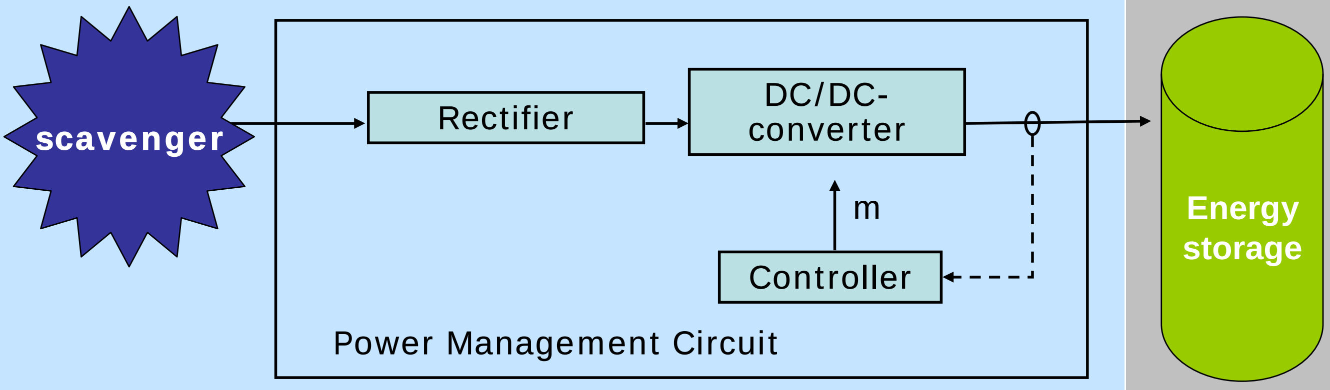
Midé Technology:
Volture Piezo Energy Harvester - v20w

Piezoelectric Power Harvester

Comparison of various vibrational-harvesting technologies

Technology	**Power**	**Conditions**	**Size**	**Source**
PZT	0.375mW	9.1g, 2.25m/s^2, 85 Hz	1cm^3	Roundy (2005)
Electromagnetic	3mW	50g, 0.5m/s^2, 50Hz	41.3cm^3	Beeby et al. (2007)
Capacitive	3.7µW	1.2mg, 10m/s^2, 800Hz	0.75cm^3	Mitcheson et al. (2003)

Power management – from scavenger to storage

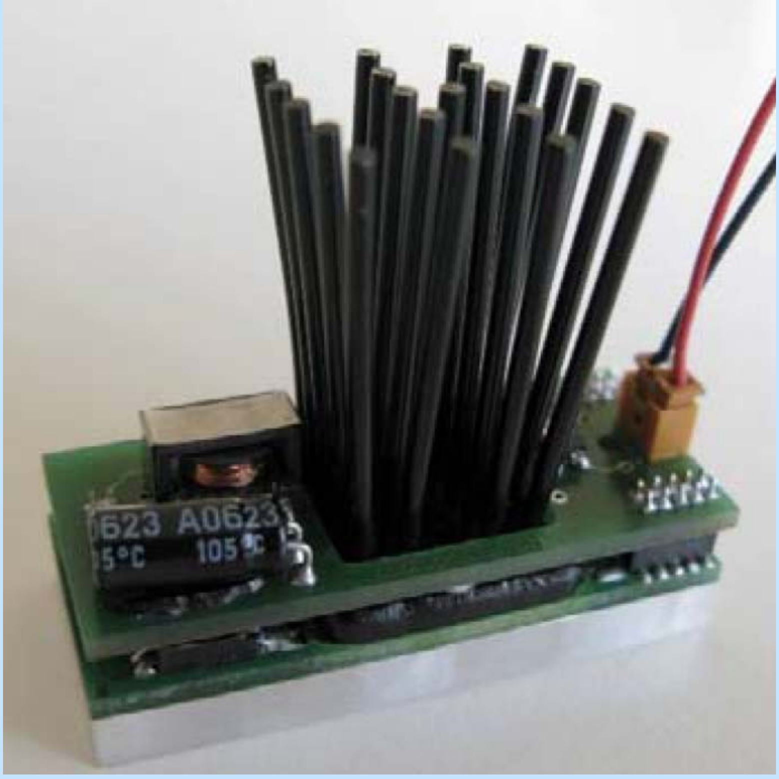


Thermal Methods

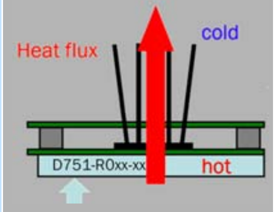
Performance of various thermoelectric systems

