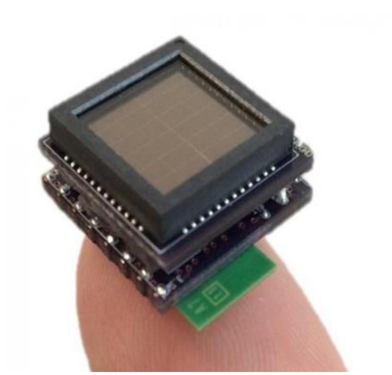
Maxim

nano Power

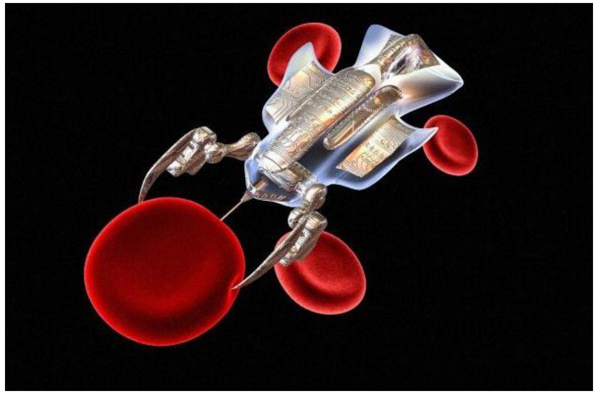
JP Ryu

What are we trying to accomplish?



Autonomous sensors?

Smaller devices?



Nanobots?

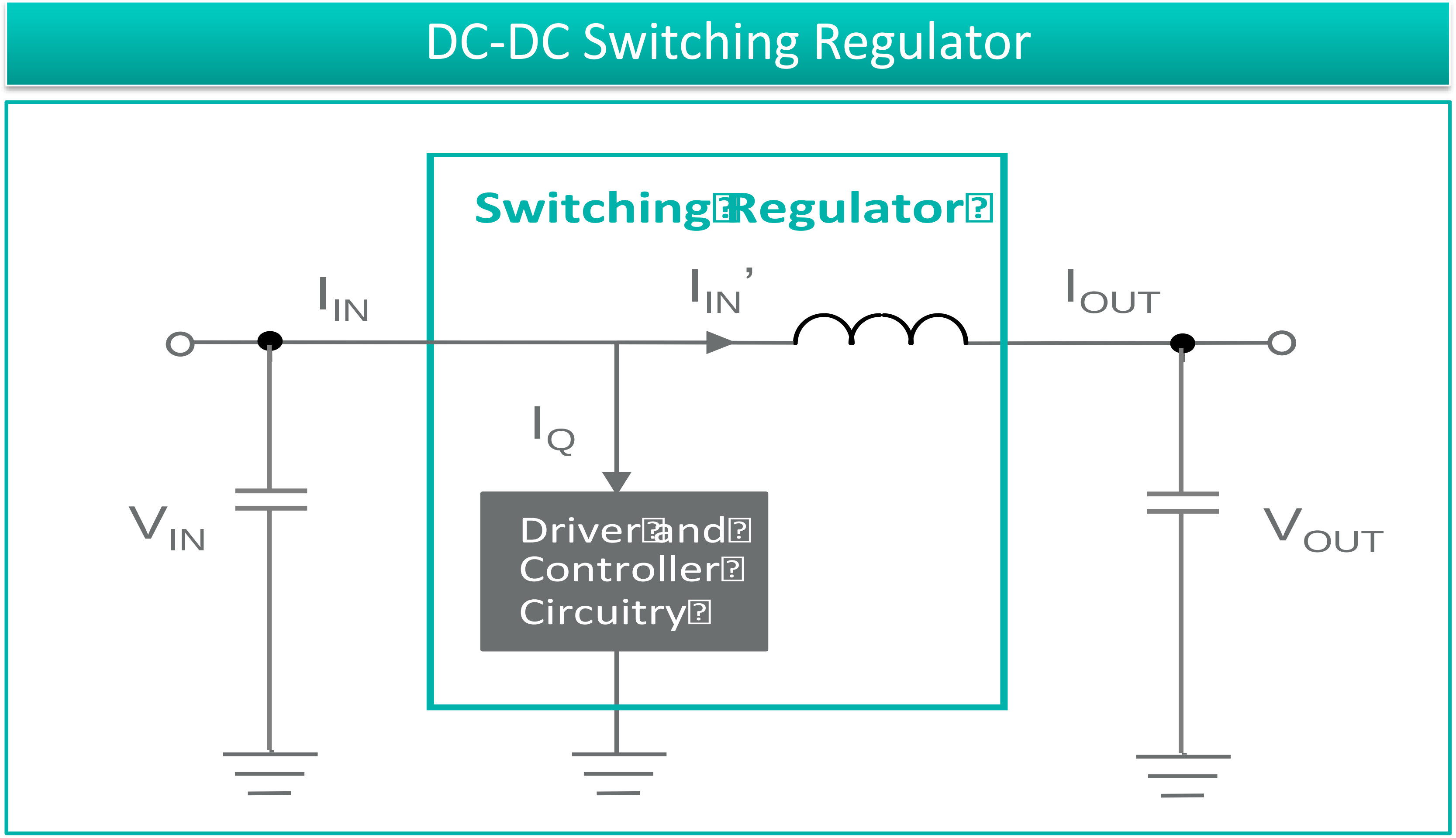
New applications?

What is nanoPower?

