TI Solutions for Self Powered Systems

www.ti.com/energyharvesting

Helga Stevenson

Solutions Marketing – Renewable Energy

Agenda

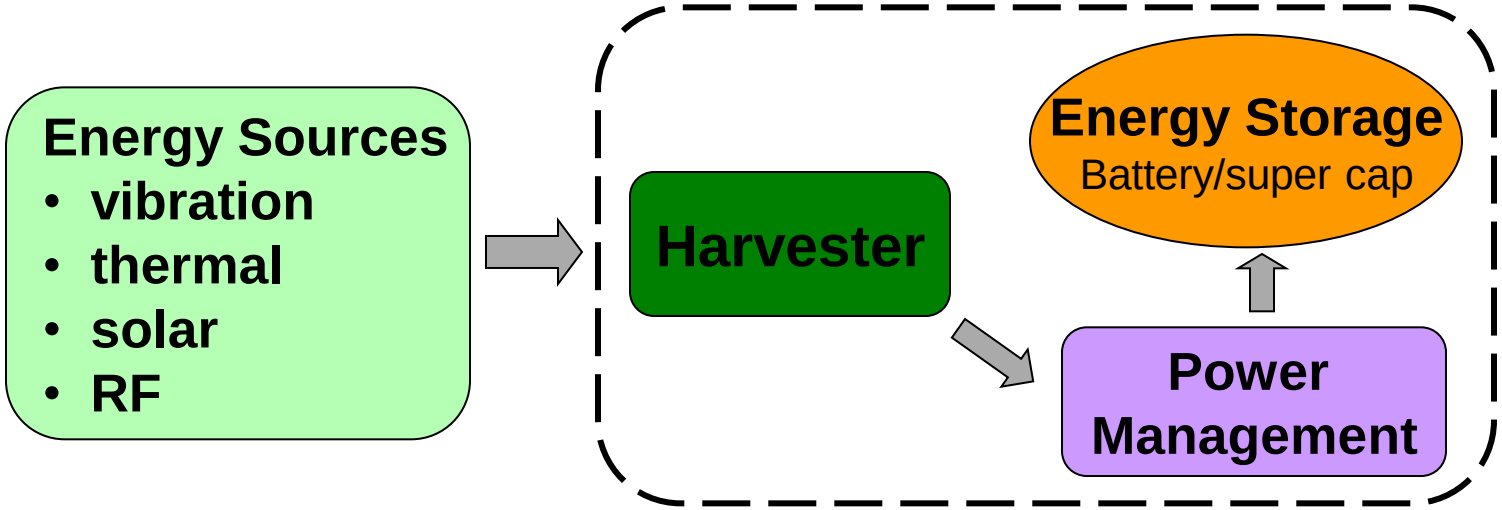
- Introduction
- TI solutions in EH
- TI MCU/RF based EH Development Tools
- Existing Third Party Solutions
- Applications Notes
- Summary

Agenda

- Introduction
  - What is Energy Harvesting
  - When does it make sense
  - Forms of Energy Harvesting
- TI solutions in EH
- TI MCU/RF based EH Development Tools
- Existing Third Party Solutions
- Applications Notes
- Summary

Introduction

- ***Energy harvesting*** is the process by which energy is ***captured*** and ***stored***
- "conversion of ***ambient energy*** into usable electrical energy", also known as energy scavenging and power harvesting
- Battery replacement is ***impractical, costly***, or ***dangerous*** such as implants, remote locations, etc.



Energy Harvest Module

When Does Harvesting Make Sense?

- Harvestable energy available
- Difficult to install or power devices
- Difficult to reach devices for maintenance
- Cords/wiring too costly
- Numerous devices – high maintenance in the case of battery driven
- Environmentally friendliness required
- High uptime demanded – battery failure problematic or expensive

One or more of these characteristics are required for energy harvesting to make sense compared to batteries

Energy Harvesting Applications - examples

Remote monitoring for structural soundness

Body worn monitoring devices powered by body heat, movement

Monitor environmental conditions on farm, winery, etc.

Mesh networking for environmental monitoring (e.g. forest fire detection)

Automotive monitoring (e.g. tire pressure gauges powered by vibration)

Low data rate, low duty cycle, low power

Characteristics of EH applications

- Ability to operate with lowest standby current to maximize storage of energy.
- Consume lowest possible power when active.
- Ability to turn on and turn off instantaneously.
- Efficient operation with lowest duty cycle of active vs. standby modes.
- Analog capability for sensor interfacing and measurements.
- Ability to operate with a low voltage range.
- Lowest leakage currents to maximize harvested energy

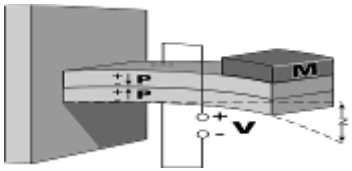
Energy Harvesting Design Guides

- Power budget – peak & standby
- Energy duty cycle
  - E_{in} vs. E_{out}
- Energy source
- Energy storage
- Operating condition
- Storage conditions
- Response time
- Cost of ownership

Vibration and Thermal Energy Harvesting

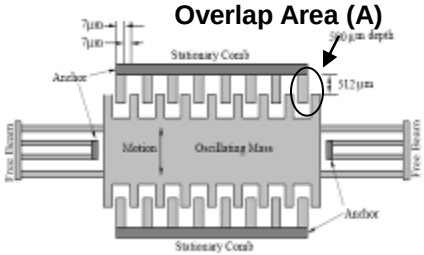
Vibration energy

Piezoelectric



- **Piezoelectric material (AlN,or PZT) converts mechanical strain into electrical energy.**

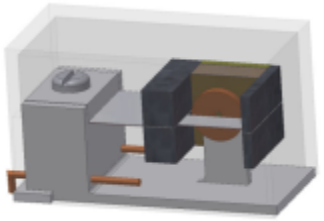
Electrostatic



- **Vibration ->motion of oscillating mass**
- **Vary A, d or ε_0**

$$C = \frac{\varepsilon_0 A}{d} \qquad Q = CV$$

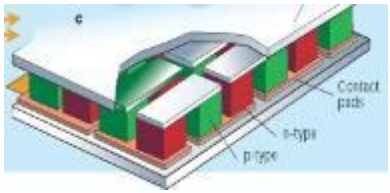
Electromagnetic



- **Vibration -> motion of magnetic field;**
- **Current flows in the static copper coil;**

Thermal energy

Thermocouple



Nature 413, Oct. 2001

Thermopiles

- thermally in parallel
- electrically in serial

Seebeck Effect

ΔT drives heat flow

⇩

Electrons and holes flow in N-type and P-type semiconductor materials

⇩

Electrical energy

$V = \alpha(-\Delta T)$

Texas Instruments

RF and Solar Energy Harvesting

RF energy

Power output: ~ E^2/Zo

E is the electric field, V/m

Zo is the radiation resistance of free space (377 Ohms)

Example: E = 1 V/m, yield 0.26 uW/cm^2

Need large collection area or close to transmitter

Solar energy

Photovoltaic cells

~ 100mW/cm^2 in bright sun

~ 100 uW/cm^2 in illuminated office

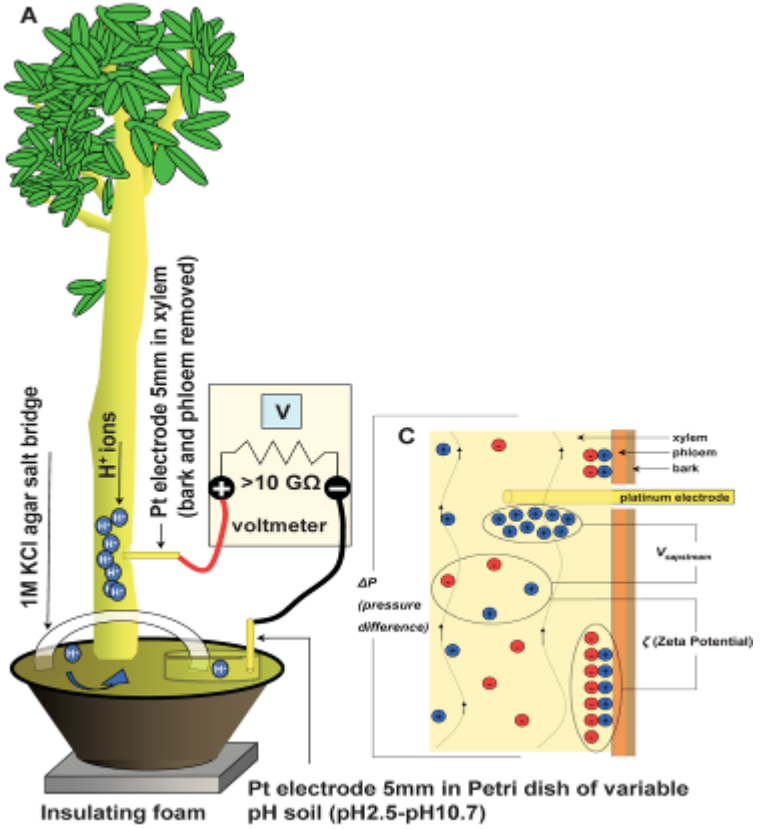
Energy conversion efficiency 10% ~20%

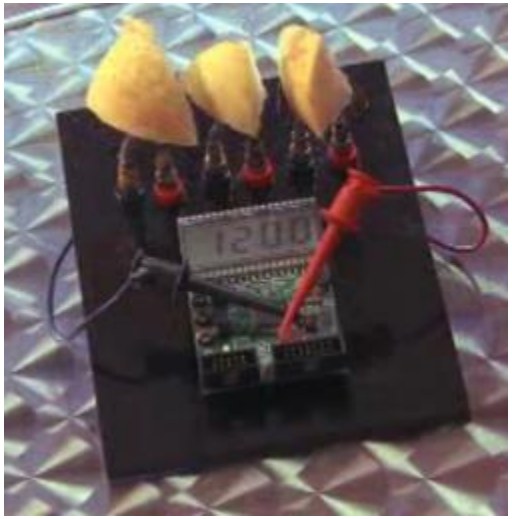
Active developing area to improve efficiency

Other Energy Harvesting Technology

Chemistry difference
In soil and trees

Voltree (10s to 100s of µW)





TI's MSP430 demo module
Using fruits as power source

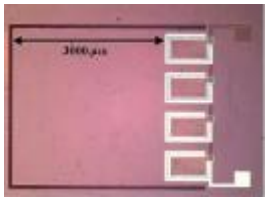
http://www.youtube.com/watch?v=ZxGZIiyyxrM

Energy Harvesting Sources

Energy Source	Characteristics	Efficiency	Harvested Power
Light	Outdoor	10~24%	100 mW/cm^2
	Indoor		100 µW/cm^2
Thermal	Human	~0.1%	60 µW/cm^2
	Industrial	~3%	~1-10 mW/cm^2
Vibration	~Hz–human	25~50%	~4 µW/cm^3
	~kHz–machines		~800 µW/cm^3
RF	GSM 900 MHz	~50%	0.1 µW/cm^2
	WiFi		0.001 µW/cm^2

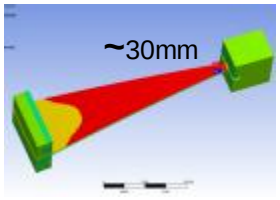
Seiko watch ~5uW

Holst Center ~40uW



2 channel EEG ~1mW

AdaptivEnergy ~10mW



Elastometer ~800mW

BigBelly ~40W

1uW 10uW 100uW 1mW 10mW 100mW 1W+

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Use cases of EH RF sensors

- Consumer
  - Several
- Industrial
  - Machinery Health Monitoring
  - Structural Health Monitoring
  - Wireless sensing
- Building automation
  - Lighting Controls
  - HVAC Controls and Monitoring
  - Security
- Automotive
  - Asset tracking
  - Wireless sensing
  - Wireless switching
- Medical
  - Patient monitoring
  - Patient Id and tracking
  - Smart patches
- Agriculture
  - Soil conditions, Plant pH, Wind

