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)

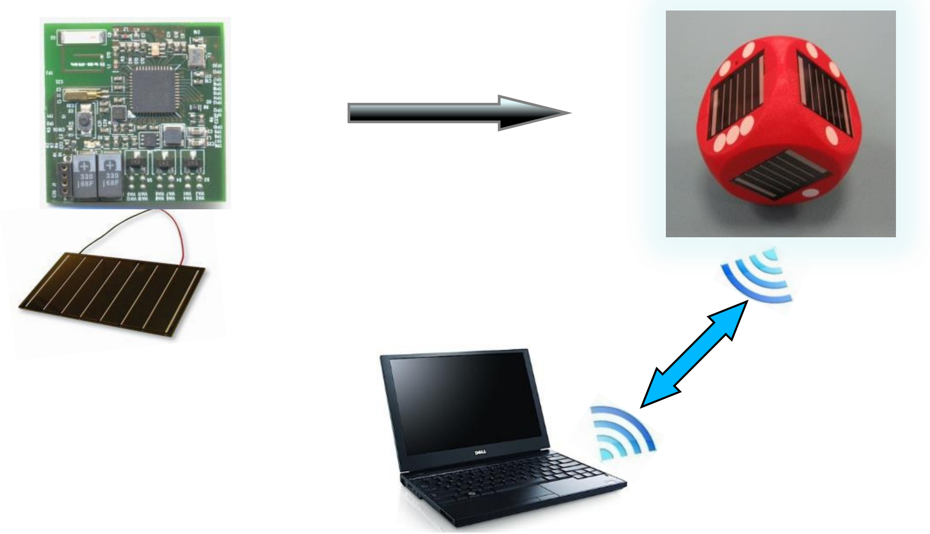
– without any batteries!