A device with quiescent current less than 1µA

$$1\text{nA} = \frac{1}{1{,}000{,}000{,}000}\text{A} = 0.000000001\text{ A}$$

I_Q = Quiescent Current/Standby Current

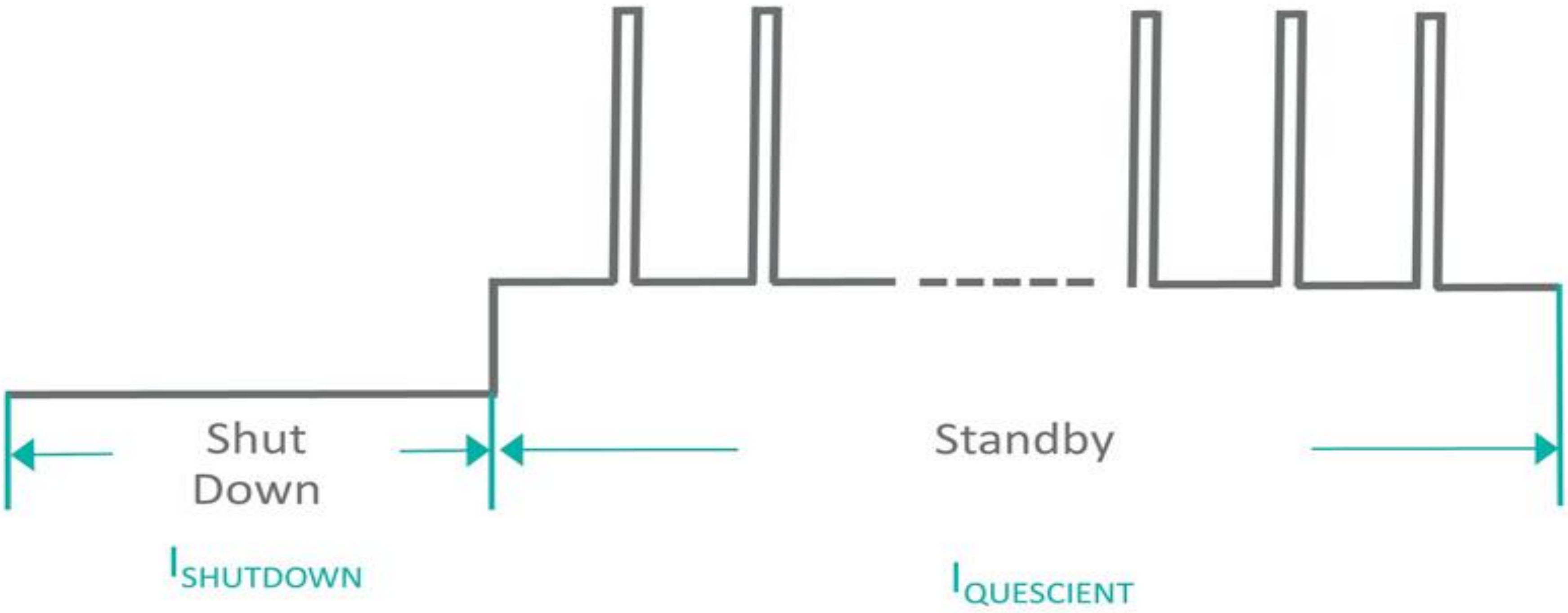


Quiescent Current is the minimum amount of current for the converter to stay alive when it is not in use

(no switching, no load but enabled).

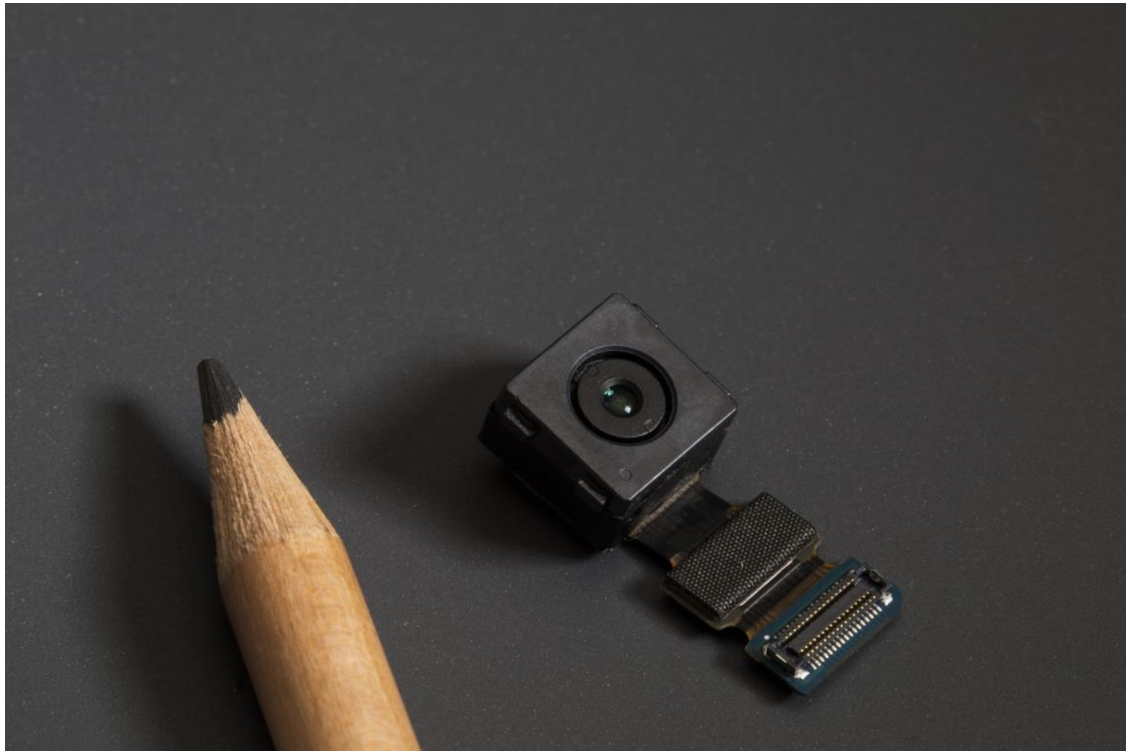
$I_Q \neq$ Shutdown Current

- Shutdown current - device is “asleep”
- Quiescent current – device is “resting” and ready to work