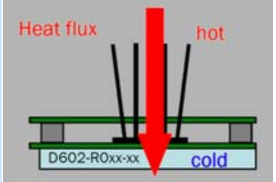
System	Power (mW)	Conditions	Source
Bismuth telluride (Bi_2Te_3)	60	20°C above RT, 16cm^2	Schneider et al. (2006)
Bismuth telluride (Bi_2Te_3)	0.67	5°C above RT, 1mm^2	Bottner et al. (2004)
Bismuth telluride (Bi_2Te_3)	45	5°C above RT, 287mm^2	Stordeur and Stark (1997)

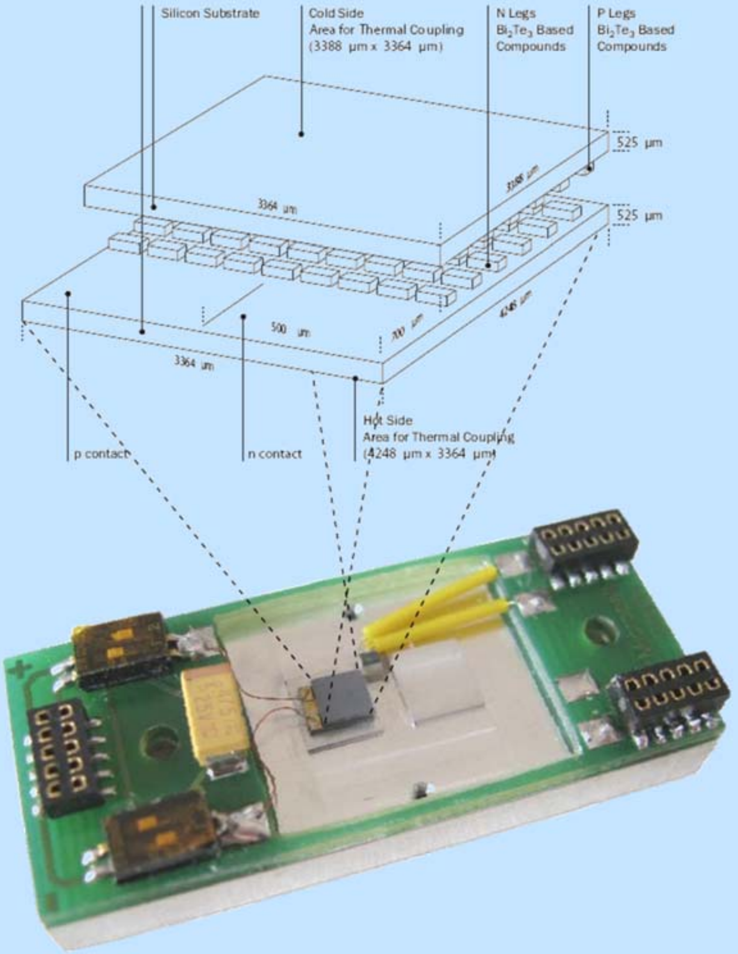
