Solar Dice
CC430F5147 & TPS62740
Agenda

• Solar Dice demo:
  – Description
  – Setup and getting started

• Implementation: powering a low power wireless sensor
  – Requirements of powering low power wireless sensors based on the example of the “Solar Dice”
  – Solar cell characteristics
  – Selecting the storage capacitor
  – Requirements for the DC-DC converter
  – System bench data and scope plots

• CC430 energy optimized software tuning

• Conclusion and Summary
Energy Harvesting: Solar dice
Demo description

The demo demonstrates a wireless communication (CC430) between a dice and a computer powered by solar cells and step-down DC-DC converter (TPS62740)

– without any batteries!

The dice transmits wirelessly its position to a computer. Energy is harvested from 6 solar panels and the position is determined by an acceleration sensor.

- Transmission of dice position to the computer
- For voltage control, ADC10 application is running
- CC430 is running in low power mode
- Lowest current consumption is 2.36uA
- Transmission minimum cycle time is ~ 1s
- RF protocol is ~ 50 bytes
- PV voltage is ~ 4V
- Working with PV low leakage 330uF capacitor
- Optimized firmware for low current application
Energy Harvesting: Solar Dice
TPS62740 + CC430F5147

• DC-DC TPS62740 spec digest:
  – Super low quiescent current: 360nA
  – Slew Rate Controlled Load Switch
  – 16 Pin-selectable output voltages between 1.8V – 3.3V
  – Up to 90% Efficiency
  – Up to 300mA Output Current

• MCU CC430F5147 + RF core features digest:
  – RF frequency 868MHz/915MHz
  – Data rate 250 kBaud, Deviation 127kHz
  – Filter BW 541kHz, 36bit data, 16bit CRC
  – RF Protocol length 50Byte total, RF Power level -1dBm
  – Software optimized protocol to reduce current consumption

• Accelerometer and Solar Cell digest:
  – Thin film Solar Panel Type Sanyo AM-5610 4.7V
  – Digital, triaxial acceleration sensor BMA250 for cube side location
Solar powered dice
Simplified system block diagram

Energy Harvesting CC430F5147 Solar cube
Portable wireless sensor module UHF

Humidity Sensor → Acceleration Sensor → Temp Sensor

MCU → Enable → SPI → I2C

RF UHF Front End

ADC

868MHz

typ: 4.7V

C_BUF

VDD: 2.1V

Control

TPS62740
Step-down Converter
Vin: 2.0 to 15V

System Power

CC430F5147

TPS62740

Texas Instruments
Implementation: Powering a low power wireless sensor

Requirements for powering low power wireless sensors

- Reduce RF Peak Power consumption
- Minimize RF transmission time
- Minimize time of CC430 active mode
- Energy optimized MCU startup
Solar dice with CC430 and TPS62740

Energy source:
Amorphous solar panel (Sanyo)
Effective size 18.6 x 17.6 mm (3.27cm²); 4.7V no load

High efficiency step down converter:
- Ensures proper start up of CC430
- Provides regulated and optimized operating point for CC430
- Handles peak currents
Panel **can** deliver average power, but **can’t** handle peak power during TX!
Energy Storage Capacitor
Principle

Capacitor C1

- **Vmin** = 2.1V (system supply voltage)
- **Vmax** ≈ 3.6 – 4.5V panel voltage (maximum output power)

Usable voltage range:
- 2.6V
- 3.6V
- 4.5V

Non extractable energy

Energy in storage cap ~ V^2:
- Vmin = 2.1V (system supply voltage)
- Vmax ≈ 3.6 – 4.5V panel voltage (maximum output power)

TPS62740 DC/DC
Start up

Optimum solar panel operating area

0V
Energy Storage Capacitor
Calculating available energy

\[ dQ := C_1 \cdot dV \quad \quad dE := dQ \cdot V \]

\[ E := \int_{V_1}^{V_2} C_1 \cdot V \, dV \]

\[ E_{C1 \_total} := \frac{1}{2} C_1 \cdot V_{\text{max}}^2 \]

\[ E_{C1 \_usable} := \frac{1}{2} C_1 \cdot \left( V_{\text{max \_C1}}^2 - V_{\text{min \_C1}}^2 \right) \]