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

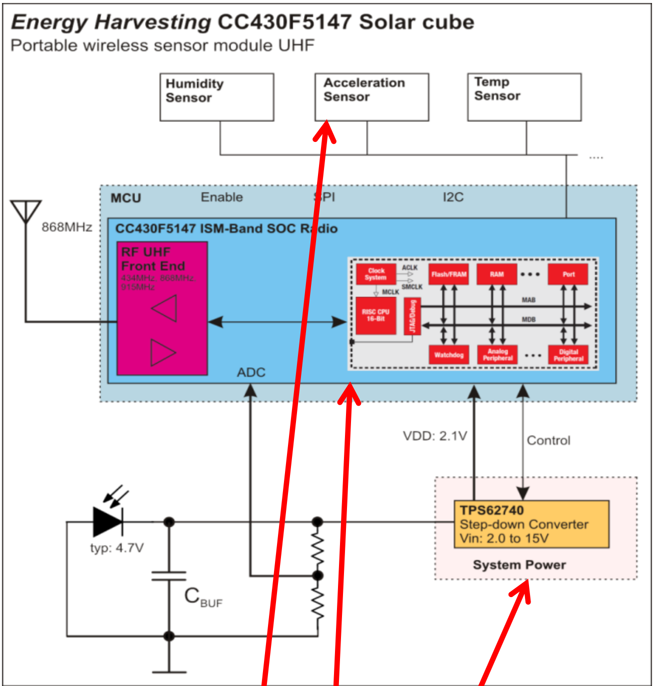
TPS62740 + CC430F5147



- **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

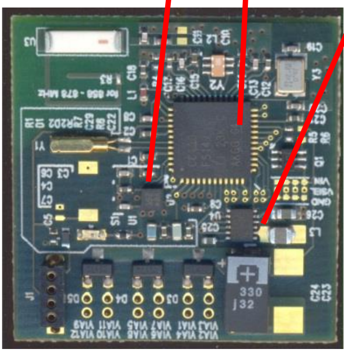
Solar powered dice

Simplified system block diagram



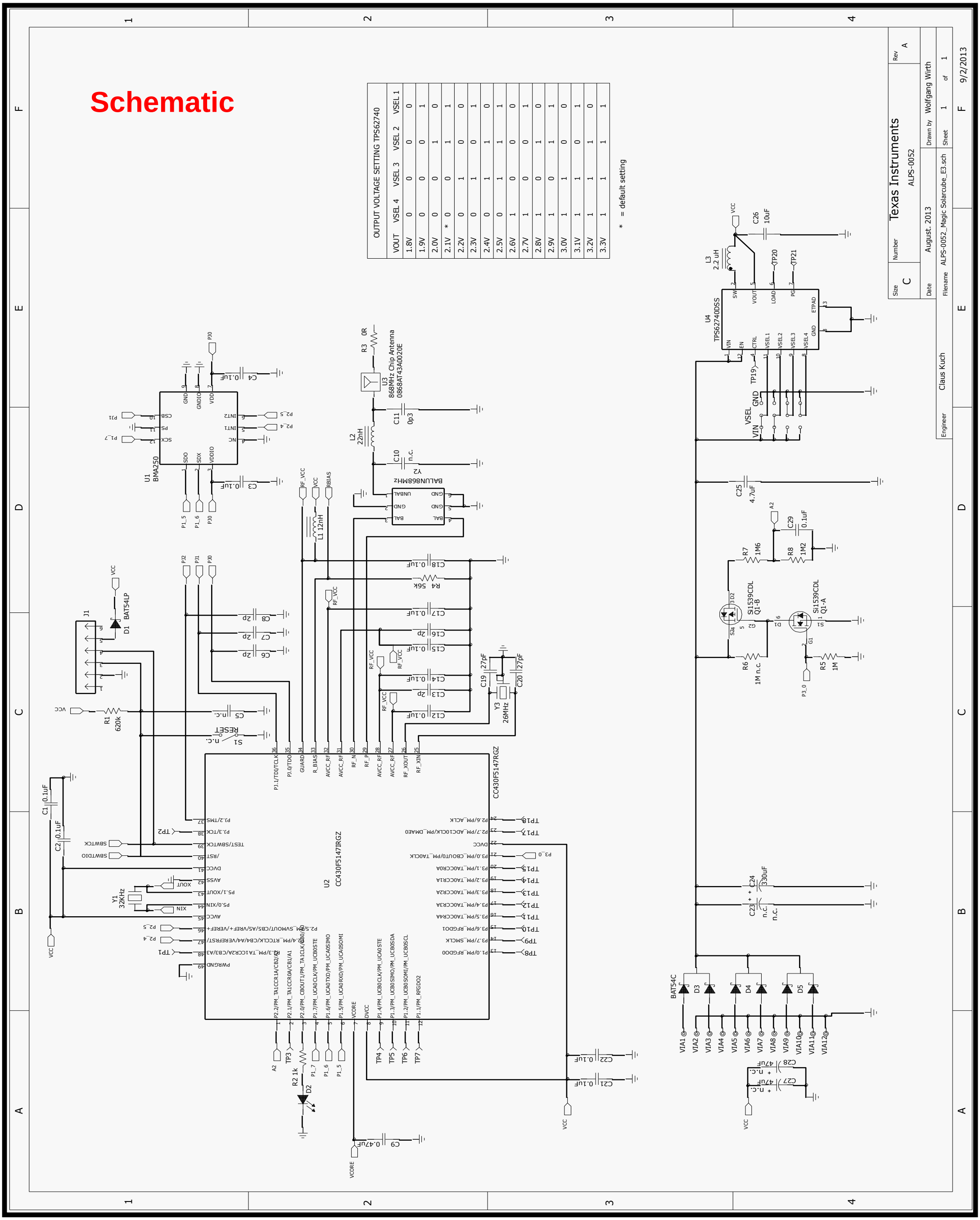
CC430F5147

TPS62740



Solar Dice Energy Harvesting CC430F5147 & TPS62740

Schematic



OUTPUT VOLTAGE SETTING TPS62740				
VOUT	VSEL 4	VSEL 3	VSEL 2	VSEL 1
1.8V	0	0	0	0
1.9V	0	0	0	1
2.0V	0	0	1	0
2.1V *	0	0	1	1
2.2V	0	1	0	0
2.3V	0	1	0	1
2.4V	0	1	1	0
2.5V	0	1	1	1
2.6V	1	0	0	0
2.7V	1	0	0	1
2.8V	1	0	1	0
2.9V	1	0	1	1
3.0V	1	1	0	0
3.1V	1	1	0	1
3.2V	1	1	1	0
3.3V	1	1	1	1