Agenda

- Introduction
- TI solutions in EH
  - Generic systems block diagram
  - RFiD
  - Micro-controller
  - RF
  - Power
  - Sensor
  - Example
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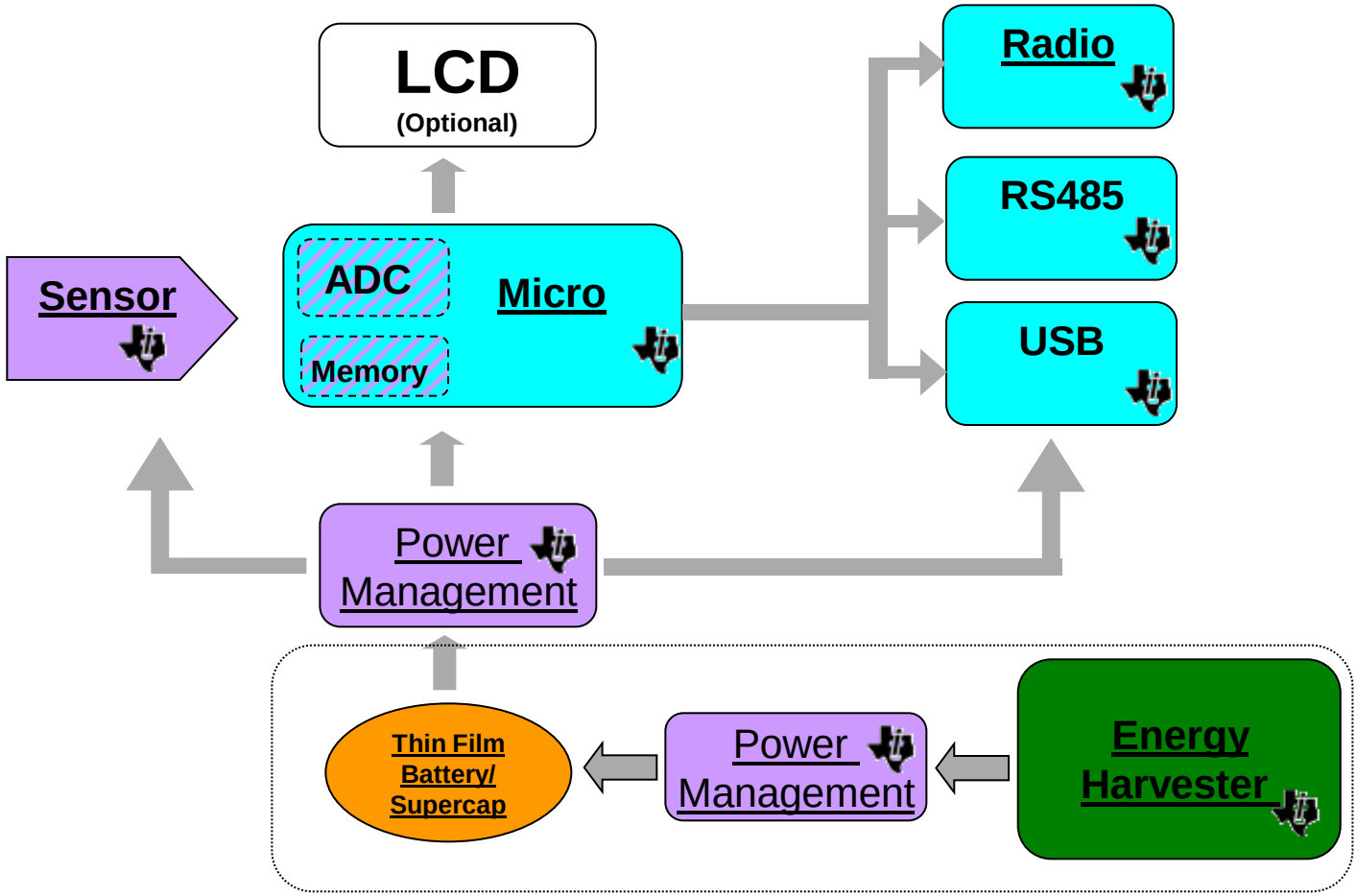
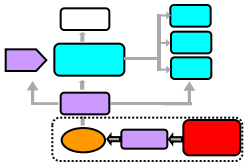
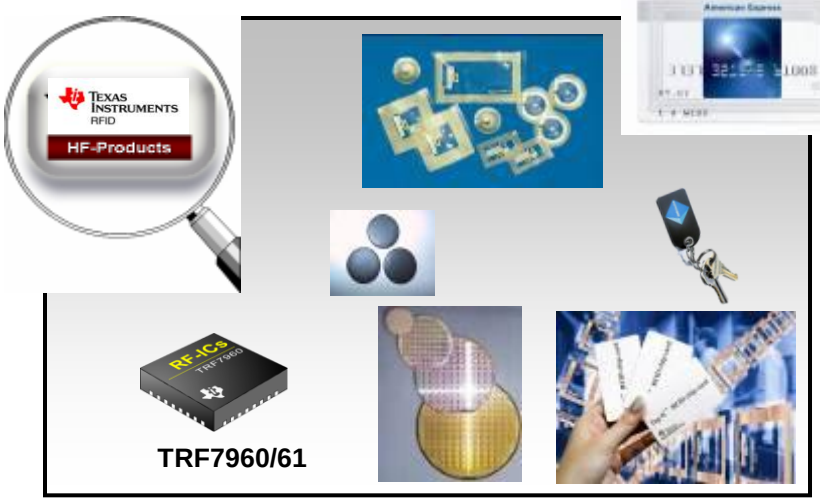
Energy Harvesting Block Diagram



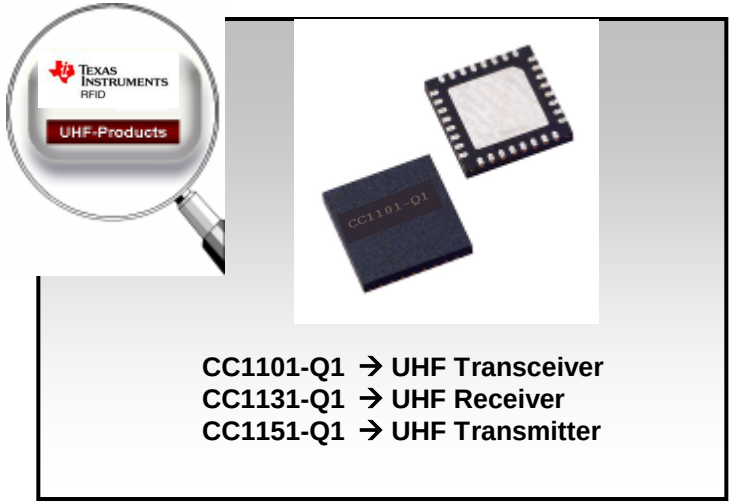
RFID Catalog Products





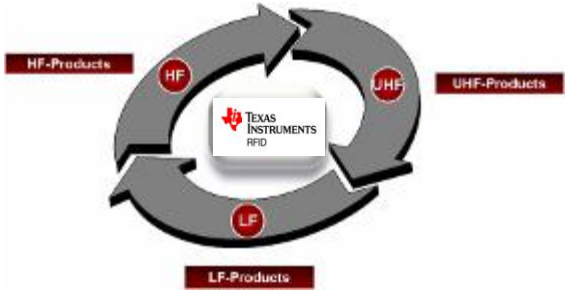
TRF7960/61

HF (13.56MHz) Passive



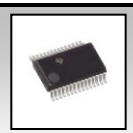
CC1101-Q1 → UHF Transceiver
CC1131-Q1 → UHF Receiver
CC1151-Q1 → UHF Transmitter

UHF (Sub 1Ghz) Active

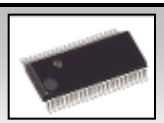


LF (134.2 kHz) Passive

TMS37C158ADBTIRG4



TMS37126D3XDBTRG4



TMS37F128D3DBTRG4

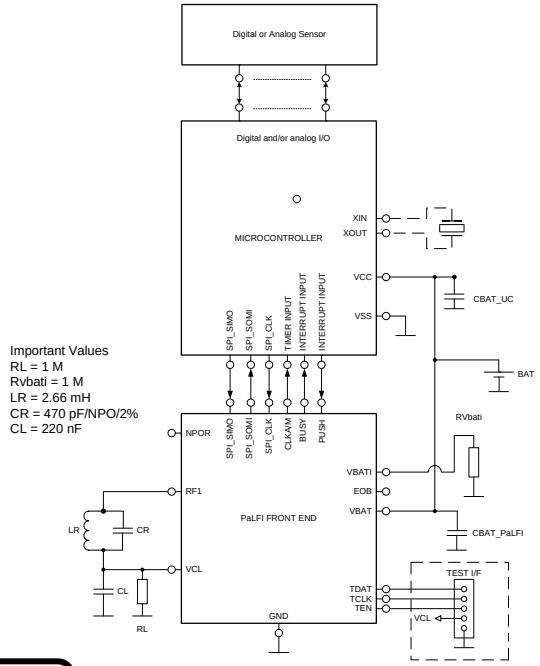
TEXAS INSTRUMENTS

TMS37157

PaLFI – Passive Low Frequency Interface Device

Supply voltage range: 2 – 3.6V

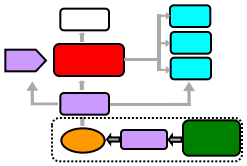
- **Ultra Low Current Consumption**
  - **50nA in standby**
  - **70µA in active mode**
- **Integrated battery less LF Interface**
- **Half Duplex LF Communication achieving up to 10cm read range**
- **3-Wire SPI Interface to any microcontroller**
- **Up to 8kbit/s LF uplink data rate**
- **121 Bytes free available EEPROM user memory**
  - **32 Bit unique serial number**
- **High EEPROM security and flexibility**
  - **Pages are irreversible lockable**
- **Battery check and charge function**



LF Benefits

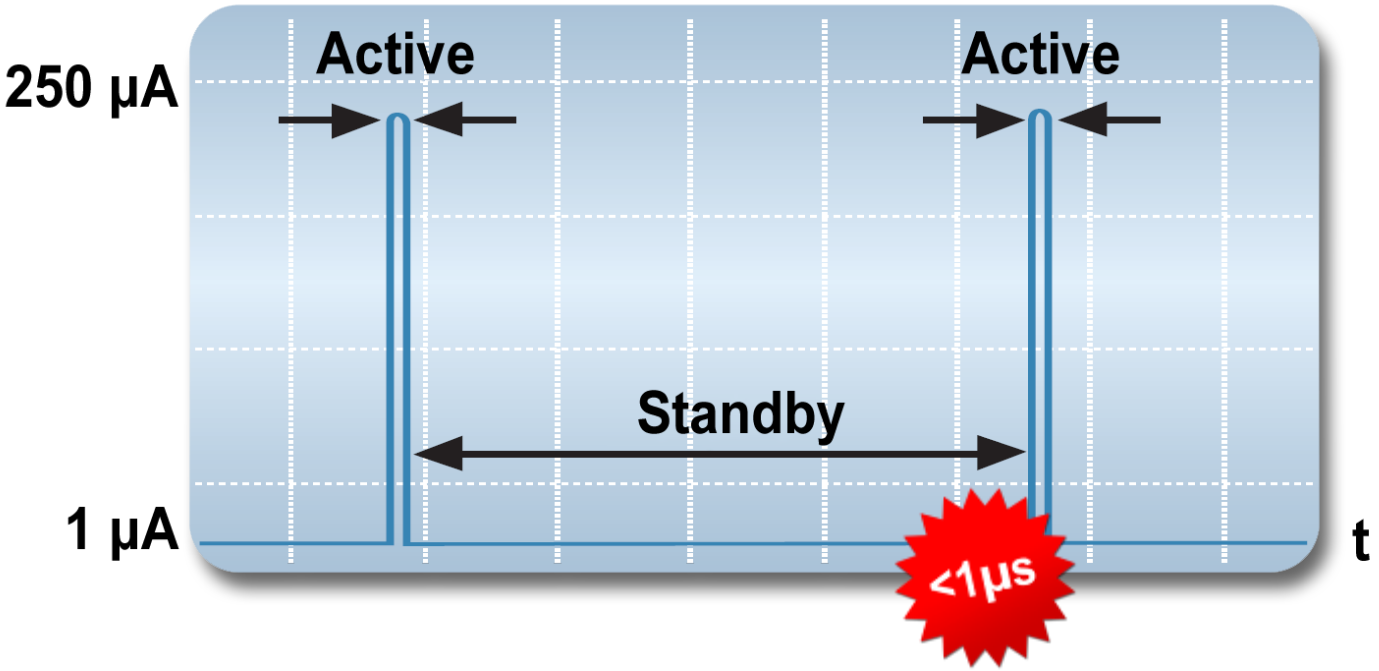
- **Highest Noise Immunity due to HDX Communication**
- **50% higher read range compared to FDX system**
- **High-Secure and High-Reliable EEPROM**
- **µC access via LF Interface**