Power Profile of IoT Node Devices

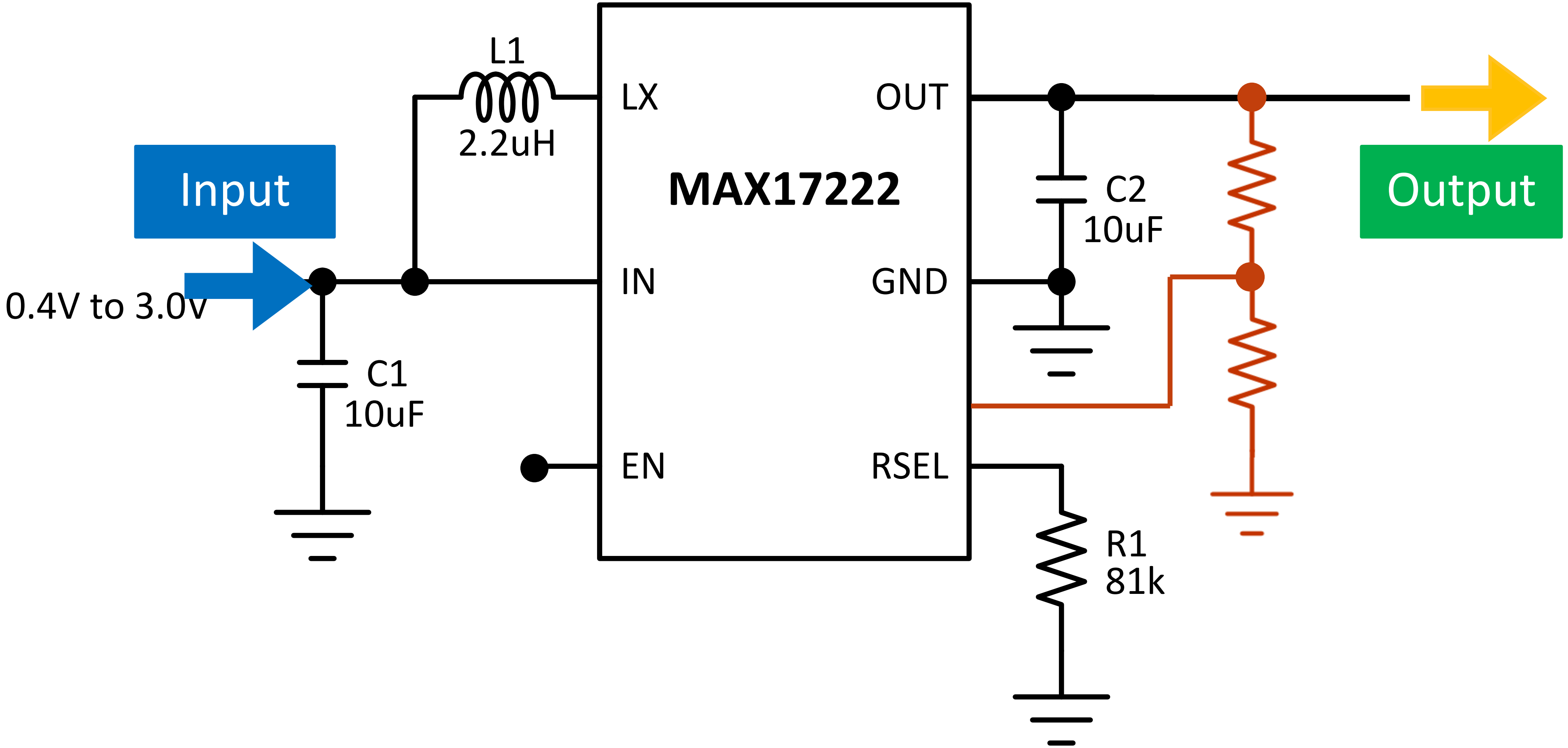
Critical Trends



Smaller devices

Low duty cycle hardware

nanoPower Boost with True Shutdown



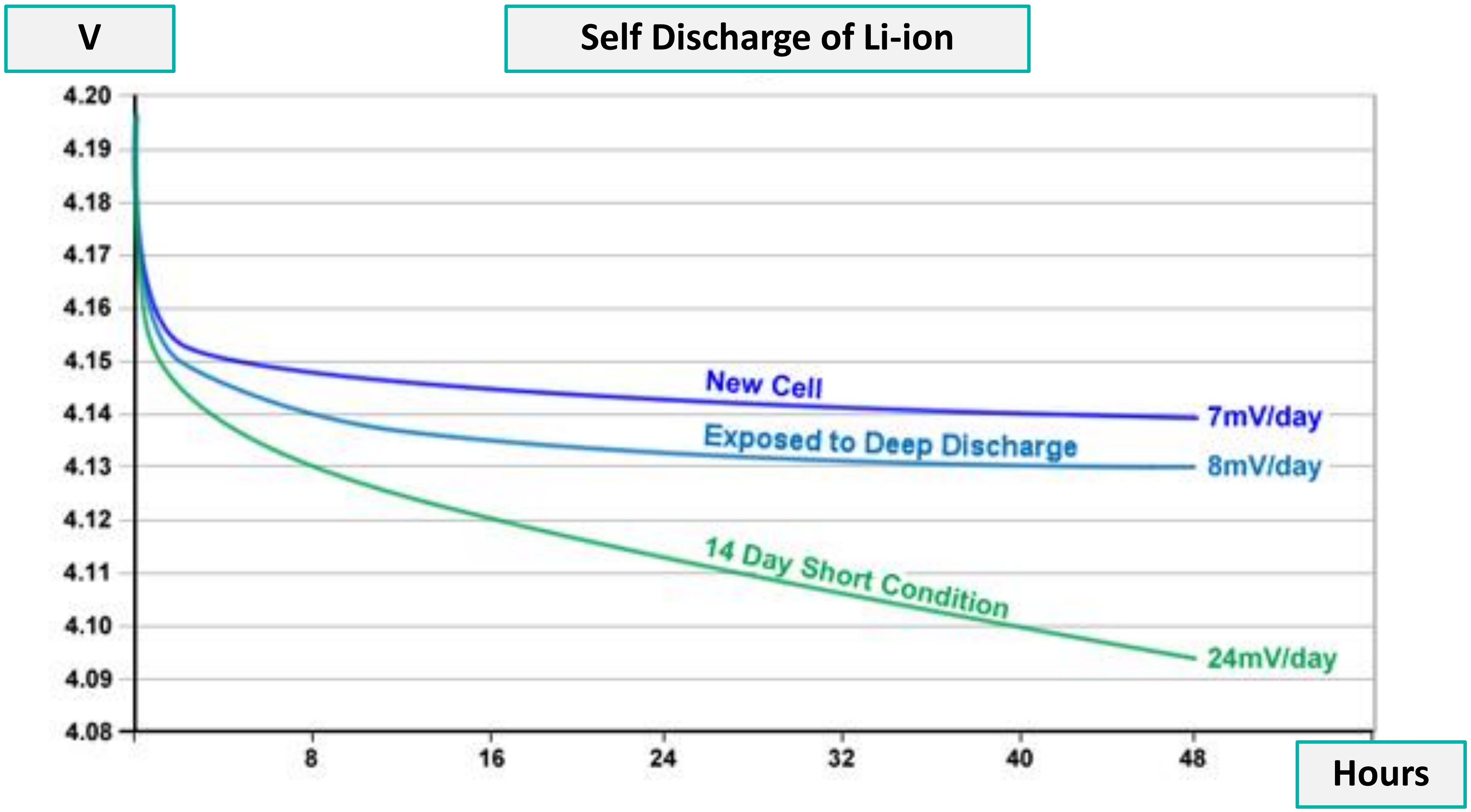
Why is nanoPower important?