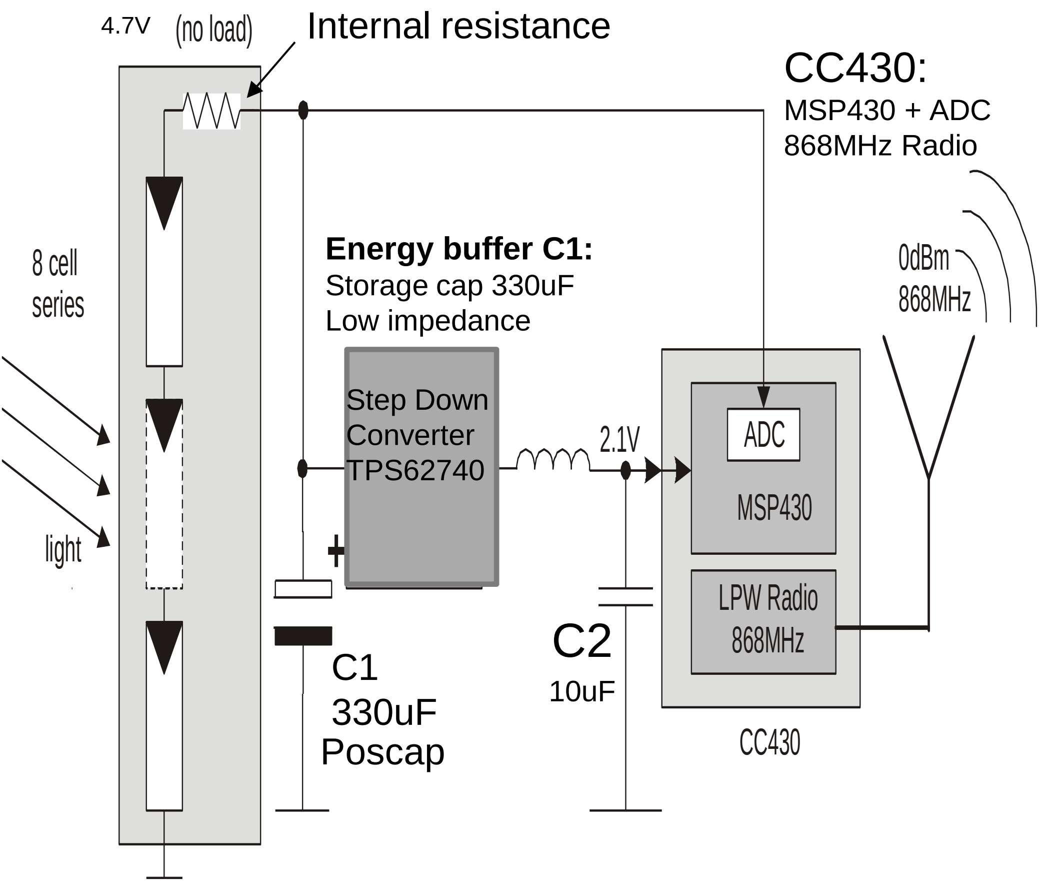
* = default setting

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

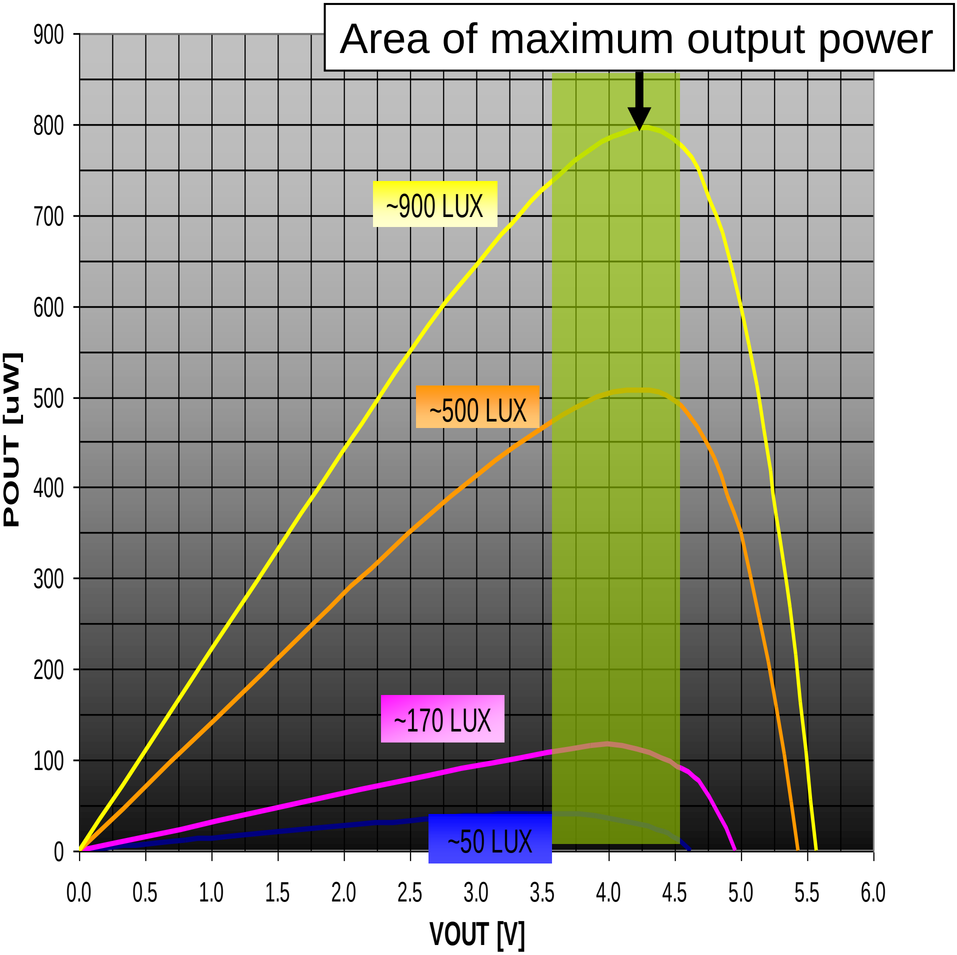


Energy source:
Amorphous solar panel (Sanyo)
Effective size 18.6 x 17.6 mm (3.27cm2); 4.7V no load

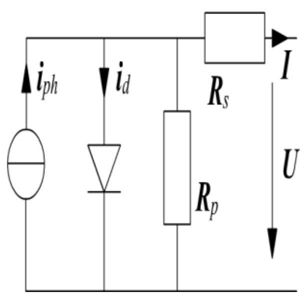
High efficiency step down converter:

- Ensures proper start up of CC430
- Provides regulated and optimized operating point for CC430
- Handles peak currents