Ultra-Low-Power Processing Required



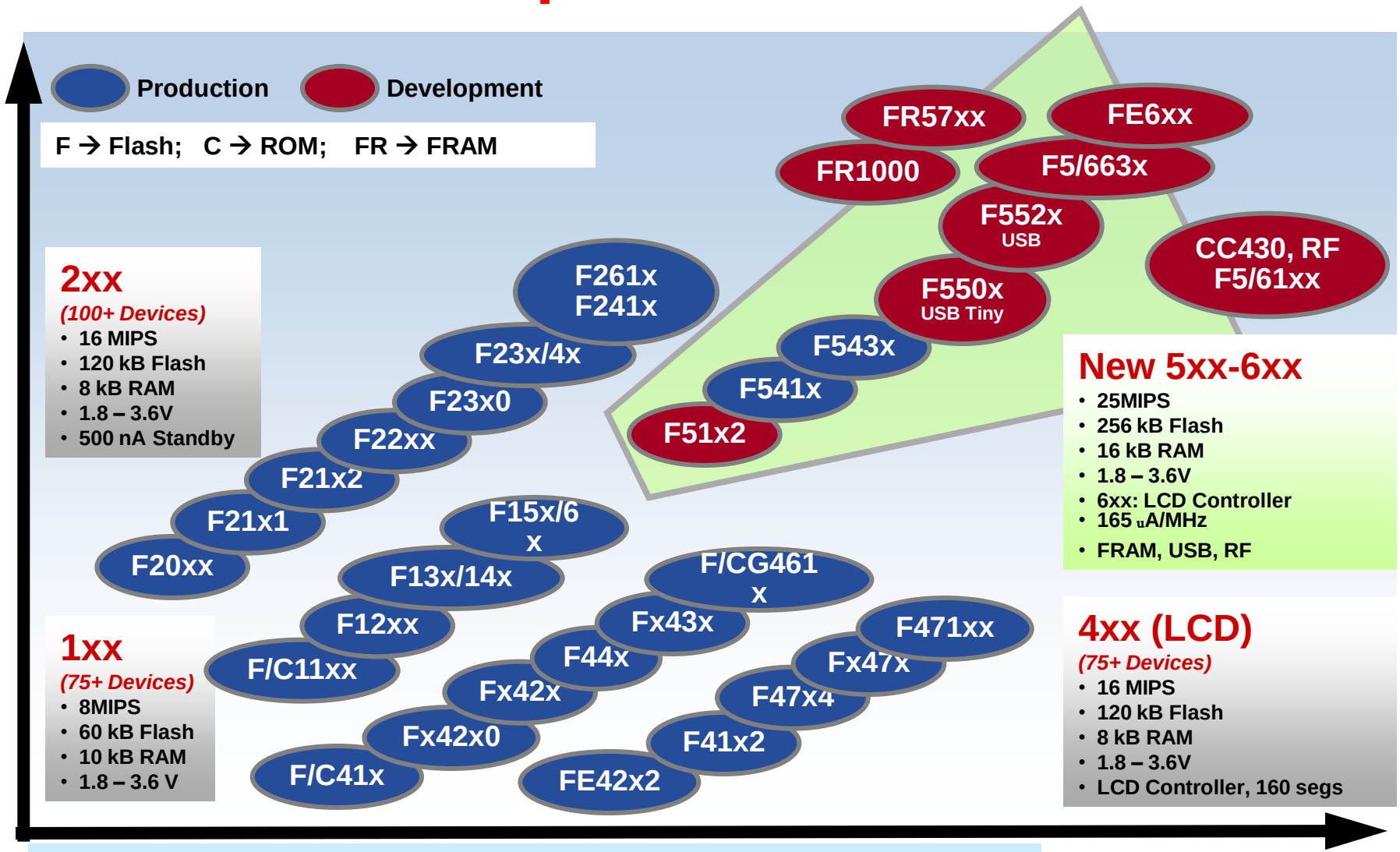
- MSP430 is ideal for energy harvesting
- Low standby current <1uA
- Low active current 160uA/MHz
- Instant off and quick wakeup time <1us
- Integrated low power ADC for precision measurements (great for sensors)
- Low operating voltage 1.8V to 3.6V
- Low pin leakage <50nA
- Lower power, highly integrated new products: 5xx-based RF SoC
- Efficient 16-bit architecture with high code density and processing power

Ultra-Low-Power Activity Profile



- Extended *Ultra-Low-Power* standby mode
- Minimum active duty cycle
- Interrupt driven performance on-demand

MSP430 Roadmap



Analog integration: ADC10/12, 16-bit sigma delta, 12-bit DAC, OpAmps
Digital peripherals: 16×16/32×32 multiplier, DMA, HW RTX, AES encryption
Communications: USB, RF, UART, I2C, SPI, LIN, IrDA

Texas Instruments

MSP430F22xx

16-MHz SoC MCU

Performance

- 16-bit Orthogonal RISC Microcontroller
- Ultra-Low-Power, Integrated Intelligent Peripherals and Easy-to-Use

Features

- **Power**
  - Low Supply Voltage Range 1.8 V to 3.6 V
  - Ultra-low Power Consumption
    - Active Mode: 270 µA at 1 MHz, 2.2 V
    - Standby Mode: 0.7 µA
    - Off Mode (RAM Retention): 0.1 µA
  - Ultrafast Wake-Up from Standby Mode in Less Than 1 µs
- **Package**
  - 38-Pin DA (TSSOP): 12.60mm x 8.40mm
  - 40-Pin RHA (QFN): 6.0mm x 6.0mm

Benefits

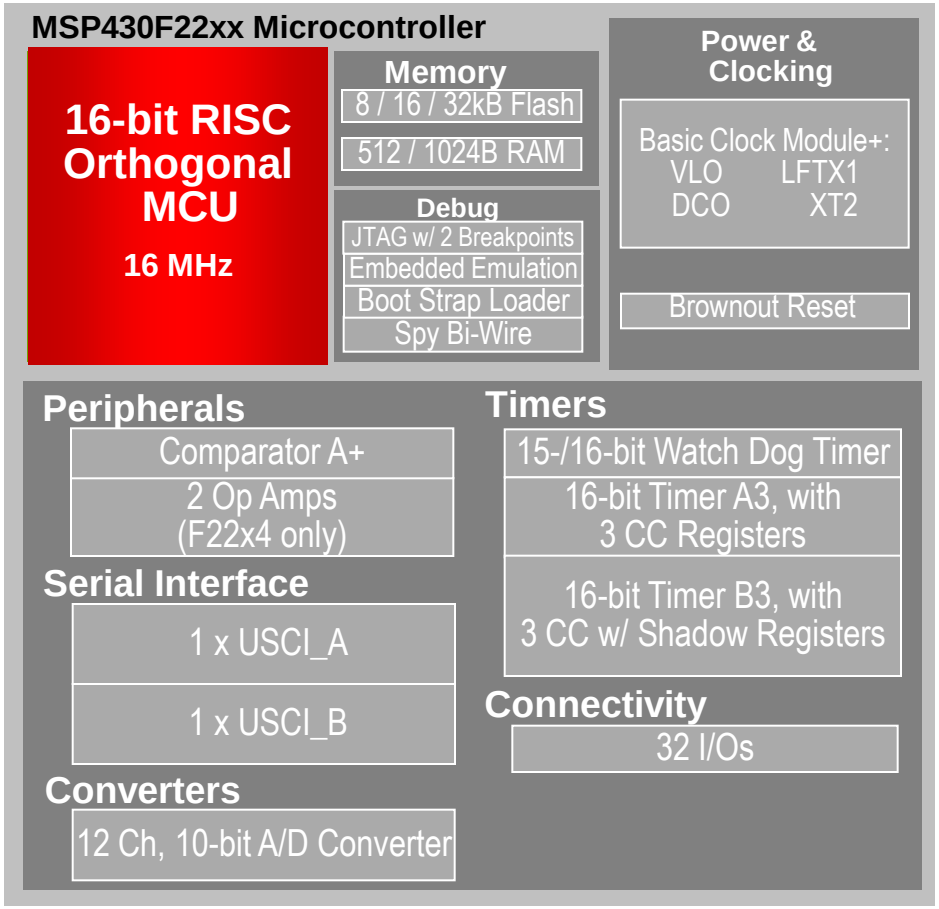
- Five optimized low power modes
- ADC channels with temperature sensing
- Two configurable Op Amps

Development Board and Programmer

- eZ430-RF2500 => I'face, 2 target bds, bat'ry bd's F2274, $49
- eZ430-RF2500T => target bd, bat'ry bds, F2274, $20
- eZ430-RF2480 => I'face,3 target bds, 2 bat'ry bds, F2274, $99
- MSP-FET430U38 => 38-Pin DA (TSSOP), $149
- MSP-FET430UIF=>USB Prog I'face only, $99

Applications

- Portable battery-powered devices
- Intelligent sensor systems
- Stand-alone RF sensor front end



Product Folder
(Internet Required)

Texas Instruments

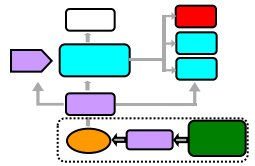
MSP430F2xx Series Summary

Family	Flash / RAM	GPIO	16-bit Timers	ADC	Comm.	Other Integrated Peripherals
F20x1	2 KB / 128 B	10	A2, WDT	Slope		Comp
F20x2	2 KB / 128 B	10	A2, WDT	ADC10	USI	
F20x3	2 KB / 128 B	10	A2, WDT	SD16	USI	
F21x1	8 KB / 256 B	10	A2, A3, WDT	Slope		Comp
F21x2	8 KB / 512 B	10	A2, A3, WDT	ADC10	USCI	
F22x2	32 KB / 1 KB	10	B3, A3, WDT	ADC10	USCI	
F22x4	32 KB / 1 KB	10	B3, A3, WDT	ADC10	USCI	2 Op Amp
F23x0	32 KB / 2 KB	10	B3, A3, WDT	Slope	USCI	Comp, MPY (16x16)
F23x	16 KB / 2 KB	10	B3, A3, WDT	ADC12	USCI	SVS, Comp, MPY (16x16)
F241x	120 KB / 4 KB	48, 10	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY (16x16)
F24x	56 KB / 4 KB	10	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY (16x16)
F24x1	60 KB / 2 KB	10	B7, A3, WDT	Slope	2 USCI	SVS, Comp, MPY (16x16)
F261x	120 KB / 4 KB	48, 10	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY (16x16), 2 DAC12, 3 DMA

• **USCI_A**: UART + SPI • **USCI_B**: I2C + SPI • **USI**: I2C + SPI • **USART**: SPI or UART

Texas Instruments

LPRF Product Portfolio



	Sub 1 GHz		2.4 GHz	
	Narrowband	Proprietary	ZigBee / IEEE802.15.4	Proprietary
Software		SimpliciTI	Z-Stack, TIMAC, SimpliciTI	SimpliciTI
Protocol Processor			CC2480	
System on Chip		CC430, CC111x	CC2530, CC2431, CC2430	CC251x
Transceiver	CC1020	CC1100E, CC1101	CC2520	CC2500
Transmitter	CC1070	CC1150		CC2550
RF Front End			CC2590	CC2591

★ EH parts

Texas Instruments

CC1101
Low-Power Sub-1GHz RF transceiver

Features

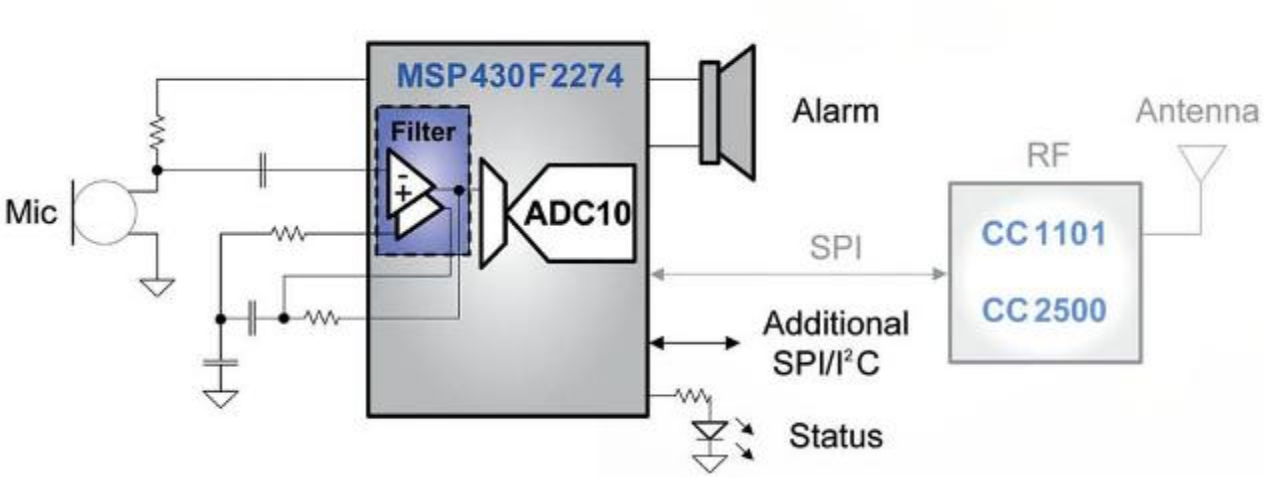
- Wake-on-radio functionality
- Integrated packet handling with 64 byte data FIFOs
- High RF flexibility: FSK, MSK, OOK, 1.2-500kbps
- Extremely fast PLL turn-on/ hop time

Benefits

- Ideal for low-power systems
- Any low-end MCU can be used
- Backwards compatible with existing systems
- Suitable for fast frequency hopping systems

Applications

- Alarm & Security systems
- Automatic Meter Reading
- Industrial monitoring & control
- Home & Building automation