- Extending battery life – why batteries?

How do we get more usable power?

- How do we keep the device enabled?

Battery Challenge - Self Discharge



Courtesy of Battery University
http://batteryuniversity.com/learn/article/elevating_self_discharge

Examples

Battery system	Estimated self-discharge
Primary lithium-metal	10% in 5 years
Alkaline	2–3% per year
Lead-acid	5% per month
Nickel-based	10–15% in 24h, then 10-15% per month
Lithium-ion	5% in 24h, then 1–2% per month (plus 3% for safety circuit)
Silver oxide	0.7% per month*

Courtesy of Battery University
http://batteryuniversity.com/learn/article/elevating_self_discharge
* https://www.eetimes.com/author.asp?section_id=36&doc_id=1322736

Why NanoPower Regulators?

Lithium Coin

Specifications

Classification:	"Lithium Coin"
Chemical System:	Lithium / Manganese Dioxide (Li/MnO_2)
Designation:	ANSI-5034LC, IEC-CR1216
Nominal Voltage:	3.0 Volts
Typical Capacity:	34 mAh (to 2.0 volts) (Rated at 62K ohms at 21°C)
Typical Weight:	0.6 grams (0.02 oz.)
Typical Volume:	0.2 cubic centimeters (0.01 cubic inch)
Max Rev Charge:	1 microampere
Energy Density:	118 milliwatt hr/g, 413 milliwatt hr/cc
Typical Li Content:	0.008 grams (0.0003 oz.)
UL Recognized:	MH29980
Operating Temp:	-30C to 70C
Self Discharge:	~1% / year

ENERGIZER CR1216

Why NanoPower Regulators?

- Smaller Devices Need Smaller Batteries
  - > CR1216 Lithium Coin Cell
    - 34mAh from 2V to 3V Terminal Voltage
    - That's Only **39nA** Self Discharge Current!
    - **10 Year** Operating Life is **390nA** Average Load

- NanoPower Regulators
  - > Need to Power Circuitry with Long Idle States
  - > Regulator Quiescent Current Should Compete with Battery Self-Discharge
  - > NanoPower Regulators Draw <1uA Quiescent Current While Regulating

Product Standby life

- CR1216, 34mAh, Lithium coin cell

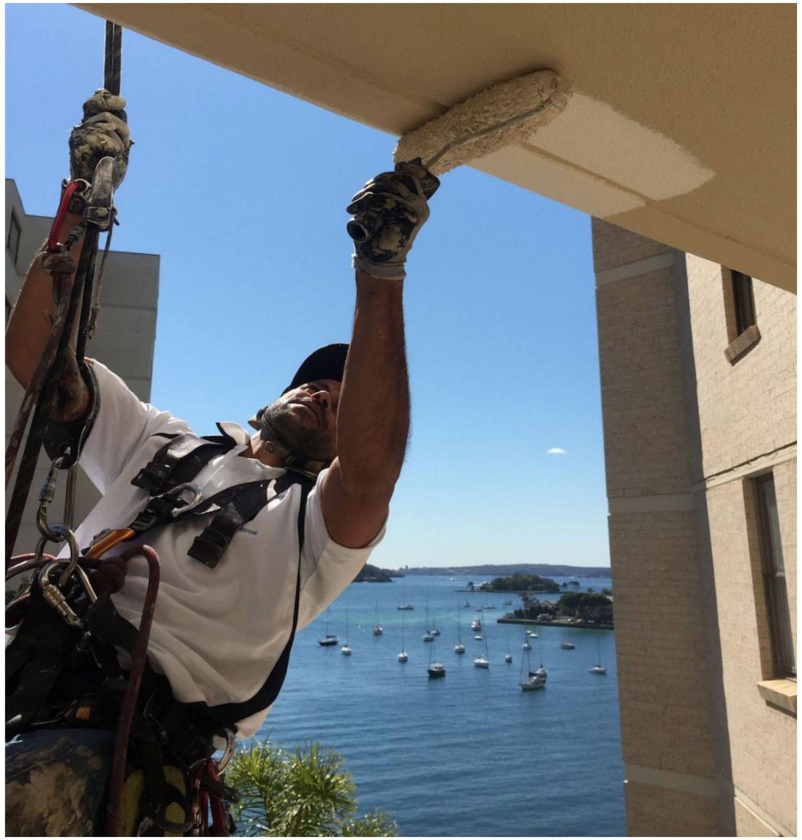
Circuit quiescent current	Standby life
4µA	1 year
3µA	1.3 years
2µA	1.9 years
1µA	3.9 years