Solar Panel characteristic

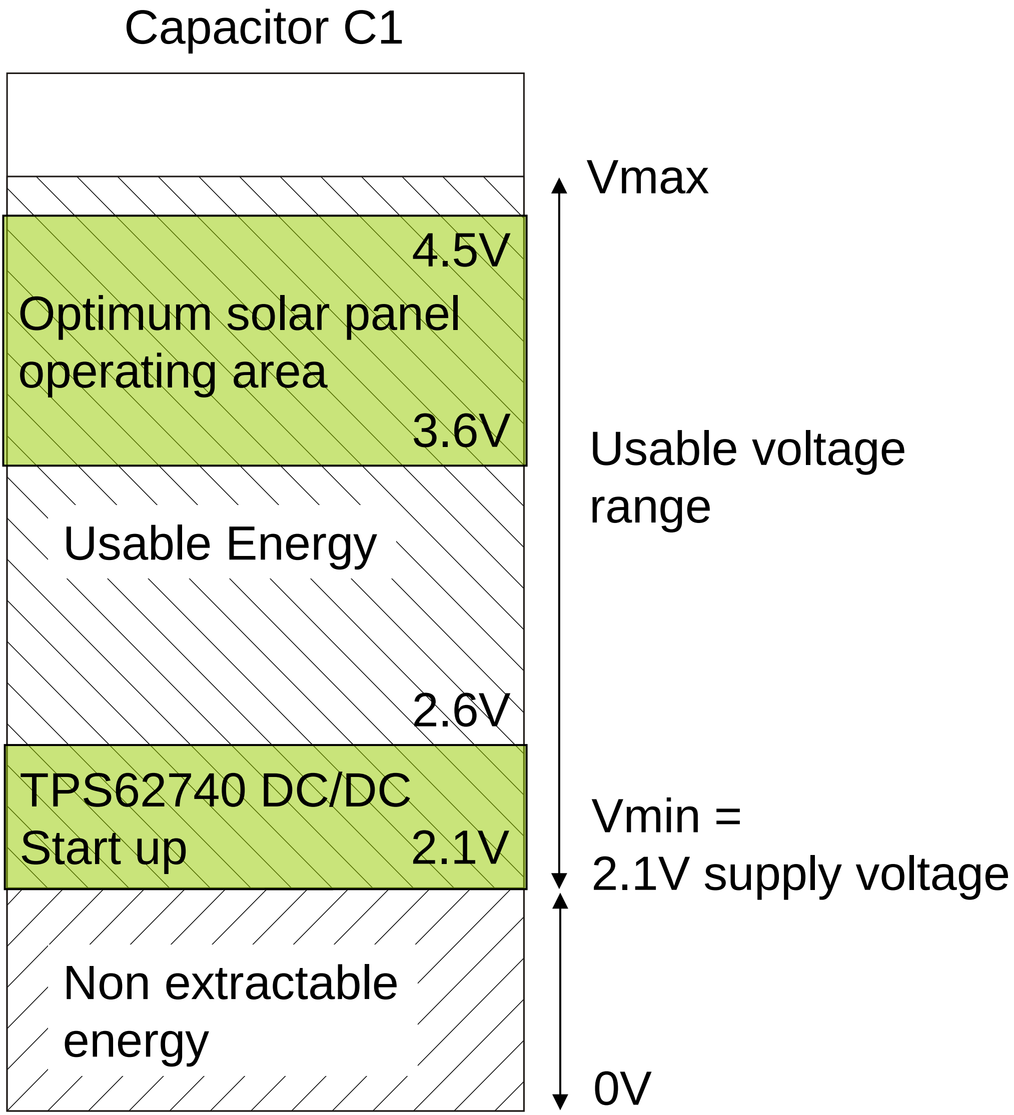


Panel **can** deliver average power, but **can't** handle peak power during TX!



Energy Storage Capacitor

Principle



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

Energy Storage Capacitor

Calculating available energy

$$dQ := C_1 \cdot dV \qquad dE := dQ \cdot V$$

$$E := \int_{V1}^{V2} C_1 \cdot V \, dV$$

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

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

Example:

Usuable energy in buffer capacitor:

300uF @ 4V ➔ 1900uWs

Energy in storage cap ~ V^2
Vmin = 2.1V (system supply voltage)
Vmax ~ 3.6 – 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)