EVM

CC1101DK-433
CC1101DK-868

CC2500

Low-Cost Low-Power 2.4 GHz Transceiver

Features

- Very few low cost external components required and reference design with two layer PCB with all components mounted on the same side
- Many powerful digital features: Full packet handling including preamble generation, sync word insertion/detection, address check, flexible packet length and automatic CRC
- Programmable Carrier Sense indicator, digital RSSI output and excellent selectivity and blocking performance

Benefits

- Fast development time and low system cost
- Enables use of inexpensive microcontroller
- Enables adaptive channel selection with increased robustness and coexistence of the wireless link

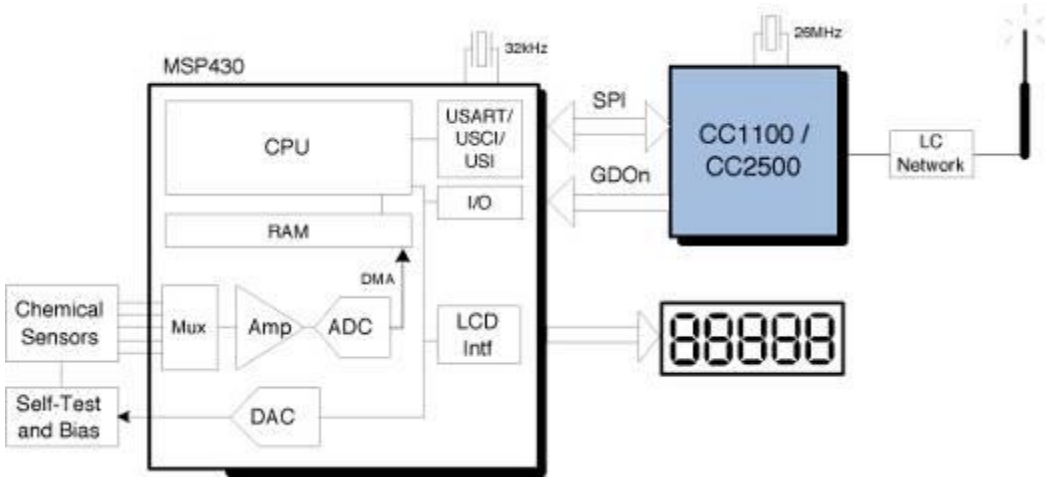
EVM

CC2500DK Dev Kit

CC2500EMK Eval Module Kit

Applications

- Wireless game controllers
- Wireless keyboard/mouse
- Consumer electronics
- Wireless audio
- Sports and leisure equipment



Pricing:

www.ti.com

CC2530/CC2531

Second generation 2.4 GHz ZigBee®/IEEE 802.15.4 RF System-on-Chip

Features

- Up to 256 Kb Flash / 8Kb of RAM
- Excellent link budget (101.5 dB)
- 51dB adjacent channel rejection (best in class)
- Four flexible power modes
- Extended temperature range: -40 to +125 degrees C
- AES-128 security module
- 21 GPIOs, 2 USARTs, and a rich peripheral set
- CC2531 supports USB 2.0 Full Speed device
- Fully compatible with the CC259x range extenders
- RoHS compliant 6x6mm QFN40
- Powerful IR generation circuitry

Benefits

- 2X FLASH over closest competitor
- Supports ZigBee PRO, ZigBee RF4CE, and more!
- 400m+ LOS range with CC2530EM dev boards
- 12dB better than closest competitor filters interference from a jammer over 4x closer
- Lowest current consumption power down mode for long battery life low duty-cycle applications
- Widest temperature range for superior robustness
- Efficient security takes up little FLASH or MCU cycles
- Reduced part list and lower BOM cost
- Ideal for Gateway or Bridge device
- Simple low-cost solution to 1000+ meter range
- Allows smaller PCB to help miniaturize product
- Provides legacy IR support with no added cost

Applications

- 2.4 GHz IEEE 802.15.4 Systems
- ZigBee RF4CE Remote Controls
- Set-Top Boxes and RF controlled TVs
- ZigBee-Pro AMI systems
- Low-Power Wireless Sensor Networks
- Lighting and Home Controls

Suitable for systems targeting compliance
- ETSI EN 300 328 and EN 300 400 class 2 (Europe)
- FCC CFR47 Part 15 (US)
- ARIB STD-T66 (Japan)

RTM Q2 2009

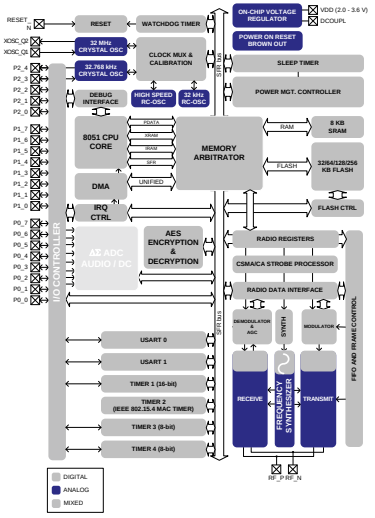
EVM

CC2530 DK

CC2530 ZDK

CC2530/1 EMK

RemoTI-CC2530DK



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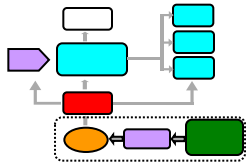
Step-down DC/DC Converter – TPS62…



Output Current		V_{out}	smallest package
1.5A	TPS62510	0.6 to 3.8V	3x3 QFN
	TPS62110	1.2 to 16V	4x4 QFN
	LBI/LBO TPS62113	1.2 to 16V	4x4 QFN
1.2A	TPS62040	0.7 to 6V	3x3 QFN
1.0A	dual TPS62420 1.0A+0.6A — EasyScale interface	0.6 to 6V	3x3 QFN
	TPS62290	0.6 to 6V	2x2 QFN
	TPS62590 — Released Feb 09	0.6 to 6V	2x2 QFN
0.8A	TPS62350 — I2C Interface	0.75 to 1.5V	2.2x1.4 CSP
	TPS62050	0.7 to 6V	3x5 MSOP
	dual TPS62410 0.8A+0.8A — EasyScale interface	0.6 to 6V	3x3 QFN
0.6A	TPS62260 — EasyScale interface	0.6 to 6V	2x2 QFN
	dual TPS62400 0.6A+0.4A — EasyScale interface	0.6V to 6V	3x3 QFN
	TPS62620 — RTM April 09	1.82V	1.3x0.9 CSP
0.5A	TPS62300	0.6 to 5.4V	2x1 CSP
	★ TPS62230 — RTM April 09	1.2V/1.8V/2.5V	1x1.5 SON
0.4A	TPS62270/3/2 — V_{SEL}	1.15V/0.9V	2x2 QFN
	TPS62250 — USB — Released Sep 08	0.6V to 6.0V	2x2 SON
	TPS62220/5	0.7 to 6V	TSOT-23
0.3A	TPS62200	0.7 to 6V	SOT-23
	★ TPS62240	0.6 to 6.0V	2x2 QFN

Input Voltage: 1.8 2.5 2.7 5.5 6.0 9.0 10.0 17.0V

★ EH parts

Texas Instruments

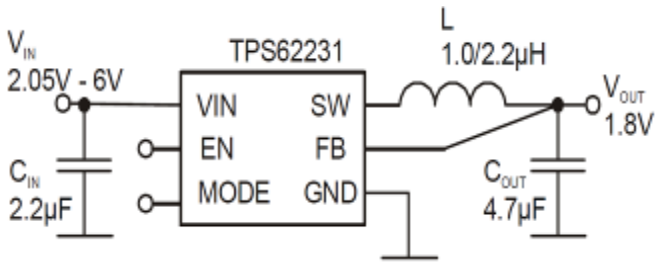
TPS62230

2.05V – 6V V_{IN}, 0.5A peak I_{out}, Synch. Buck Converter in 1x1.5mm SON

Features	Benefits
V_{IN} from 2.05V to 6V	Allows powering of applications based on **Li-Ion batteries with extended input voltage**.
Power Save Mode (PFM)	Active at **light loads**, the device skips pulses allowing **high efficiency (up to 94%)** and low quiescent current - **22uA I_Q**
Forced PWM Mode	When forced to be active with light loads, allows **simple filtering** of the switching frequency for **noise sensitive applications**
10mV PFM output voltage ripple	Generates low noise and it's optimal to be used in noise sensitive applications
Excellent AC load regulation	Together with a high PSRR (90dB), the device can be **used to replace linear regulators** and have higher efficiency
Fixed output voltages 1.2V, 1.8V, 2.5V	Factory customized
Iq 22uA typ.	**Longer battery lifetime.**
3MHz switching frequency operation	Higher frequencies allow smaller external components, L and C.
0.6mm flat 1x1.5mm SON package	Together with the small external components allows for a **very small total solution size -12mm2**

Applications

- LDO replacement
- Portable electronic
- Audio
- Low power wireless



TPS62230EVM – June 09

TPS62240

300mA, 2.25MHz Step-Down Converter in 2x2 SON

Features

- Input voltage: **2.0V to 6.0V**
- Output current: **300mA**
- Fixed and adjustable output voltage options:
  - TPS62240: **0.6V to V_{IN}** (Adjustable)
  - TPS62242: 1.2V
  - TPS62243: 1.8V
  - **+/-1.5% DC** accuracy in PWM
- Efficiency: 95% (max)
- Switching frequency: **2.25MHz**
- Power Save Mode:
  - Auto PFM/PWM in TSOT-23
  - PIN selectable Power Save Mode/ forced PWM operation in 2x2 QFN
- Quiescent current: 15µA (typ)
- Package:
  - TSOT-23
  - **2x2 SON (0.8mm height)**

Applications

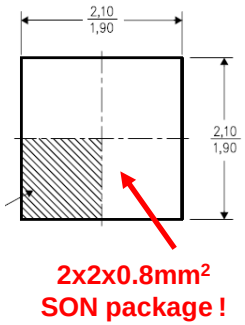
- Bluetooth Headset
- Point-of-Load
- Cell Phones, Smart-Phones
- WLAN, PDAs, Pocket PCs
- Low Power DSP Supply

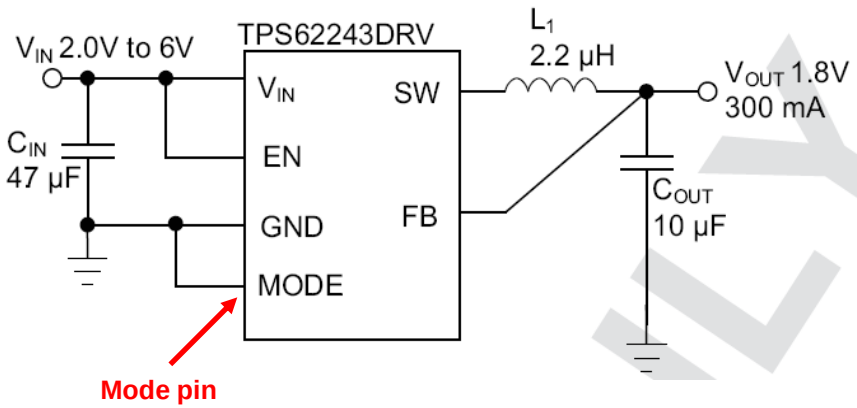
Benefits

- Extended Vin range supports **next generation Li-Ion batteries.**
- High switching frequency enables the use of tiny ceramic capacitors and small 2.2uH inductors.