**Example:**
Usable energy in buffer capacitor:
300uF @ 4V \( \rightarrow \) 1900uWs

Energy in storage cap \( \sim V^2 \)
Vmin = 2.1V (system supply voltage)
Vmax \( \sim 3.6 \text{ – 4.5V panel voltage} \)
(maximum ouput power)
Requirements for the DC/DC Converter TPS62740

- Proper system start up:
  - system start up only if sufficient energy is stored in storage capacitor
  - Provide fast and monotonic supply voltage ramp up
- High efficiency at light loads
- Provides a stable and optimum operating voltage for the system
- RF friendly behavior (frequency, VOUT ripple)

Check out for more:
- [www.ti.com/dcs-control](http://www.ti.com/dcs-control)
Analysis: TX load profile

TX 17mA peak

2sec

Peak Power consumption @ 3.6V:
17mA * 3.6V = 51mW

Energy E(TX@ 3.6V VCC):
29uAs * 3.6V = 104uWs

Optimization @ 2.1V VCC:
Peak Power:
2.1V * 17mA = 36mW

Energy E (TX @ 2.1V VCC): 61uWs
η(DC/DC) ~ 90%: 68uWs
Getting the system started

Proper system start up:
- “Energy Optimized” SW coding
- SW optimized for available energy in buffer cap
- Fast + monotonic voltage ramp (DC/DC)
- Stable supply voltage for the system

Failing start up:
- Start up sequence too energy hungry
- Supply voltage breakdown
- Panel can not support energy
- Bigger buffer cap necessary → cost
Adaption to changing light conditions

Normal operation with sufficient light:
TX every 2 sec.

Panel provides more energy than needed

Less light $\Rightarrow$ reduced energy from panel

SW controlled TX cycle adaption:
- TX cycles are reduced at lower light conditions
- TX only if Voltage @ buffer cap reached 3.8V
- Operating solar panel @ maximum power area
CC430
Energy optimized software tuning

Standard firmware is most of the time not optimized for energy harvesting applications. For solar applications follow special programming rules!

1. On startup go immediately to LPM3 mode (Low power mode)
2. Optimize the startup. Partition the tasks. This allows enough charge storage in the buffer capacitor.
3. Time your cycle for RX or TX (1 s in this example)
4. Control the usable energy with ADC module
5. Make extensive use of low power modes
6. Start your tasks only if you have enough energy
7. Power down peripherals immediately after use
8. Optimize the RF protocol (Demo ~ 50bytes)

Check out for more:
➤ www.ti.com/cc430
Start

Setup timer & activate interrupt
Toggle time 1s

Config Vcore, Ports, Radio Core

Go to LPM3 mode

Delay 5s

Init Radio

Go to LPM3 mode

Enable ADC & Reference voltage

Measure PV / VCC voltage

Disable ADC & Reference voltage

Timer interrupt?

Usable energy sufficient?

Enable Accelerator & Measure

Disable Accelerator

Enable Radio & Transmit cube pos.

Power down Radio

End

End

Solar Dice
CC430 energy optimized software tuning
Conclusions

- Know the system requirements and possible trade offs
- Analyze the load profile and detect energy peaks
- Optimize system operating points to reduce peak energy consumption by Software and Hardware
- Select the right Harvester
- DC/DC converter provides proper system start up and operating voltage
- The less components the lower your power consumption

... and read datasheets carefully 😊

Summary

- In combination with Solar module and TPS62740, the CC430 works without batteries
- CC430 firmware optimized protocol to reduce current consumption is important

Check out for more:

- www.ti.com/product/tps62740
- www.ti.com/cc430
- www.ti.com/dcs-control
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