Energy Harvesting with Thin-Film GaAs Solar Cells

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Why Solar for IoT Devices?

- **IoT Developer’s concerns:**
  - Sensors, Radio, Computer, and Data.
  - Then just use a battery and declare victory.

- **IoT Users’ concerns:**
  - Does it solve my functional need?
  - How much does it cost to maintain?

- **Why Solar energy?**
  - ...until recently, existing solar technologies have been too bulky, too rigid, or not power efficient enough to use in IoT devices.

- **High Performance Gallium Arsenide (GaAs) solar cells**
  - World record single junction power conversion efficiency 28.8%
  - Lightweight, flexible, thin-film GaAs solar cells are being produced today
Which Solar?
Lighting Environments
Gallium Arsenide (GaAs) Solar Technology

SOLAR FOR SENSORS
Which Solar?

Depends on the application

- **Organic**
  - Flexible
  - Moisture sensitive
  - Low cost (theory)
  - Low efficiency

- **a-Si**
  - Flexible
  - Low cost
  - Low efficiency

- **μc-Si**
  - Rigid
  - Cost competitive
  - Very common material

- **CIGS**
  - Flexible
  - Emerging thin-film technology
  - Moisture sensitive
  - Low cost (theory)

- **GaAs**
  - Thin-film technology
  - Flexible
  - World record efficiency
  - Higher cost (today)

- **CdTe**
  - Rigid
  - Established thin-film technology
  - Cost competitive

- **c-Si**
  - Rigid
  - Industry standard solar material

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Lighting Environments

Outdoor (Sun)

- Solar irradiance or “insolation”
  - 1 sun = 1000 W/m²
- Wide spectral distribution
  - 300-2500nm
  - Spectrum varies through day
- Varying angle (sun moves!)
- Varying intensity
  - sunny, clear 600 - 1000 W/m²
  - cloudy, fog 100 - 300 W/m²
- Varies around the globe and with the season

Indoor (artificial lighting)

- Typically measured in lux
  - Lux = lumens/m²
- Narrow spectral distribution
  - 400-700nm (visible light)
  - Depends on light source
- Typical values are
  - Office: 500-1000 lux
  - Warehouse: 200 lux
- 200 lux ≈ 0.06 mW/cm² (LED)
  - Roughly 0.1% of the power of the sun
- Usually constant but subject to “turning off the lights”!
Thin-Film GaAs Solar Cells

- **Highest Efficiency**
  - single junction cell: 28.8%
- **Highest power**
  - 26 mW/cm² outdoor in bright sun
  - 15 µW/cm² indoor in 200 lux
- **Lightweight and thin**
  - Cells are 110 µm thick and 1 W/g
- **Flexible**
- **Full sun to artificial and low light**
Solar Powered Beacon

In Very Low Light Environments

SMALL 5 CM² 100 µW GALLIUM ARSENIDE SOLAR CELL
EXTREMELY LOW POWER ENERGY HARVESTING
Extremely low power Energy Harvesting

- One example of an extremely low power energy harvester is the EM Microelectronics EM8500.
  - Designed to harvest sources as low as 3 microwatts.
  - Ideal for mating with a tiny solar cell to create an ultra low light energy harvester.
Beacons

- iBeacon is a commonly used protocol developed by Apple.
  - Bluetooth low energy broadcasted identifier and minimal data used to determine the Beacon’s physical location relative to the smart device (i.e., smart phone)
    - EM Microelectronics EMBC01 is an example of a BLE proximity Beacon
  - Extremely low power but is often used in remote locations where battery replacement is costly and causes down time.
  - Solar power can eliminate changing batteries in Beacons or other low power mobile/remote device.
Solar Powered Beacon

› Power density of GaAs solar cell harvests 100 µW in artificial light in a small area 5 cm²
› EM Microelectronic EMEVB8500 evaluation board
› EM Microelectronic EMBC01 Beacon

*Solar Beacon in a tiny package operates forever as long as there is a few hours of daily light*
Develop a Solar Powered IoT Device

HOW MUCH SOLAR?
COMMERCIALY AVAILABLE SENSORS, SUPERCAP, AND SOLAR CELL
OPTIMIZING POWER CONSUMPTION
PRODUCT DESIGN INTEGRATION
Develop a Solar Powered BLE Sensor

Architect the simple design

- Solar cell
- Energy harvesting IC
- Energy Storage
- Sensors and other electronics
How Much Solar?

1. Calculate the load’s average energy consumption in a 24 hour day in Watt-Hours
2. Divide by the battery efficiency (about 80%)
3. Divide by the energy harvesting electronics efficiency (about 80%)
4. Estimate the number of hours of light (i.e., how long the lights are turned on)
5. Divide solar energy needed by the lighted hours

1. Example 1 mW-Hrs.
2. 1 mW-Hrs / 80% = 1.25 mW-Hrs.
3. 1.25 mW-Hrs / 80% = 1.56 mW-Hrs.
Result is the solar energy needed in one day in W-Hrs.
4. Example 12 Hrs.
5. 1.56 mW-Hrs / 12 Hrs. = 130 µW
Result is the solar power needed

A single 10 cm² GaAs solar cell can harvest 130 µW in 100-200 Lux
Choose an Energy Harvesting Device

**Analog Devices**
- Analog Devices ADP5090 is an ultra-low power, boost dc-to-dc converter.
- The ADP5091 is a newer device with faster startup.

**Texas Instruments**
- BQ25504 ultralow power energy harvesters and charger
- BQ25505 for primary battery extension designs
- BQ25570 adds an integrated buck regulator.

**ST Microelectronics**
- The SPV1050 is an ultra-low power and high-efficiency energy harvester and battery charger.
- The SPV1040 is a low power, step-up converter with embedded Perturb and Observe MPPT algorithm.

**EM Microelectronics**
- EM8500 is an integrated power management solution for ultra-low power applications in the W to mW range.
Choose Some Sensor Electronics

› There are many commercially available BT-BLE Sensors
  • Environmental Sensors
    • myBlue temperature sensor
  • Texas Instruments Sensor Tag
    • Development kit with many sensors
    • CC2650 Microcontroller with built-in BLE

Or use your own microcontroller, radio, and sensors
Add More Sensors

• Texas Instruments **CC2650STK** Bluetooth BLE Sensor Tag Development Kit

• TI sensor tag include several sensors – although it is not optimized for low power
Optimizing Power Consumption

- **Troubleshooting**
  - If the supercap/battery is too small - needs to be fully charged before plugging in the sensor tag
  - The sensor tag default settings use too much power

- **Use the App to lower the power consumption**
  - Turn off unused sensors
  - Change BLE broadcast interval
  - Monitor power and optimize

- **Further optimize to reduce power by modifying the sensor tag firmware**
  - Use the TI *CC-DEVPACK-DEBUG* development and debug pack
  - Comes with Code Composer dev environment
Integrating Solar into Product Design

› Many mounting options
  • Product enclosure surface
  • PCB
  • Flex circuit

› Protection from elements
  • Lamination or encapsulation

› Flexible cell allows mounting on curved surfaces.
Takeaways

• For further information
  • Alta Devices Thin-Film GaAs Solar cells
    http://www.altadevices.com
  • Analog Devices energy harvesting
    http://www.analog.com
  • Texas Instruments Sensor Tag and energy harvesting
    http://www.ti.com
  • EM Microelectronics energy harvesting and Beacon
    http://www.emmicroelectronic.com
  • ST Microelectronics energy harvesting
    http://www.st.com/
Questions?

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