-> in combination with 0.8mm SON package **a 1mm max. height solution size** is achievable**!**

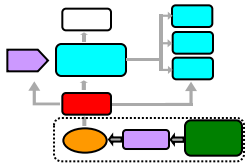
- Mode pin (SON only) for highest efficiency or lowest noise selection !
- Pin-to-pin compatible (SON) to other current versions: TPS62260 (600mA), TPS62290 (1000mA)
- Pin-to-pin compatible (TSOT-23) to older versions: TPS62200, TPS62220





TEXAS INSTRUMENTS

Step-Up DC/DC Converter Portfolio



	V_{out}	smallest package
TPS61030	1.8 to 5.5V	4x4 QFN
TPS61087	2.5 to 6.0	3x3 QFN
TPS61090	1.8 to 5.5V	4x4 QFN
TPS61029	1.8 to 5.5V	3x3 QFN
TPS63000	0.7 to 5.5V	3x3 QFN
TPS61200	1.8 to 5.5V	3x3 QFN
TPS61020	1.8 to 5.5V	3x3 QFN
	2.5 to 5.5V	3x3 QFN
dual TPS61100 +LDO	1.5 to 5.5V	4x4 QFN
dual TPS61120 +LDO	2.5 to 5.5V	4x4 QFN
TPS61130	2.5 to 5.5V	4x4 QFN
TPS61081	2.5 to 27V	3x3 QFN
	2.5 to 5.5V	3x3 QFN
TPS61000, TPS61010	1.5 to 3.3V	
TPS61170	3.0 to 38V	2x2 QFN
TPS63700 INVERTER	-2 to -15V	3x3 QFN
TPS61028	1.8 to 5.5V	3x3 QFN
dual TPS61140 LED+OLED	2.5 to 27V	3x3 QFN
dual TPS61150 LED+LED	2.7 to 27V	3x3 QFN
TPS61070	1.8 to 5.5V	TSOT-23
TPS61001/2, TPS61011/2	1.5 to 3.3V	3x5 MSOP
TPS61080	2.5 to 27V	3x3 QFN
TPS61040	1.8 to 28V	2x2 QFN
TPS61060	2.7 to 25V	
TPS61220	1.8 to 5.5V	2x2 QFN

Switch Current Limit: 4.5A, 3.2A, 2.0A, 1.8A, 1.5A, 1.3A, 1.1A, 1.0A, 0.8A, 0.7A, 0.6A, 0.5A, 0.4A, 0.2A

Input Voltage: 0.3, 0.8, 0.9, 1.8, 2.5, 2.7, 3.3, 5.5, 6.0, 18V

Boost with Downmode

Boost

Buck/Boost

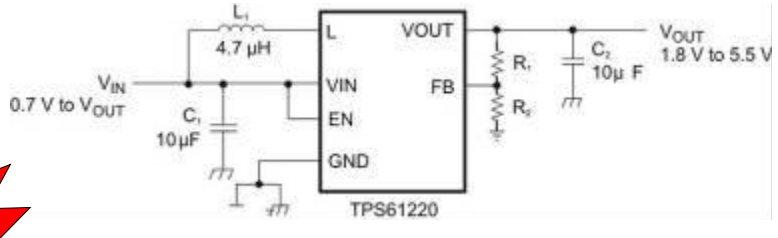
★ EH parts

Texas Instruments

0.7V_{IN} Boost Converter with 5µA I_Q - TPS6122x

Benefits

- Extended battery life due to extreme low quiescent current <5µA
- Ideal for low current applications due to low switch current limit
- Works together with low power microcontroller like MSP430™ and others
- Switching frequency: 2MHz



NEW 1Q09

Applications

- Battery powered applications:
  - 1 to 3 Cell Alkaline, NiCd or NiMH
  - 1 cell Li-Ion or Li-primary
- Microcontroller power supply
- Consumer and Portable medical products
- Personal care products.
- White or status LEDs

Features	V_{IN}	V_{OUT}	Typ Current Switch	Package
TPS61220	0.7V to 5.5V	1.8V to 5.5V	400mA	SC-70
TPS61221	"	3.3V	"	"
TPS62222	"	5.0V	"	"

www.ti.com/sc/device/tps61220

EVM: TPS61220EVM

Texas Instruments

TPS61200 Series
0.3V Input Voltage Synchronous Boost Converter with 1.5A Switches

Features

- Input voltage: 0.3V to 5.5V
- Startup into full load at 0.5V input voltage
- Fixed and adjustable output voltages:
  - TPS61200: 1.8V to 5.5V (Adjustable)
  - TPS61201: 3.3V (Fixed)
  - TPS61202: 5V (Fixed)
- Switch current limit: 1.5A (max)
- More than 90% efficiency at:
  - 600mA output current at 3.3V (V_{IN} ≥ 1.2V)
  - 600mA output current at 5V (V_{IN} ≥ 3.3V)
- Quiescent current: < 55µA
- Package: 3x3 QFN

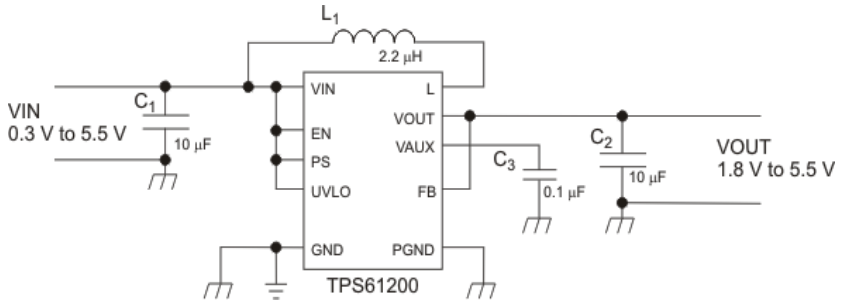
Special Features

- Integrated 'DownMode' enables continues operation during $V_{IN} > V_{OUT}$ conditions
- Automatic transition between Boost mode and Down Conversion mode
- Programmable undervoltage lockout threshold, down to 0.0V possible
- Load disconnect during shutdown

Applications

- 1-/2-/3-cell alkaline, NiCd or NiMH battery or 1-cell Li battery powered products
- Single-solar cell and micro-fuel cell powered products
- Portable audio or media players
- Portable solar charger

Typical Application



Texas Instruments

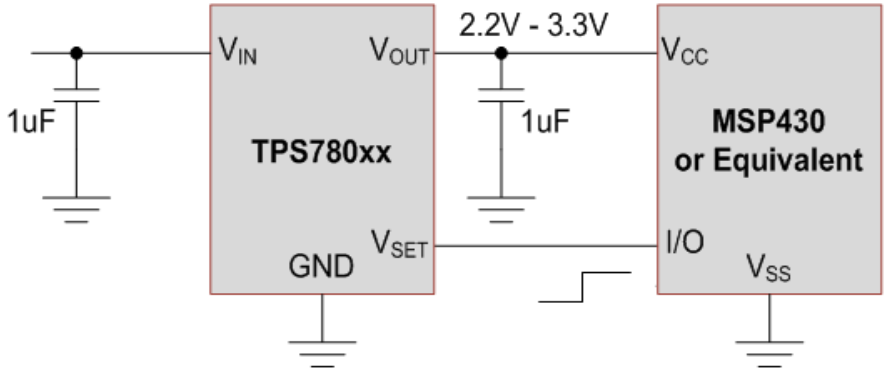
TPS780xx/781xx
Ultra Low I_Q LDO with Dual-Level Outputs

Features

- Rated Output Current: 150mA
- Ultra-Low I_Q:
  - 500nA typ (TPS780xx)
  - 1uA typ (TPS781xx)
- Drop out Voltage: 200mV @ 150mA
- Input Voltage Range: 2.2V to 5.5V
- Output Voltages: Fixed (1.5 to 4.2V) and Adjustable (1.22 to 5.25V)
- V_{SET} Pin allows V_{OUT} to Toggle Between Two Factory EEPROM Preset Values
- Stable with 1µF Ceramic Output Capacitor
- TSOT23-5, 2X2mm SON Packages

Benefits

- Fits a wide variety of power requirements
- Very low power consumption
- Powered from standard voltage rails
- Full range of µC voltage needs
- Optimizes performance or power saving modes
- Small solution size

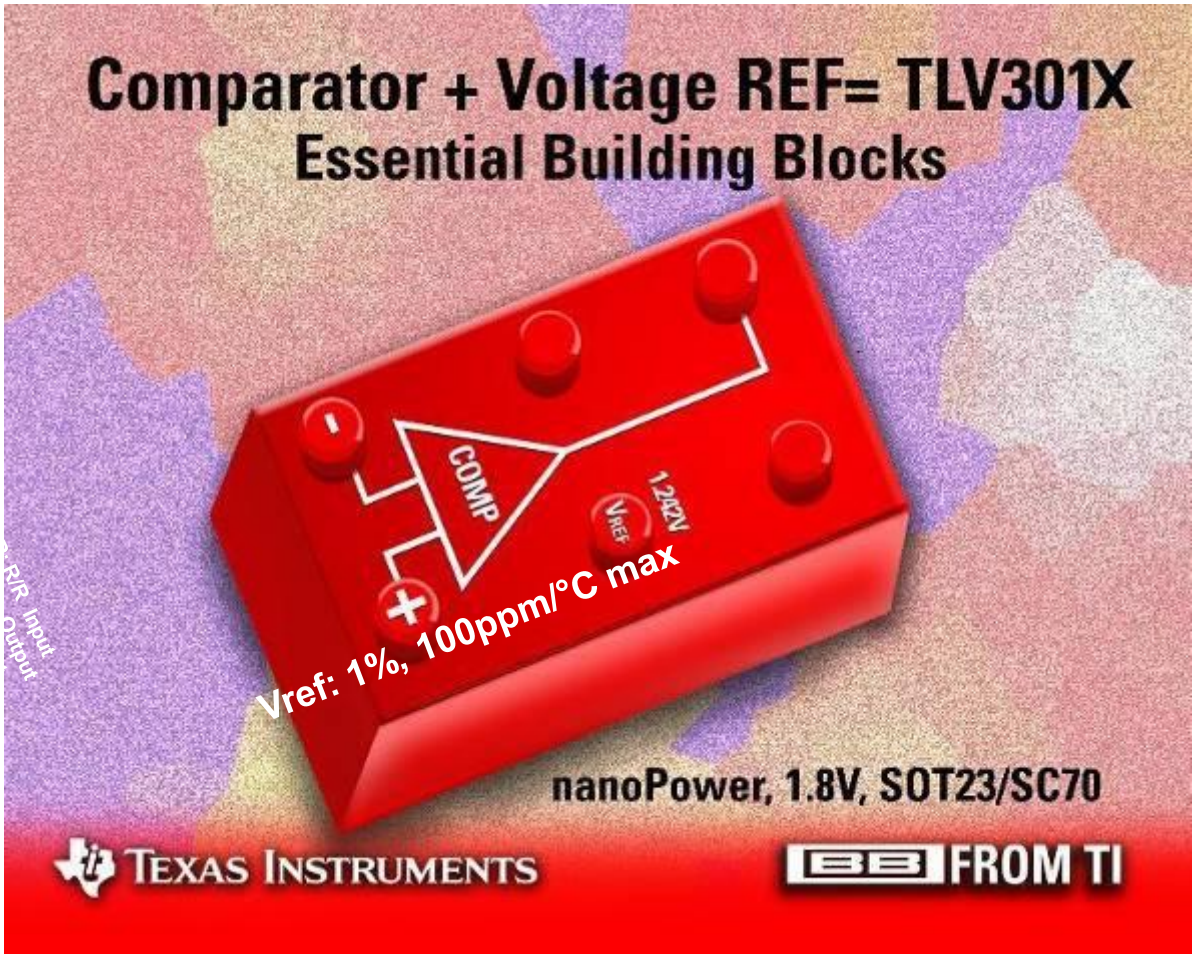


Applications

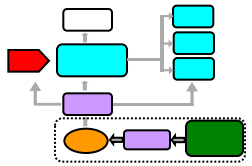
- TI MSP430 Attach Applications
- Wireless Handsets
- Portable Media Players
- Battery Operated Devices w/ extended sleep times

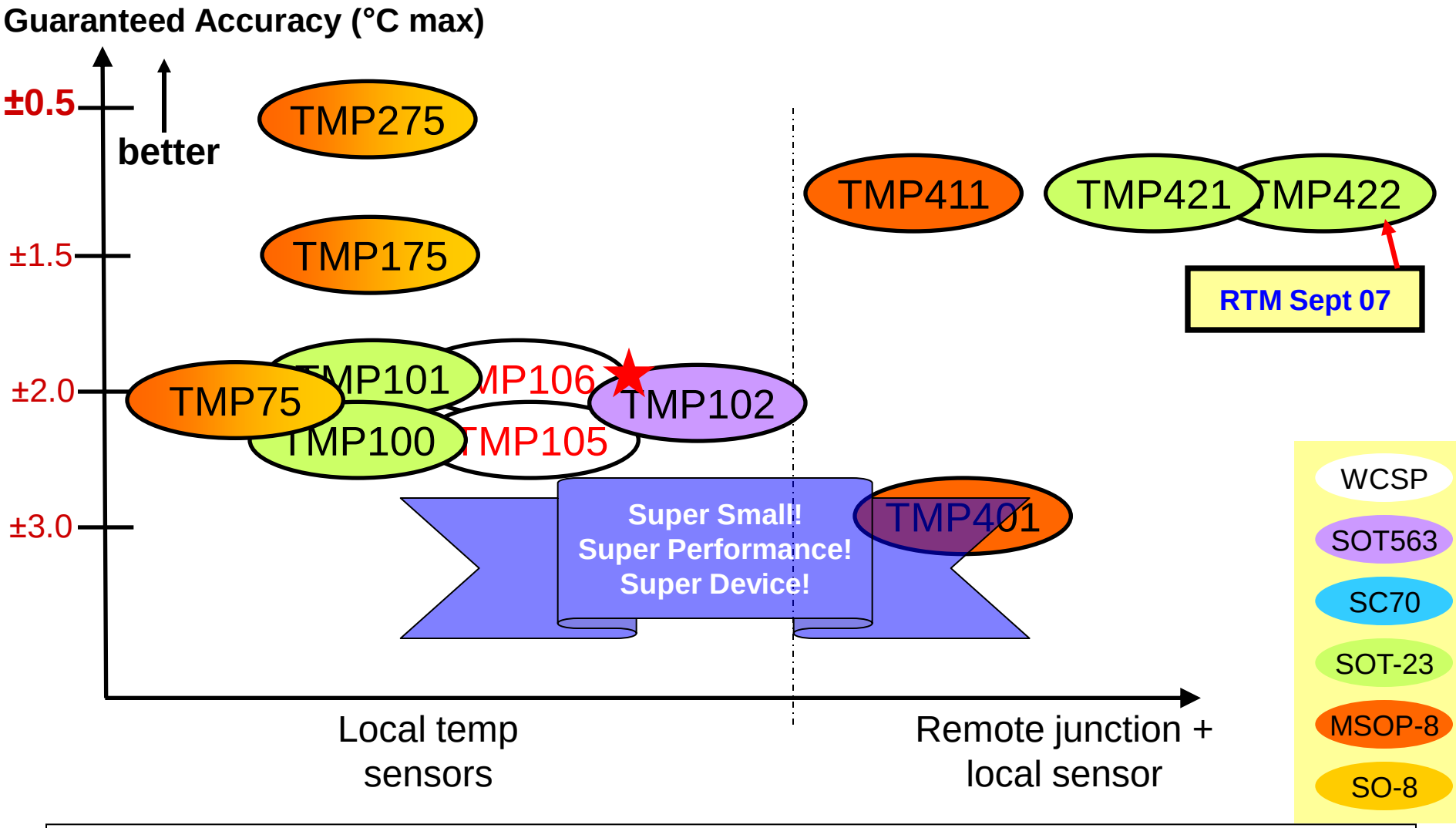
TLV3012 Comparator
2.8uA low power comparator