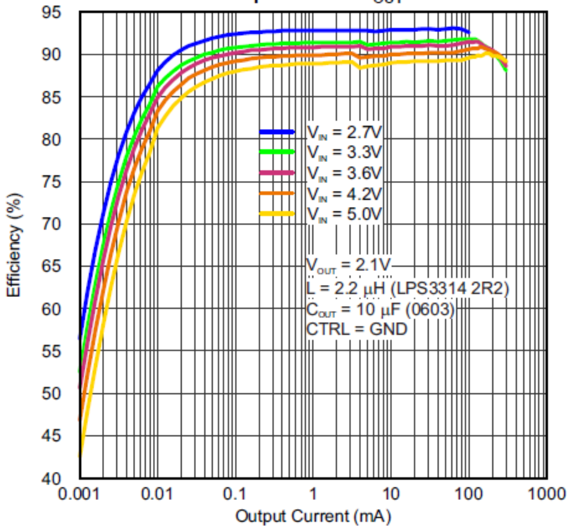
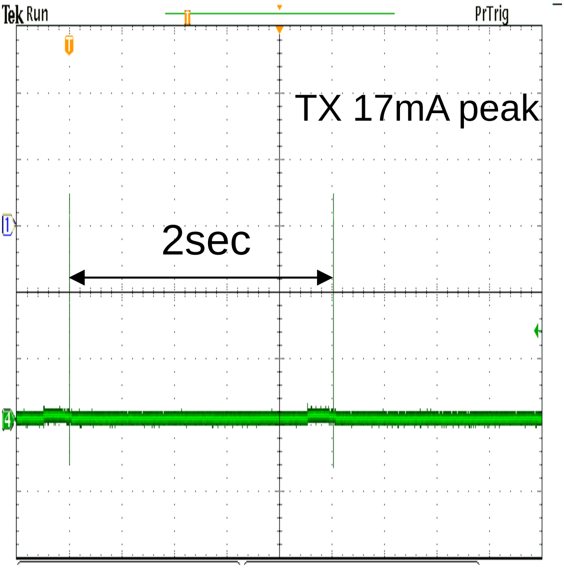


Figure 8. Efficiency V_{OUT} = 2.1V

Check out for more:

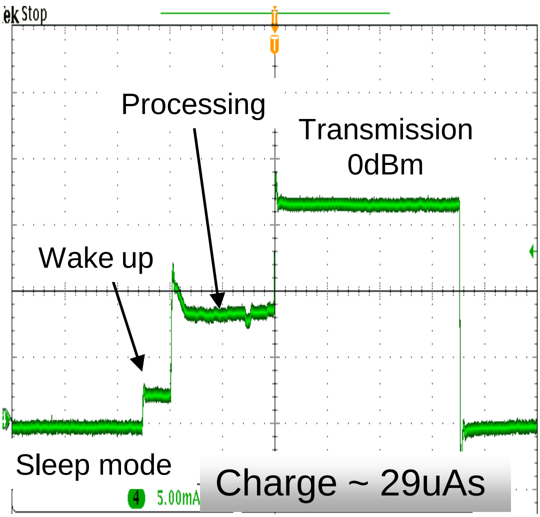
- www.ti.com/product/tps62740
- www.ti.com/dcs-control

Analysis: TX load profile



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

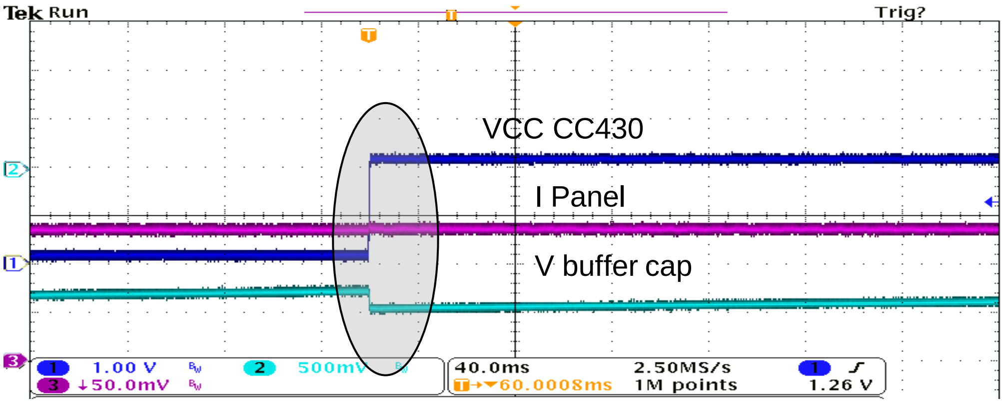
Energy E(TX@ 3.6V VCC):
29uAs * 3.6V = 104uWs