Additional Benefits - Extended Battery Life/Smaller Battery

New form factors/applications

- Medical
- Consumer
- Industrial

Additional Benefits of Extended Battery Life

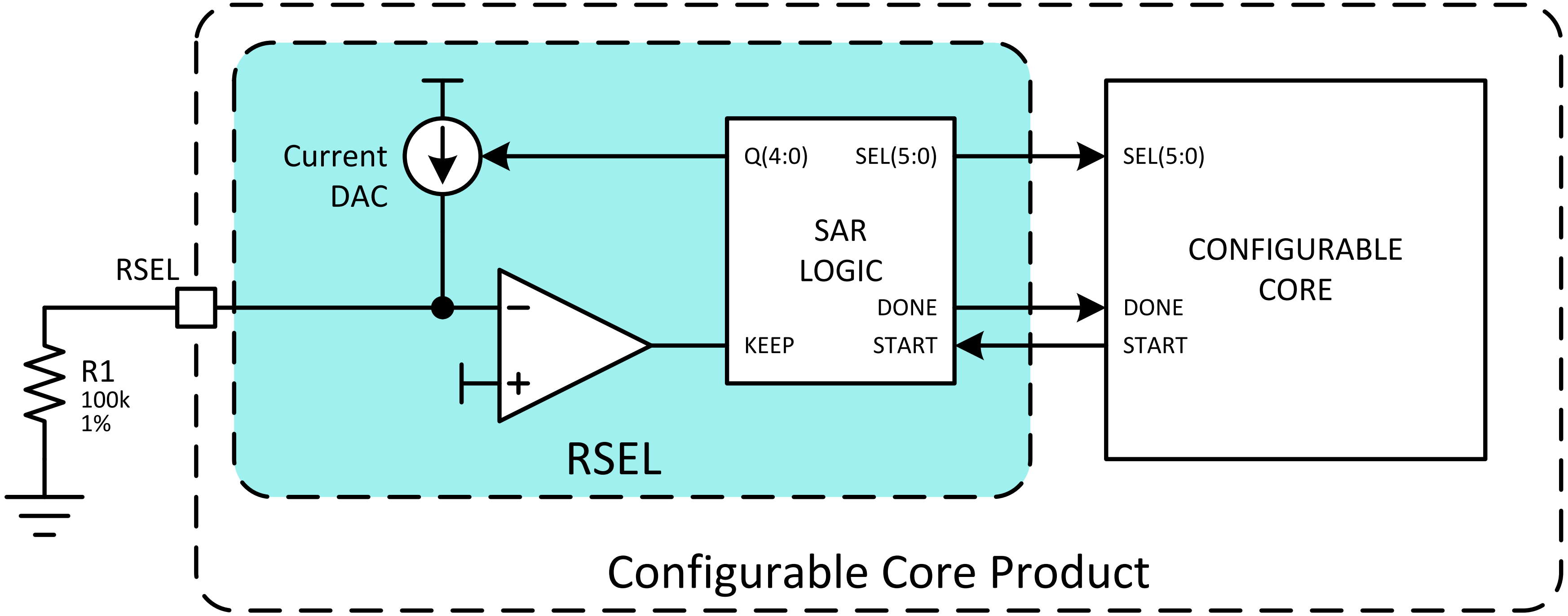


Reduce limited access/costly maintenance

Achieving nanoPower

How do we achieve nanoPower?

- Single Resistor Output Selection - RSEL
- 33 configuration states
- No supply current after initial acquisition



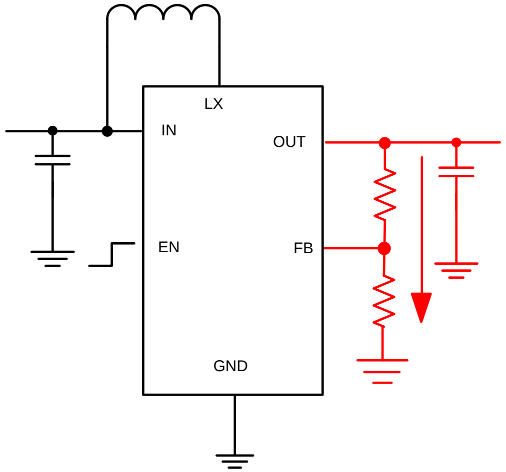
RSEL Eliminates Power Loss Through Feedback Network

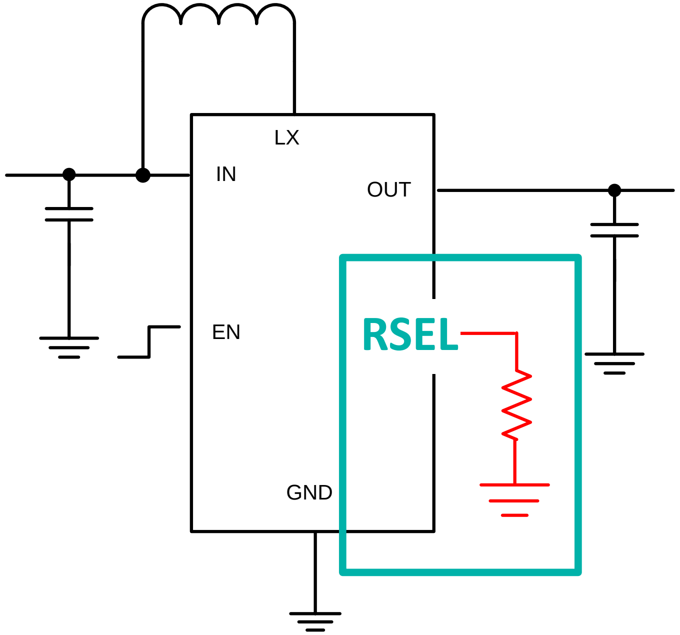
Feedback network

- Setting output voltages with high impedance resistor
- 1MΩ = 3.3uA for 3.3V output

RSEL IP enables Ultra-low power sensitive applications

- Unique single resistor voltage setting
- Uses 200µA for 600µs during startup
- Zero Losses during power regulating