- Lower Power Comparator
- Hysteresis control for trickle charge



I²C Temperature Sensor





TMP102

Low Power Digital Temperature Sensor in SOT563

Features

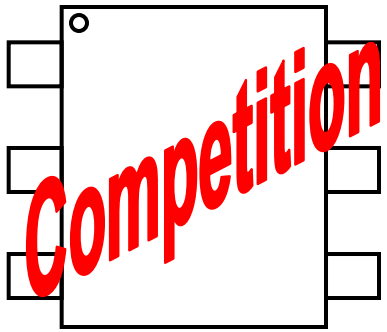
- **Tiny SOT563 Package**
- **Accuracy: 0.5°C (–25°C to +85°C)**
- **12 Bit Resolution**
- **Low Quiescent Current:**
  - **10μA Active**
  - **1μA Shutdown**
- **I²C/SMBus Output**
- **1.4V to 3.6V Supply Voltage**
- **Software compatible with TMP75/LM75**

Benefits

- Tiny SOT563 ensures device fits anywhere.
- Accuracy improves performance of temperature monitoring and feedback systems.
- Temperature can be resolved to 0.0625°C
- Perfect for portable systems
- Easy to upgrade existing systems

Applications

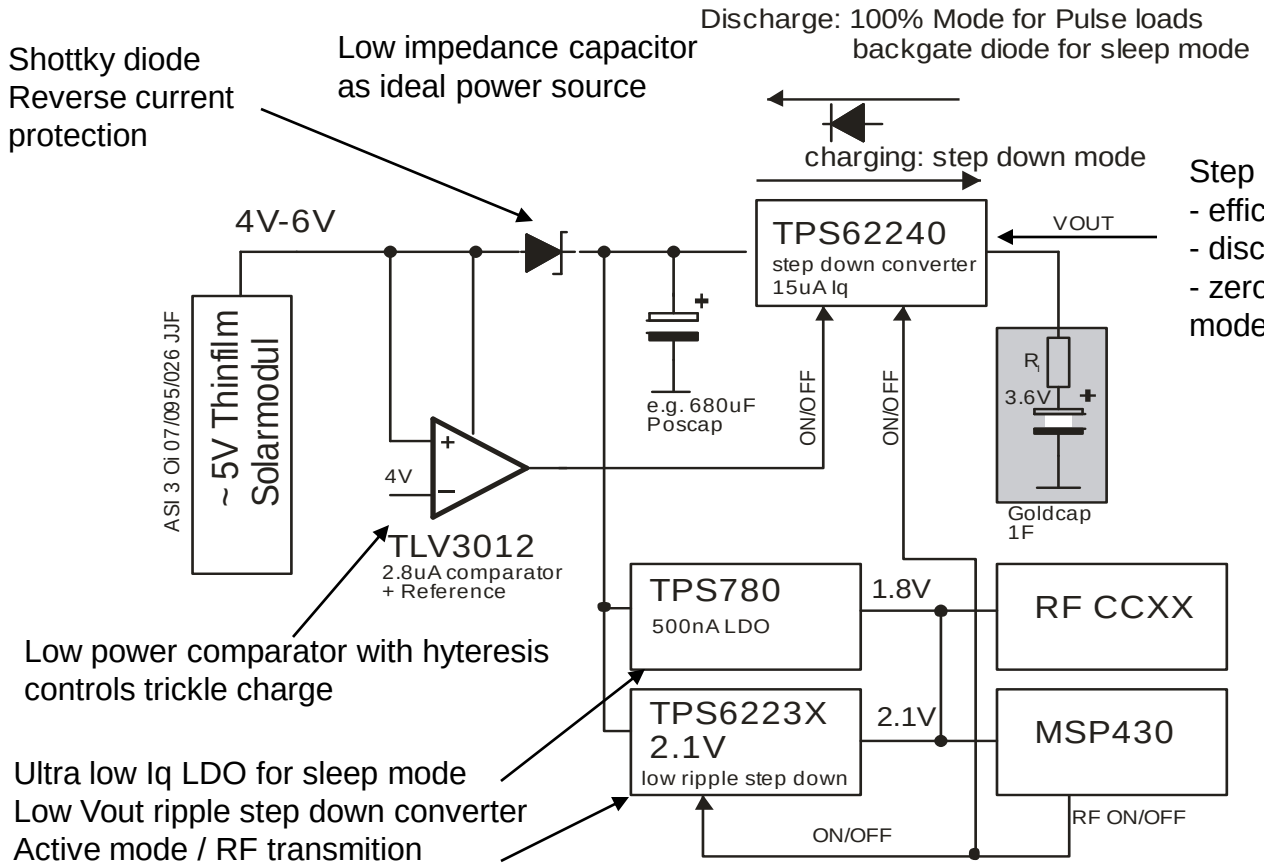
- **Power-Supply Temperature Monitoring**
- **Notebook Computers**
- **Thermostat Controls**
- **Electromechanical Device Temperatures**
- **Industrial Controls**
- **Test Equipment**
- **Medical Instrumentation**



SOT23

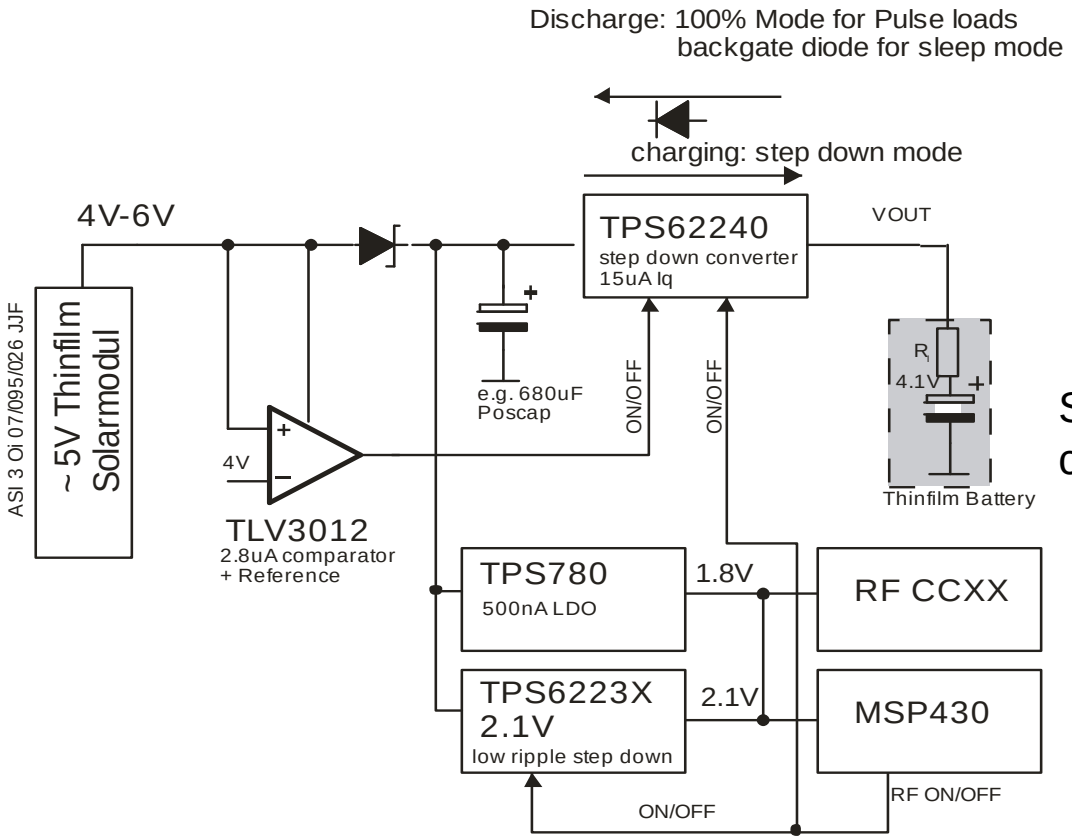
76% Smaller than the SOT23

Power concept proposal (Super Cap)



Texas Instruments

Power concept proposal (Li-thin film battery)



Same as before, but higher charge voltage

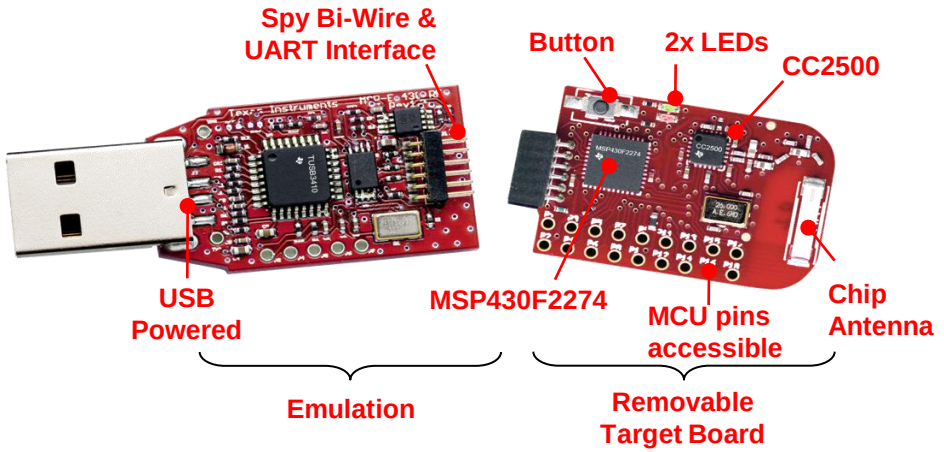
Texas Instruments

Agenda

- Introduction
- TI solutions in EH
  - Micro-controller
  - RF
  - Power
  - Signal Conditioning
- TI MCU/RF based EH Development Tools
- Existing Third Party Solutions
- Applications Notes
- Summary

eZ430-RF2500 – Development Tool

- Easy to use, Wireless development tool
- Ultra Low Power: MSP430F2274 + CC2500
- 2.4 GHz ISM wireless
- Includes SimpliciTI Network Stack
- Includes Wireless Sensor Network Demo Project
- Compatible with all MSP430 Spy Bi-Wire devices
- $49
- Standalone target boards & eZ430-RF2480 also available



www.ti.com/eZ430-rf

Power Consumption (SimpliciTI 1.03)

- **Datasheet Specs @ 3.0V:**

	Standby		TX	
MSP430F2274	**LPM3 (VLO):**	**0.6µA**	**8 MHz DCO:**	**2.8mA**
CC2500	**Sleep Mode:**	**0.4µA**	**0 dBm TX:**	**21mA**
		1µA		23.8mA

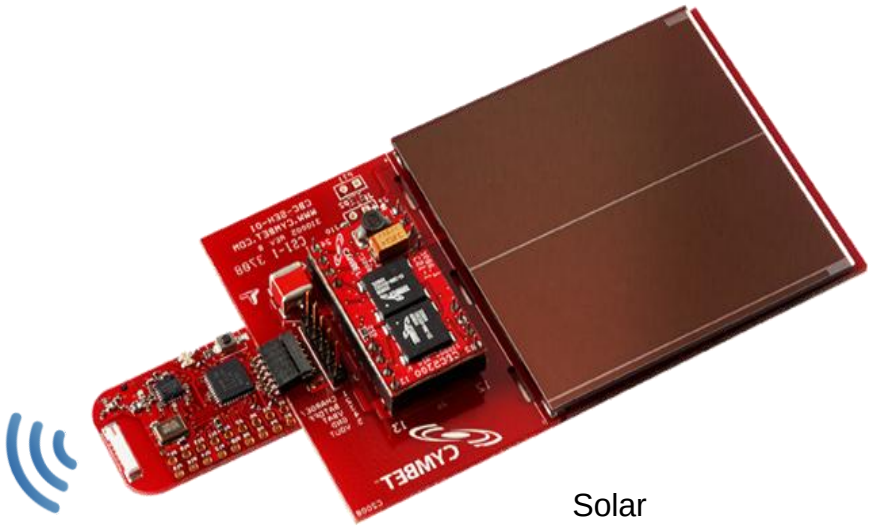
- **Real Performance @ 3.0V, 1 sec TX period**