Thin Film Thermogenerator

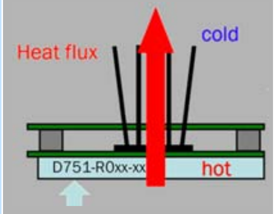


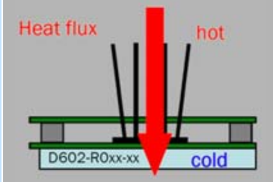
Micropelt: TE-Power-One











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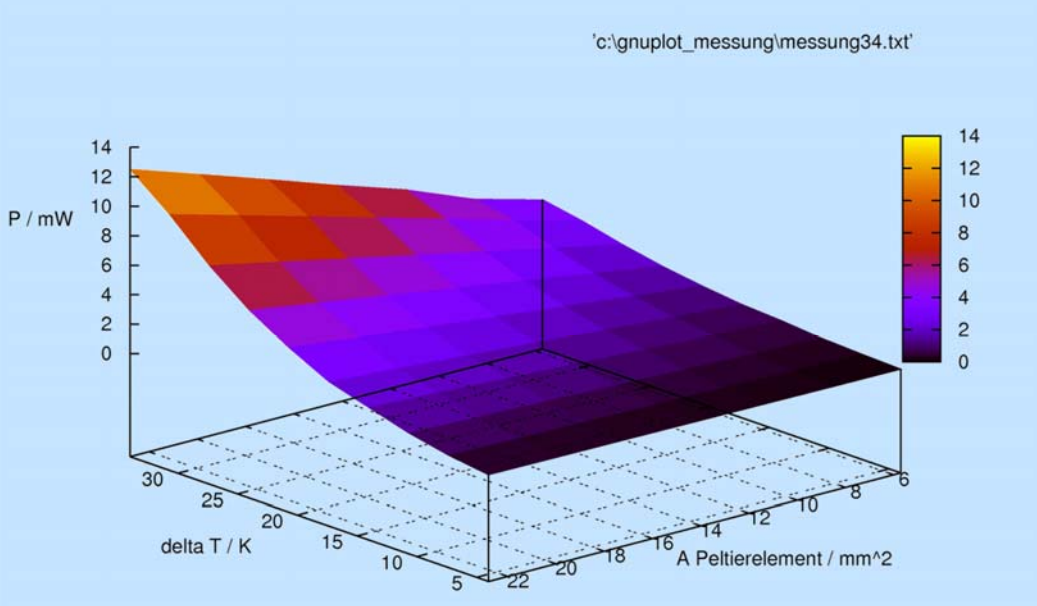
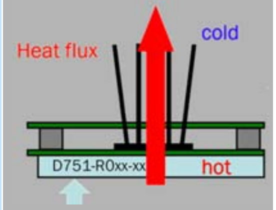
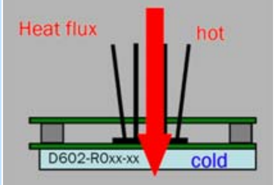
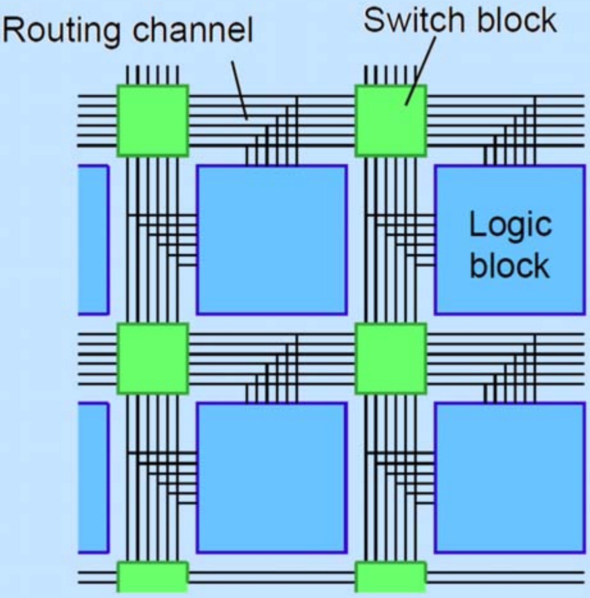