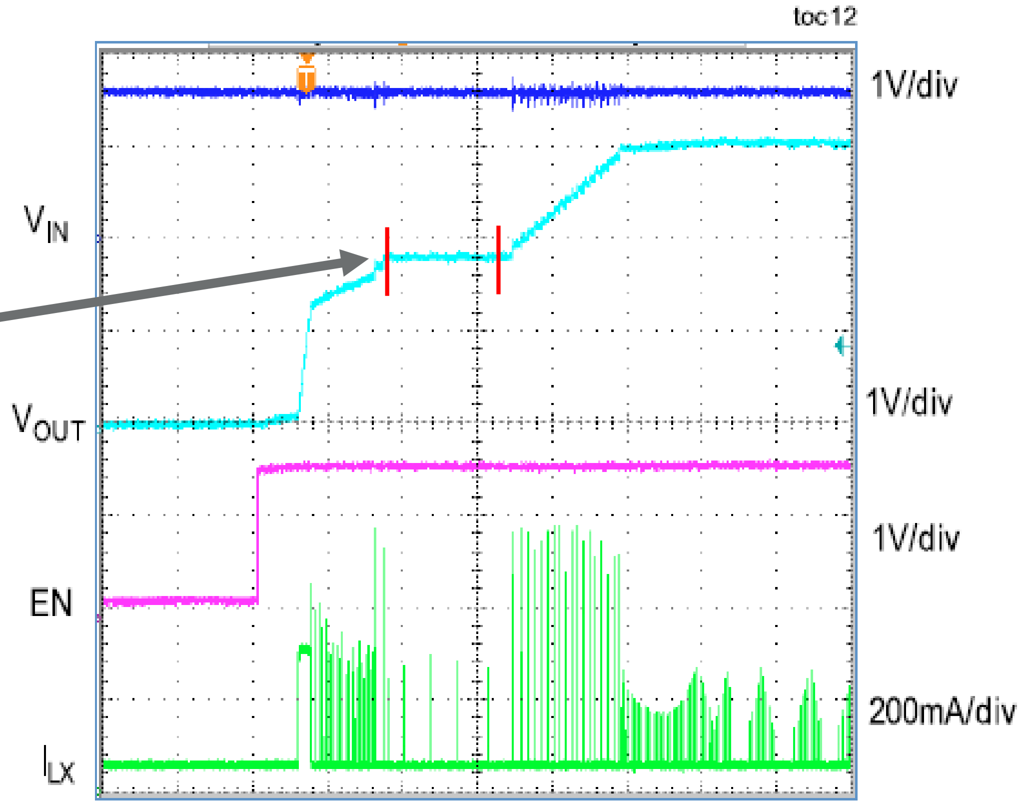




RSEL in Action

Vout plateau during startup

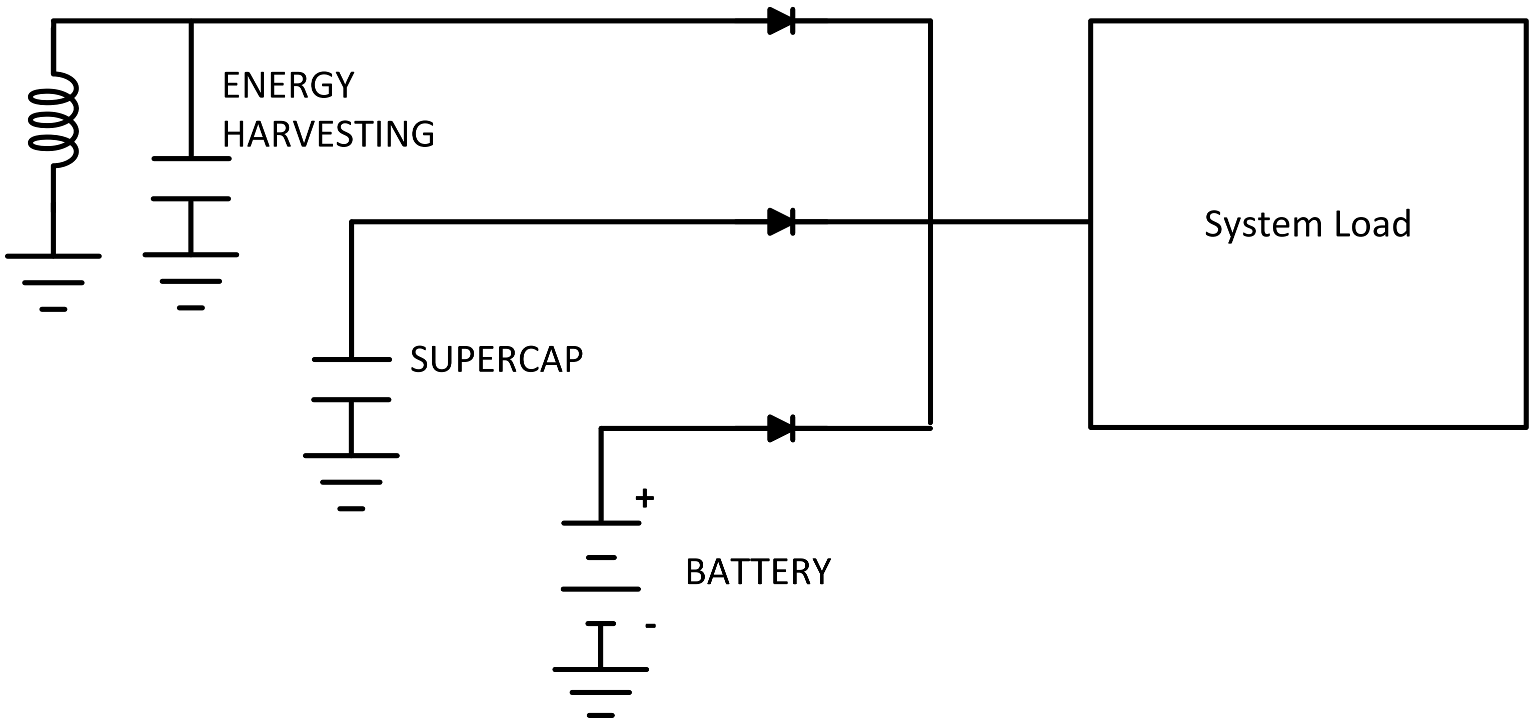
STARTUP



V_{IN} = 1.5V, V_{OUT} = 3V, I_{OUT} = 3K
400µs/div

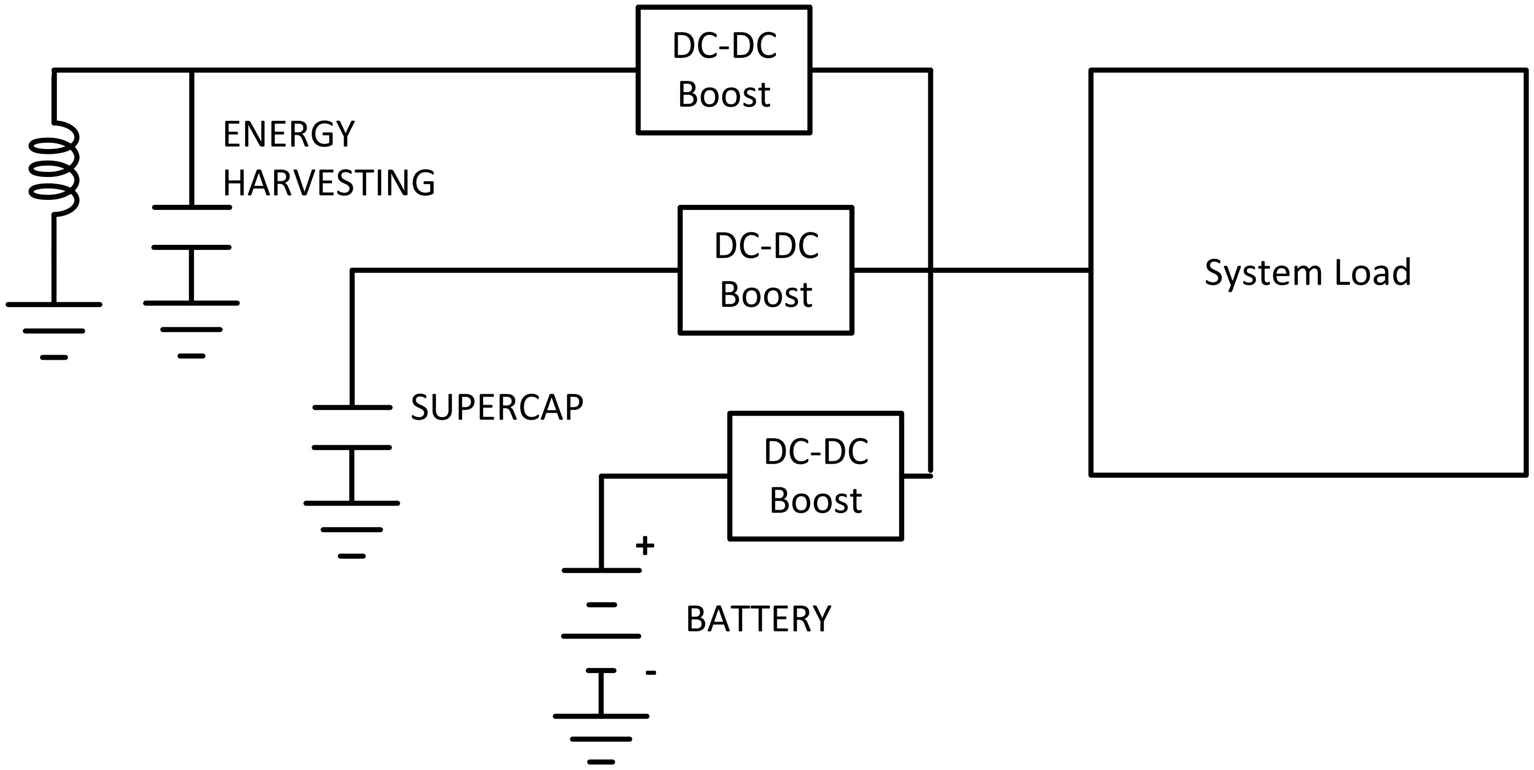
Diode Losses

- Multiple energy sources
- Loss ~ 0.7V



Diode Losses

- Multiple energy sources
- Loss ~ 0.7V
- Additional power
- True shutdown eliminates diode losses



Savings:

- I_{diode} = 3µA sleep/5mA run
- 3V supply
- 3% duty cycle
- ~ 153µA
- ~ 107µW
- 2AA batteries
- 18% improvement in battery life