Standby	Avg. TX Current	Avg. System Current
0.7µA	18.09mA	52.8 µA

- 2.5 years lifetime with 1 second TX period
  - AAA batteries @ 1200 mAh
- See App Note: slaa378a

ez430-RF2500-SEH EVK

- Solar Energy Harvesting module for eZ430-RF2500
- Works in low ambient light
- Negligible self-discharge
- 400+ transmission with no light
- Adaptable to any sensor and RF network



eZ430-RF2500T
Wireless Target

Solar
Energy Harvester

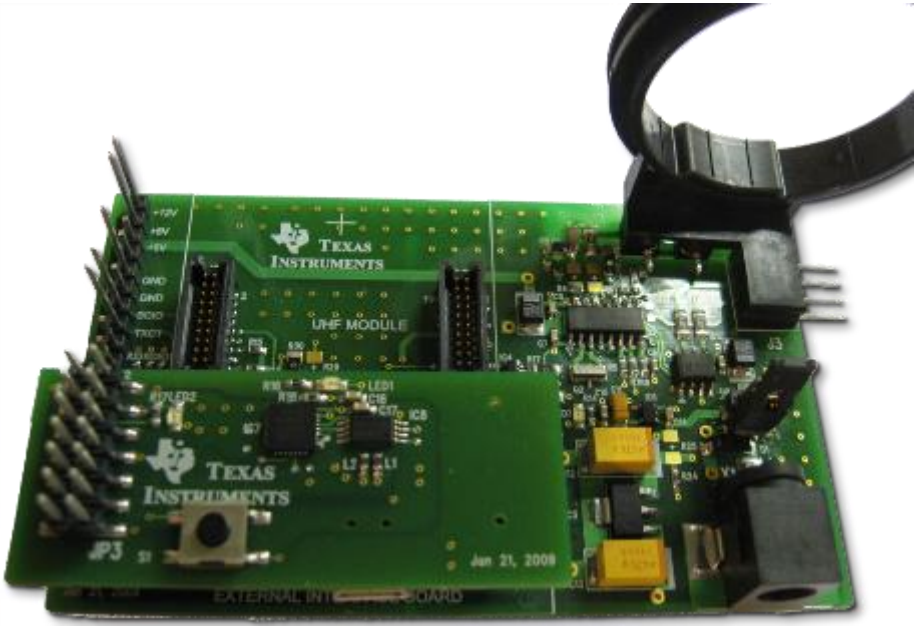
TMS37157

PaLFI – Passive Low Frequency Interface Device

eZ430 - PaLFI

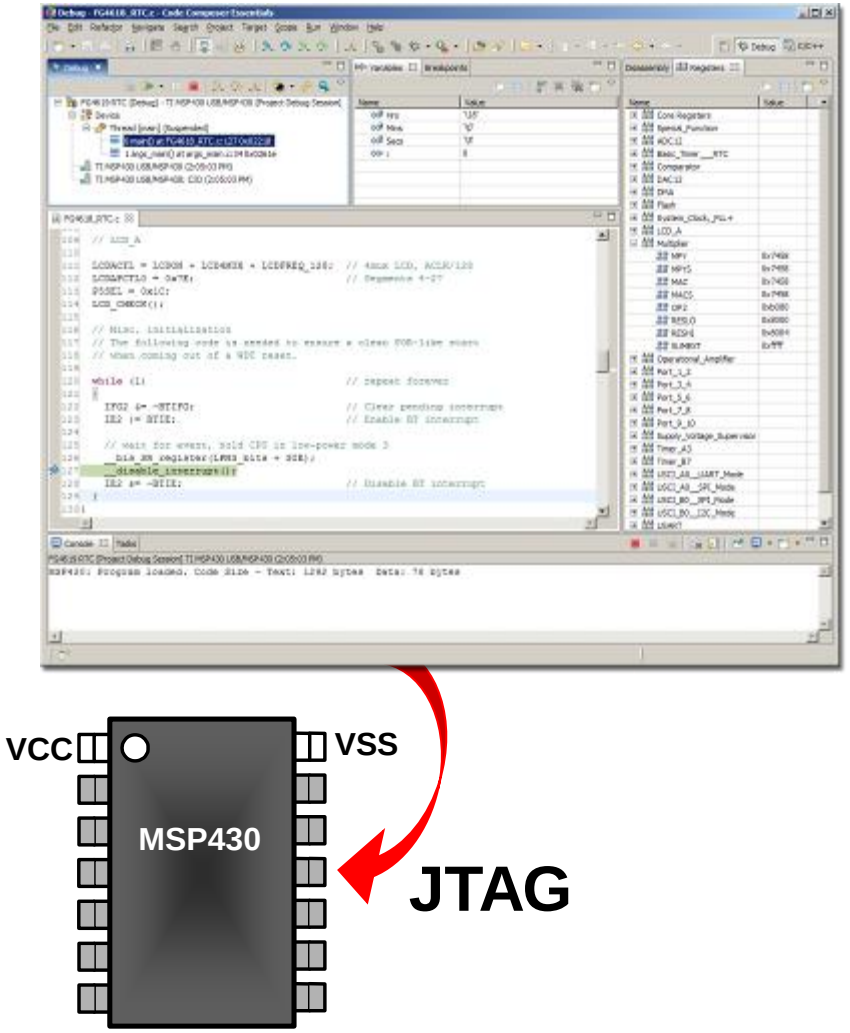
Development Kit:

- **Compatible to the eZ430-RF2500**
- **Includes:**
- **eZ430 Emulator Stick**
- **eZ430 Battery Board**
- **eZ430-PaLFI Target Board**
- **USB RFID Reader with Antenna**
- **USB cable**



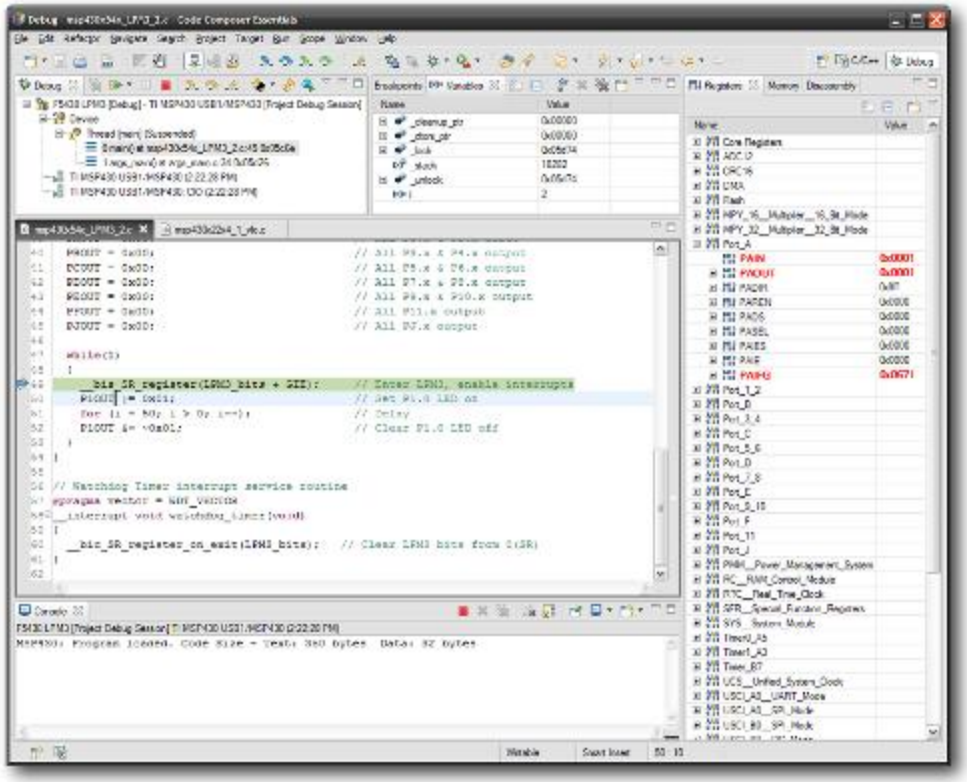
Embedded Emulation

- Real-time, in-system debug
  - No application resources
  - Full speed execution
  - H/W breakpoints
  - Single stepping
  - Complex triggering
  - Trace capability
- Powerful, easy to use tools
- Spy Bi-Wire
  - 2-wire debug interface
  - No pin function impact



Code Composer Essentials v3

- Eclipse-based IDE for the MSP430
- Supports *all* MSP430 devices
- $499 for CCE v3 Professional
- Free for apps <16KB
- Available today at www.ti.com/cce



Texas Instruments

IAR Embedded Workbench V4.11B

- Kickstart Version – Free
  - 4KB Limit on C code size
  - 8KB Limit on MSP430X devices
  - Unlimited assembler code size
  - Supported by TI PIC
- Support all MSP430 devices
- Available at www.ti.com/iarkickstart

USB Flash Emulation Tool (FET)

- MSP430 FET: real-time debug and programming tool
- Supports *ALL* MSP430 devices
  - 4-wire JTAG
  - 2-wire Spy Bi-Wire
- Available with socketed target board
  - Example: MSP-FET430U14 = FET + 14-pin target board
- Supported by all MSP430 IDEs
- Starting at $99

Tools Portfolio

Debugging and Programming Interfaces

Part Number	PC Port	Contents Include	Devices Supported	Price[1]
MSP-FET430UIF	USB	Interface only	All	$ 99
MSP-GANG430	Serial	Production programmer	All (8 devices at one time)	$ 199

Development Kits

Part Number	Contents Include	Devices Supported	Price[1]
MSP-FET430U14	Interface and target board	14-pin PW (TSSOP)	$ 149
MSP-FET430U28	Interface and target board	20-/28-pin PW (TSSOP)	$ 149
MSP-FET430U38	Interface and target board	38-pin DA (TSSOP)	$ 149
MSP-FET430U23x0	Interface and target board	MSP430F23x0 40-pin RHA (QFN)	$ 149
MSP-FET430U48	Interface and target board	48-pin DL (SSOP)	$ 149
MSP-FET430U64	Interface and target board	64-pin PM (LQFP)	$ 149
MSP-FET430U80	Interface and target board	80-pin PN (LQFP)	$ 149
MSP-FET430U100	Interface and target board	100-pin PZ (LQFP)	$ 149
MSP-FET430U5x100	Interface and target board	100-pin PZ (TQFP)	$ 149
MSP-TS430PZ5x100	Target board only	100-pin PZ (TQFP)	$ 49

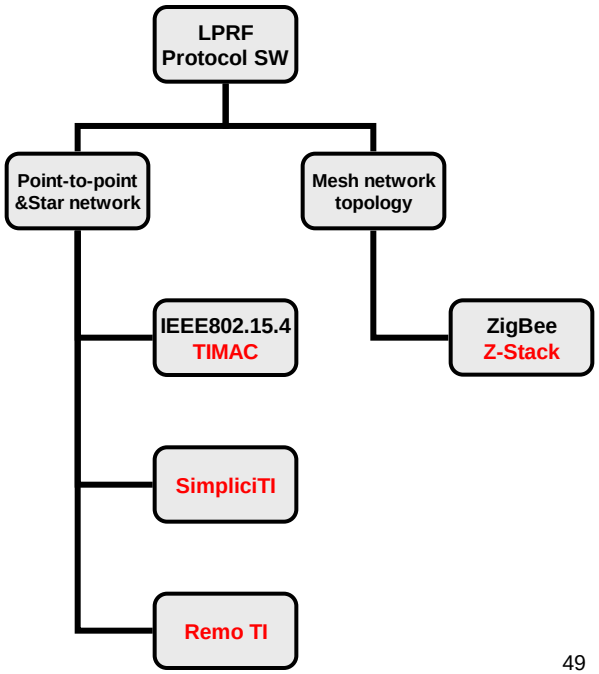
eZ430 Tools and Experimenter Boards

Part Number	Contents Include	Devices Included	Price[1]
eZ430-F2013	Interface and target board	MSP430F2013	$ 20
eZ430-F2012	3 target boards	MSP430F2012	$ 10
eZ430-RF2500	Interface, (2) target boards, battery board	MSP430F2274, CC2500	$ 49
eZ430-RF2500T	Target board, battery board	MSP430F2274, CC2500	$ 20
eZ430-RF2480	Interface, (3) target boards, 2 battery boards	MSP430F2274, CC2480	$ 99
MSP-EXP430FG4618	Board only (FET sold separately)	MSP430FG4618, MSP430F2013	$ 99

RF Protocol Software

- Z-Stack - ZigBee Protocol Stack from TI
  - One of the first ZigBee stacks with the ZigBee 2006 certification
  - Supports multiple platforms such as CC2480, CC2431 and CC2520+MSP430 platform
  - ZigBee 2007/PRO available on MSP430+CC2520 (Golden Unit 2007) and CC2530 platforms
- TIMAC
  - A standardized wireless protocol for battery-powered and/or mains powered nodes
  - Suitable for applications with low data-rate requirements
  - Support for IEEE 802.15.4-2003/2006
- SimpliciTI Network Protocol – RF Made Easy
  - A simple low-power RF network protocol aimed at small RF networks
  - Typical for networks with battery operated devices that require long battery life, low data rate and low duty cycle

All software solutions can be downloaded free from TI web



RF Network Topology

	Any Radio HW + Proprietary SW	SimpliciTI	802.15.4 TIMAC	ZigBee
Topology	**Any Topology**	**Point to Point** **Star Network**	**Star Network**	**Mesh**
Code Size	**variable**	**< 8 KByte**	**<32 KByte**	**>64 KByte**
Complexity	**variable**	**Low**	**Low**	**Medium**

RF Proprietary or Standard?