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

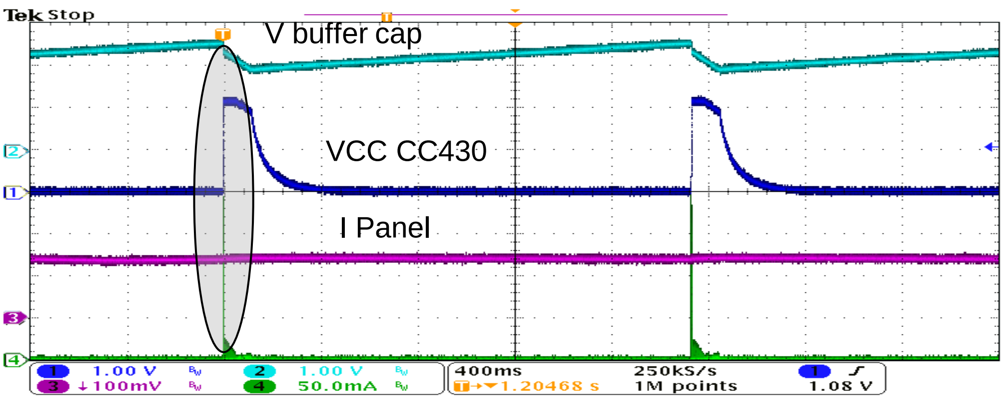
Energy E (TX @ 2.1V VCC): 61uWs
η(DC/DC) ~ 90%: 68uWs

Getting the system started



Proper system start up:

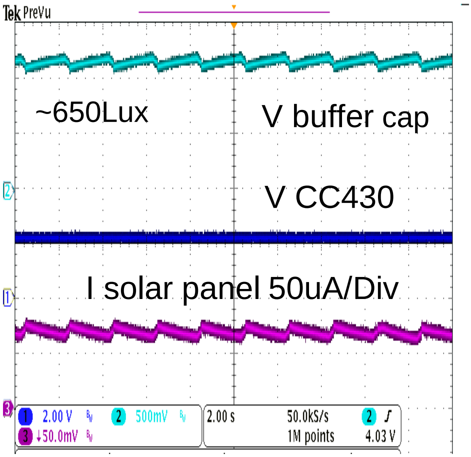
- "Energy Optimized" SW coding
- SW optimized for available energy in buffer cap
- Fast + monotonic voltage ramp (DC/DC)
- Stable supply voltage for the system



Failing start up:

- Start up sequence too energy hungry
- Supply voltage breakdown
- Panel can not support energy
- Bigger buffer cap necessary → cost

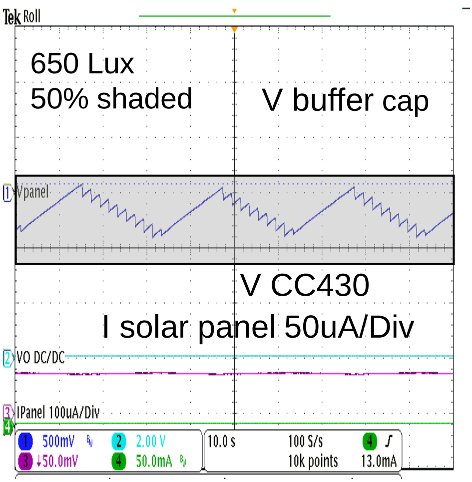
Adaption to changing light conditions



Normal operation with sufficient light:
TX every 2 sec.

Panel provides more energy than needed

Less light ➔ 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!

