Energy harvesting in nuclear environments

A solution to power WSNs used for monitoring?

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Nuclear applications

A vision from comic books

Useful...
- Electricity production
- Medical examinations
- Food sterilization

...but hazardous
- For human beings
- For environments

→ monitoring

Source: Midam, Adam, Augustin, GAME OVER.
Outline

- Introduction: WSNs for monitoring nuclear environments
- Powering WSN’s nodes
- Design challenges and how to overcome them
- Discussion & conclusion
- References
Monitoring nuclear environments

What?

Location
- In-situ
- Neighborhood

Solutions
- Humans
- Remote

How?
The sensor node

Focus of this work

Wireless Sensor Node

PMU → MEAS → TX

$V_{EHR}$ $C_{ext}$

$T \degree C, H \%$, rad [Gy, Bq]...

Environment
Outline

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How to power the WSN’s nodes?

Available power sources

- Maintenance
- Harsh condition

- ENV
- Power density

Wires
- Maintenance

[Im07] [Im08] [Im09]
Energy harvesting (1)

Overview

**DC**
- $P_{out} = 1–100 \text{ mW/cm}^2$

**AC**
- $P_{out} = 0.01–10 \text{ mW/cm}^2$

**DC**
- $P_{out} = 0.01–100 \text{ mW/cm}^2$

**AC**
- $P_{out} = 1 \text{ n–100 } \mu\text{W/cm}^2$

Main references: [1]-[6]
## Energy harvesting (2)

### Application to nuclear environments

<table>
<thead>
<tr>
<th>Nuclear pool</th>
<th>Reactor’s neighborhood</th>
<th>Medicine</th>
<th>Space</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="Im11" alt="Image" /></td>
<td><img src="Im12" alt="Image" /></td>
<td><img src="Im13" alt="Image" /></td>
<td><img src="Im14" alt="Image" /></td>
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</tbody>
</table>

| Light | ✓ | ✓ | ? | ✓ |
| Heat | ✓ | ? | ? | ? |
| Vibrations | X | ✓ | ✓ | X |
| RF | ? | ✓ | ? | X |

→ No all-purpose solution...
From harvesting to use

Energy source

Power available
- Not electric (usually)
- Time-variant
- Low amount

Circuit (application)

Power demand
- Electrical power
- Continuous power supply
- Power cycles (sleep, idle, run)

How to accommodate application to source?

Strategy (protocol) ≡ power management

Power cycle: charge and discharge of an external capacitor [7]

Sensing + coding + TX

External capacitor voltage

Vmaximum

Vsupply

High threshold = 0.6 V

Low threshold = 0.5 V

Turn on

End of transmission

Time
Power management

Power Management Unit: functional block diagram

Legend

- Block
- Action
- Measure & Control

Harvester → Voltage multiplier → Storage → Voltage regulator

Controller

- Power-on
- Reset
- Power-down
- Protections (U, I, T)
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Design challenge #1

Withstand ionizing radiation

- Undesired effects
  - Example: ionization due to $\gamma$-rays

- Consequences on the circuit

Main references: [8]-[11]
Design challenge #2

Energy harvesting as unique source

- Ultra-Low Power (ULP), Ultra-Low Voltage (ULV) design
  - Example: power-down transistor

- Main issue: ionizing radiation $\rightarrow$ permanent leakage
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Existing WSN-based solutions

For nuclear environment monitoring

- **Academic**
  - WSNs for monitoring nuclear fuel dry-cask storage
    - Thermoelectric generator (heat)
    - Claim: 50 years of operation

- **Commercial**
  - “Wasp mote”, from Libelium
    - Solar panel (light)
    - 6600 mA h battery

Main references: [12]-[13]
Research to do?

Autonomous sensors in nuclear environment
→ Still a lot to do

- **Circuit-level**
  - Use radiation hardening techniques
    combined with ultra-low power/voltage techniques

- **System-level**
  - Strategy for power management
  - Data transmission protocols
Conclusion

Monitoring nuclear environments

- **Solution: Wireless Sensor Networks**
  - Solutions exist (academic, commercial)
  - Work in progress to make autonomous sensors

- **Use energy harvesting to power WSN’s nodes?**
  - Yes but strategy required (specific power management)
  - Design: withstand ionizing radiation & minimize power consumption
Thank you

HARVESTING

IS AWESOME

It’s questions time!
References
Literature (1)


Literature (2)


Images

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