Layer \ Solution	Proprietary	SimpliciTI	IEEE 802.15.4	ZigBee
Application	Design Freedom	Design Freedom	Design Freedom	Design Freedom
Higher Layer Protocol	Design Freedom	Design Freedom	Design Freedom	Z-Stack + Simple API
Lower Layer Protocol	Design Freedom	SimpliciTI	TI MAC	TI MAC
Physical Layer	all LPRF devices	CC111x, CC251x, CC243x, CC253x, CC430, MSP430+CC1101, CC2500 or CC2520	CC253x CC243x MSP430+CC2520	CC253x CC243x CC2480
RF Frequency	2.4 GHz Sub 1 GHz	2.4 GHz Sub 1 GHz	2.4 GHz	2.4 GHz

Design

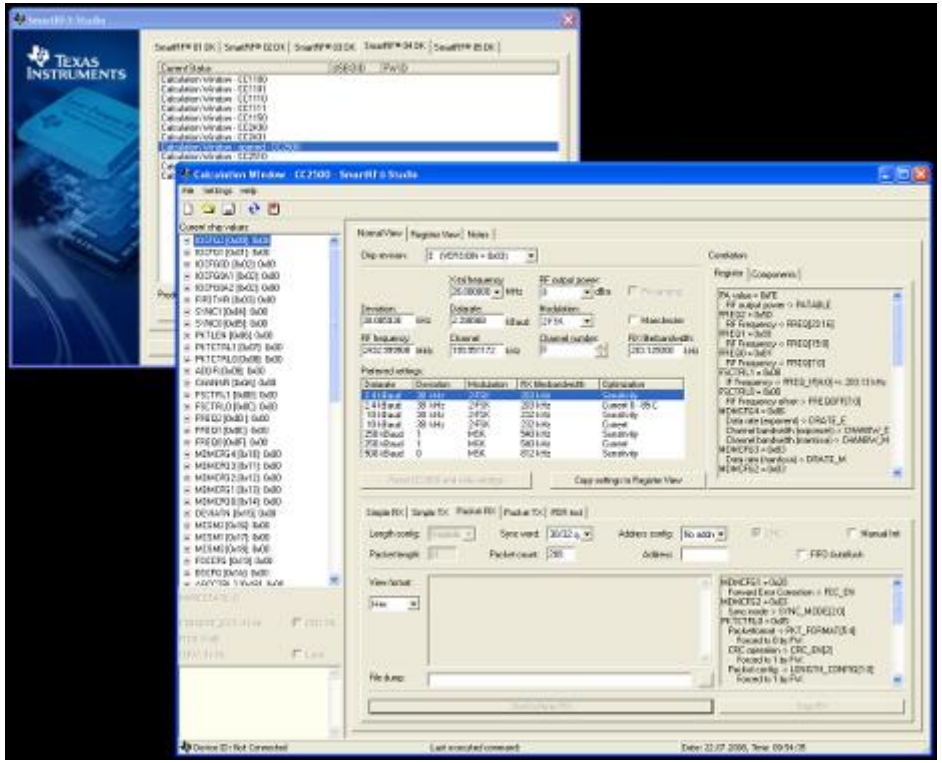
Development Tools: SmartRF® Studio

- SmartRF® Studio is a PC application to be used together with TI's development kits for ***ALL*** CCxxxx RF-ICs.

- Converts user input to associated chip register values
  - *RF frequency*
  - *Data rate*
  - *Output power*

- Allows remote control/ configuration of the RF chip when connected to a DK

- Supports quick and simple performance testing
  - *Simple RX/TX*
  - *Packet RX/TX*
  - *Packet Error Rate (PER)*



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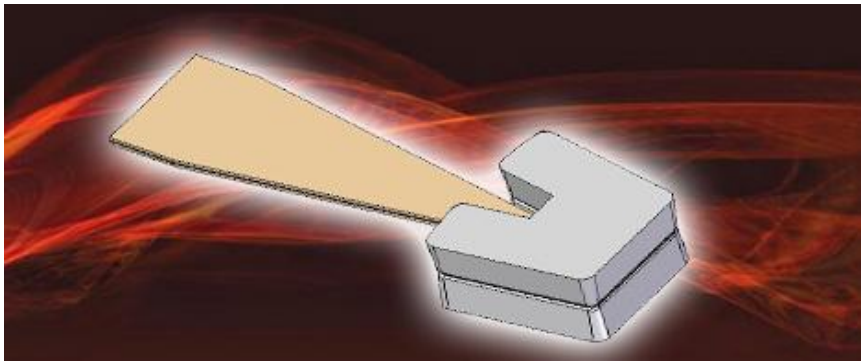
Harvester 3rd party solutions

- Adaptivenergy Joule-Thief solutions
  - Uses Ruggedized Laminated Piezo (RLP) technology
  - Highly efficient harvesting with periodic vibration sources
  - Higher energy output density with small form factor
  - Ability to customize to range of vibration frequencies
  - Complete power management solution with switching and storage
  - Joule-Thief (Li-ion version) example
    - Output Voltage: 3.6V
    - Capacity: 40 mAh
    - Size: 56.5 mm x 35.0 mm x 16.5 mm
    - Weight: 45 grams
  - www.adaptivenergy.com



Harvester 3rd party solutions

- Perpetuum
  - Vibration harvester
  - Sealed for rugged industrial environment application
  - Operates from the prevalent 100Hz and 120Hz vibration bands found on electrical machines.
  - 1mW peak power at 0.025g with >2Hz half-power bandwidth.
  - Typically >0.3mW power output on 95% of machines. (See App Note)
  - Sealed stainless steel construction.
  - Intrinsically-Safe, Zone 0, ATEX/IECEx – certified versions available.
  - www.perpetuum.com.uk

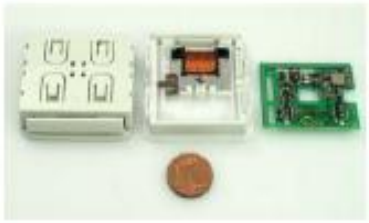
Harvester 3rd party solutions

- Micropelt
  - Thermal harvester
  - Heat sink interface for thermal path optimization
  - Plug-on DC-DC converter and sensor/wireless unit
  - USB to PC wireless receiver
  - 1 transmit/sec from 17°C temperature difference
  - www.micropelt.com

Harvester 3rd party solutions

- EnOcean
  - Battery-less, wireless sensors harvesting different energy sources
  - Focus is on smart building applications
  - Founder of EnOcean Alliance (TI is a member)
  - 50 shipping customers with 265 products
  - 300K+ installed units
  - All units inter-operable
  - 10,000+ buildings equipped
    - e.g. IBM, SAP, SIEMENS, MAN, NESTLÉ
    - Some buildings with >2,000 installed units
  - 200+ design-ins under development
  - www.enocean.com

enocean® alliance
No Wires. No Batteries. No Limits.



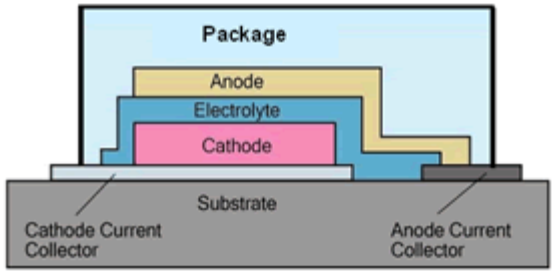
Light switch transmitter

Energy Storage Options

	Li-Ion	Thin Film Rechargeable	Super Cap
Recharge Cycles	100s	5k-10k	Millions
Self Discharge	Moderate	Negligible	High
Charge Time	Hours	Minutes	Sec-Minutes
SMT & Reflow	Poor-None	Good	Poor
Physical Size	Large	Small	Medium
Capacity	0.3-2500mAHr	12-700uAHr	10-100uAHr
Environmental Impact	High	Minimal	Minimal

What is a Thin-Film Battery?

- Small, electrochemical batteries fabricated to deposit thin layers of battery materials
- Main Features:
  - Solid State Cell Chemistry
  - Superior Cycle Life
  - High Energy Density
  - Flexible packaging options
  - Negligible leakage
  - Rapid recharge
  - Broad temperature performance



Thin Film Battery Solutions

- **Cymbet**
  - Surface-mount
  - Solid state
  - Packaged in QFN package
  - No harmful gases, liquids or special handling procedures
  - Greater than 5,000 recharge cycles
  - EnerChip CBC050 example
    - Output Voltage: 3.8V
    - Capacity: 50 µAh
    - Package: 16-pin M8 QFN
    - Size: 8 x 8 x 0.9 mm

- **Infinite Power Solutions**
  - Flexible, electrolyte based rechargeable lithium battery
  - Very thin: 0.11mm
  - Flexible
  - >10,000 recharge cycles
  - MEC101-7P example:
    - Output Voltage: 4.2V
    - Capacity: 700 µAh
    - Size: 25.4 x 25.4 x 0.11mm

Agenda

- Introduction
- TI solutions in EH
  - Micro-controller
  - RF
  - Power
  - Signal Conditioning
- TI MCU/RF based EH Development Tools
- Existing Third Party Solutions
- Applications Notes
- Summary

Relevant Applications Notes

- **DN019 -- Powering Low-Power RF Products (Rev. A)**
  - http://focus.ti.com/analog/docs/techdocsabstract.tsp?familyId=935&abstractName=swra173a
- **Interfacing the MSP430 and TMP100 I2C Temperature Sensor**
  - http://focus.ti.com/general/docs/techdocsabstract.tsp?abstractName=slaa151
- **DN400 -- Interfacing CC1100 - CC2500 with MSP430**
  - http://focus.ti.com/general/docs/techdocsabstract.tsp?abstractName=swra116a
- **Wireless Sensor Monitor Using the eZ430-RF2500 (Rev. B)**
  - http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500t.html
- **3.6V – 5.5V Input, LDO with Dual-Level Output Reference Design for MSP430**
  - http://focus.ti.com/general/docs/litabsmultiplefilelist.tsp?literatureNumber=slva329

White Papers

- **Ultra Low Power Meets Energy Harvesting – White Paper**
  - http://focus.ti.com/lit/wp/slyy018/slyy018.pdf

Software Support

- http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500t.html
  - **eZ430-RF2500T Hardware Design Files**
  - **MSP430F22x2, MSP430F22x4 Assembly Examples (CCE) (Rev. B)**
  - **MSP430F22x2/22x4 C Examples (IAR and CCE) (Rev. C)**
  - **MSP430F22x2/22x4 Assembly Examples (IAR) (Rev. B)**
  - **eZ430-RF2500 Sensor Monitor Demo (Rev. B)**
- **http://focus.ti.com/docs/toolsw/folders/print/ez430-rf2500-seh.html**
  - **eZ430-RF2500-SEH Demo and Source Code (Rev. A)**

E2e Videos

- **CC430 Energy Harvesting**
  - http://e2e.ti.com/media/p/14627.aspx
- **TI discusses Energy Harvesting, an emerging power technology and its diverse applications**
  - http://e2e.ti.com/media/p/2980.aspx

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Summary

- Ultra low power MCU/RF enable perpetually powered operation through energy harvesting
- Various energy harvesters are available for many applications
- New energy storage technology enables new class of applications
- TI technology enables low power processing, sensing, wireless transmission, and power management

Examples of various sized button cell batteries.

Americans purchase **3 billion** batteries (dry cell) every year!

Saves the environment
by harvesting more energy

THANK YOU !

www.ti.com/energyharvesting

Best of both worlds