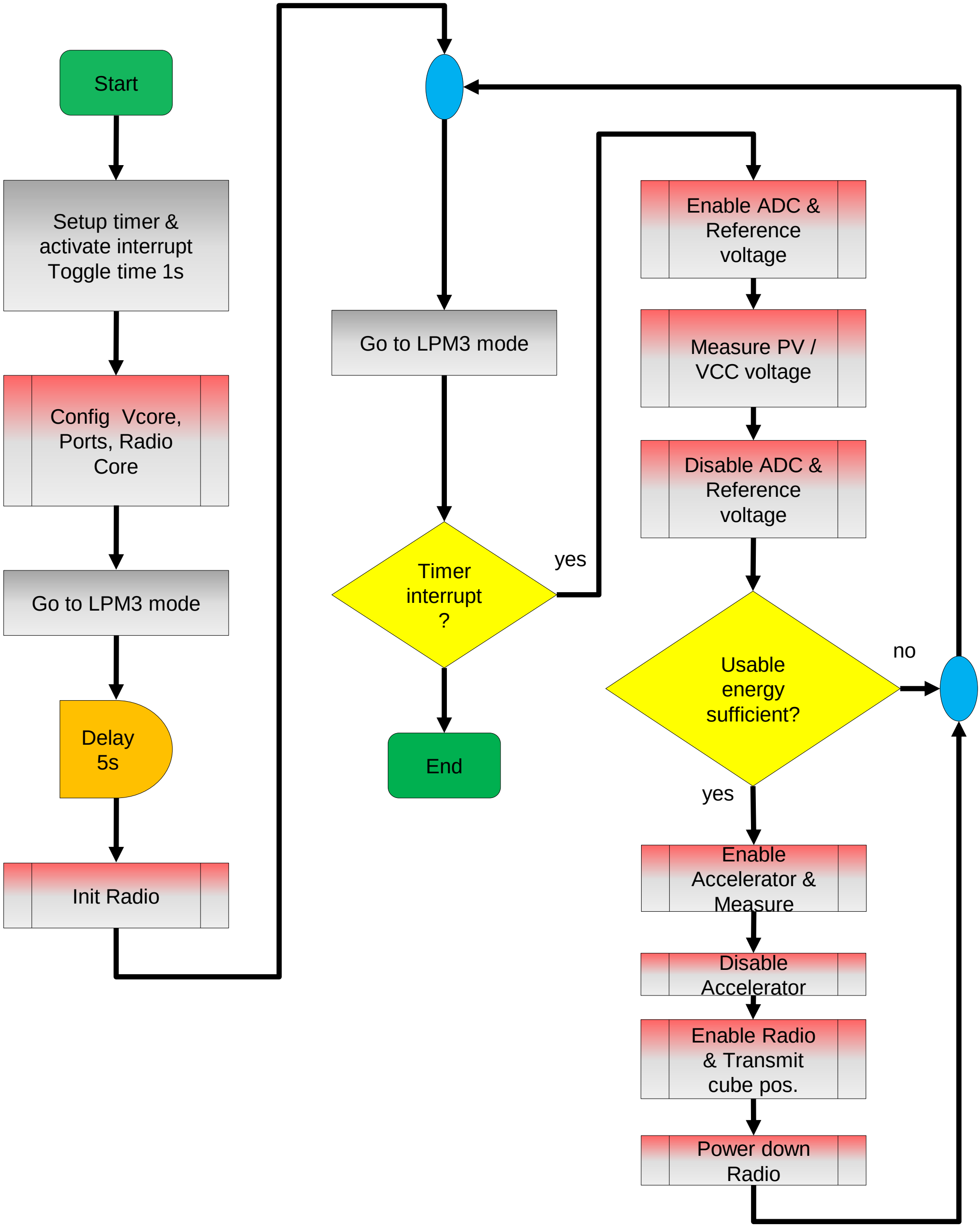
1. On startup go immediately to LPM3 mode (Low power mode)
2. Optimize the startup. Partition the tasks. This allows enough charge storage in the buffer capacitor.
3. Time your cycle for RX or TX (1 s in this example)
4. Control the usable energy with ADC module
5. Make extensive use of low power modes
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

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 workiswithout 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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