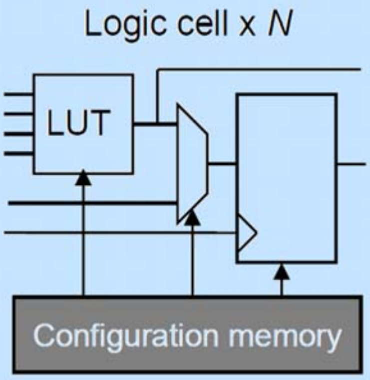




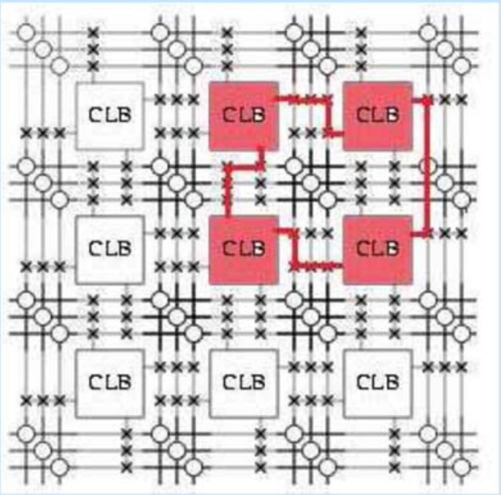
Video

Field Programmable Gate Array

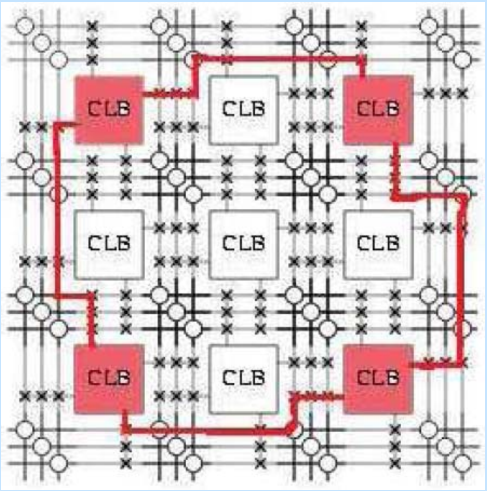




Variability-Aware Design

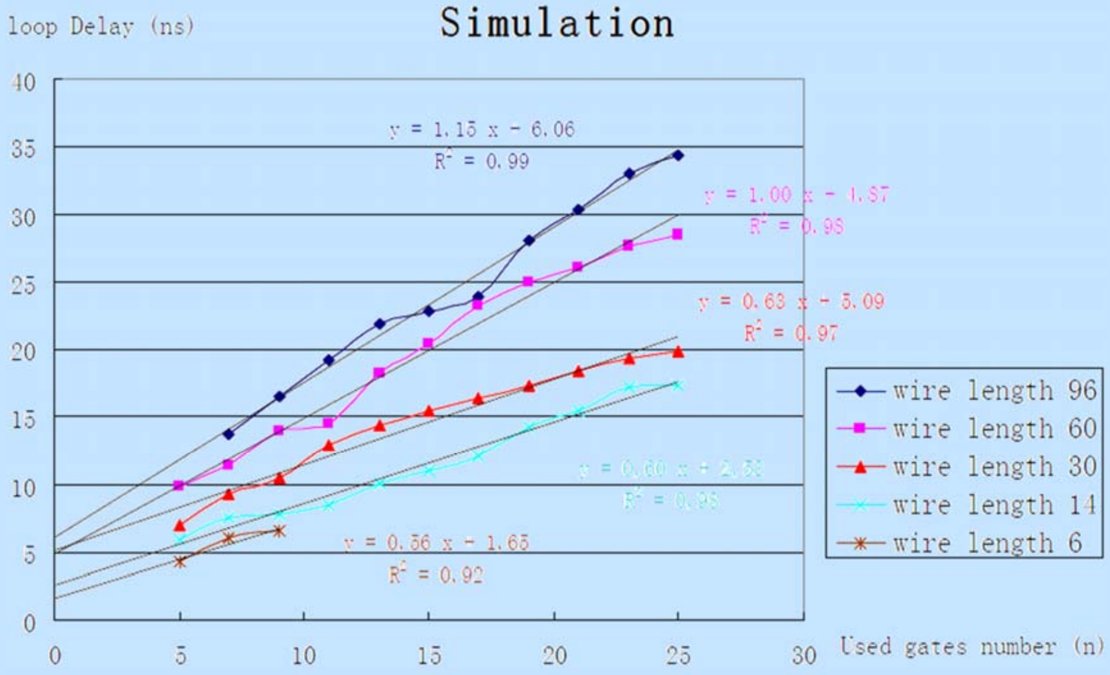


close structured circuit

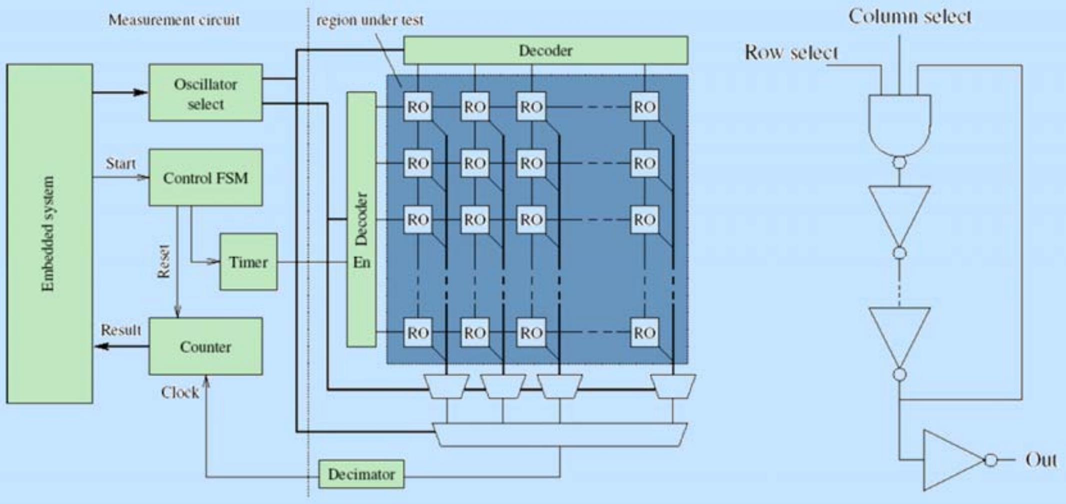


far structured circuit

Variability-Aware Design



How much Variability exist in FPGAs?



Variability-Aware Design

Next Steps:

- Variability studies using ring oscillator
- Impact of device aging (ring osc & comb. logic)
- How to deal with aging and variability? (reconfigurability ?, late binding?)