Implementing nanoPower

Shutdown

True Shutdown, I ~ tens of nA

Quiescent current, Iq ~ hundreds of nA

Power Supply Accuracy

MAX1722X

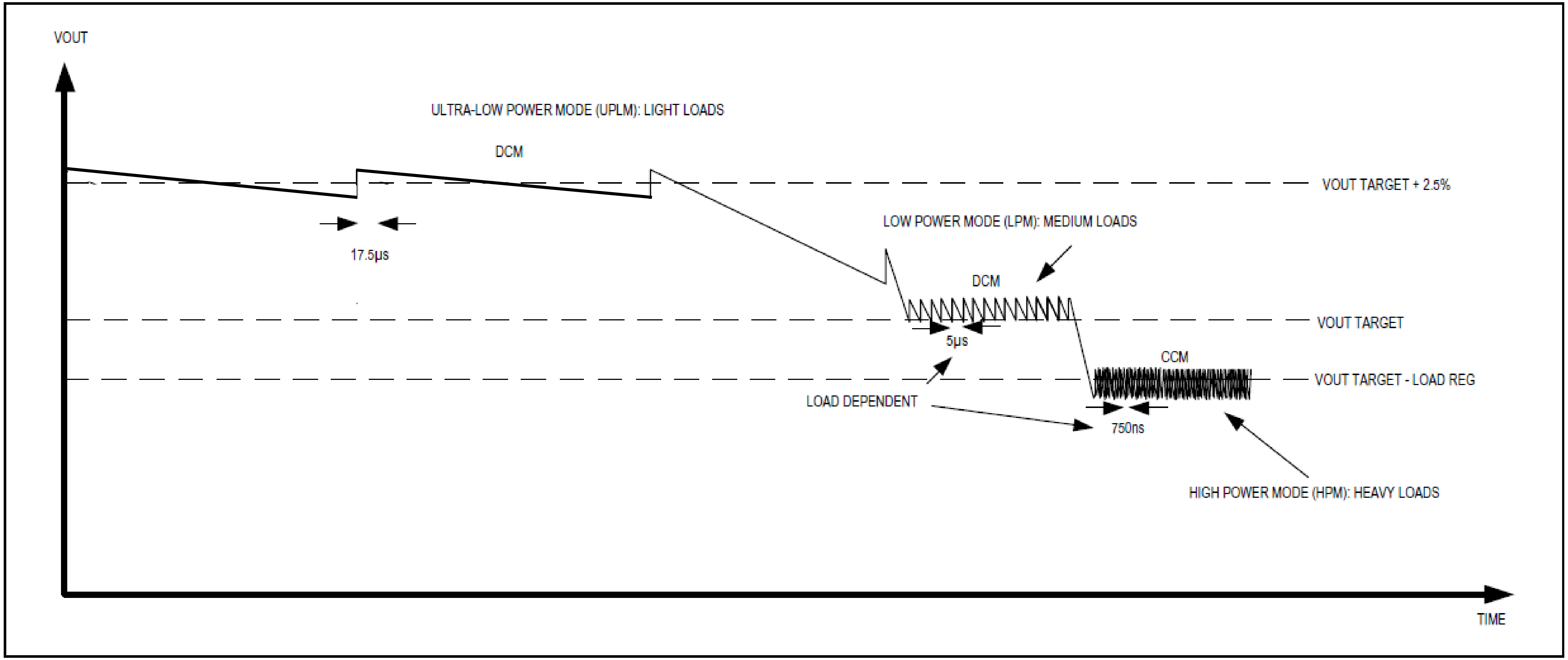


Figure 4. ULPM, LPM, and HPM Waveforms (Part 1).

Systems Requiring High Power Supply Accuracy

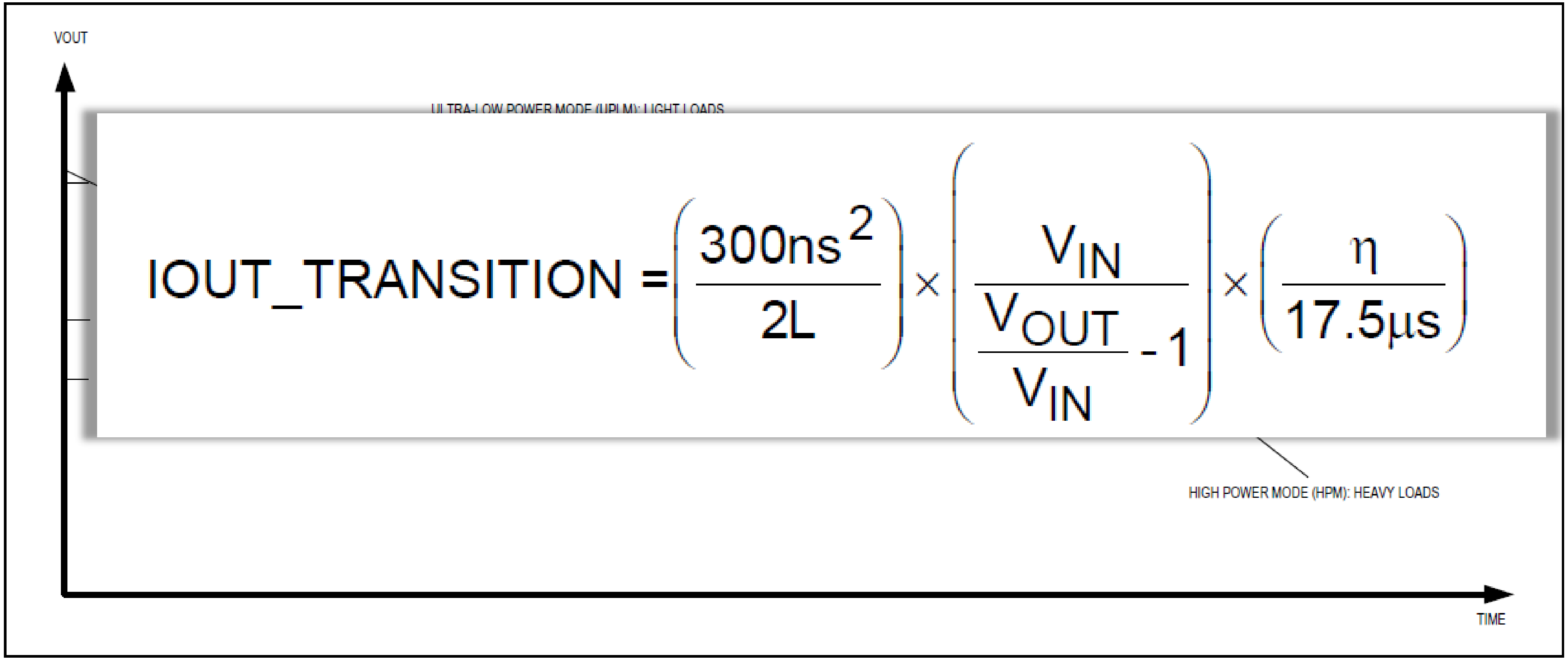
MAX1722X example – power supply only

- Accuracy:
  - 3% in Low Power Mode (LPM)
  - 4% in Ultra Low Power Mode (ULPM)

- Why?
  - Switching frequency minimized to reduce current consumption and accommodate transients

Power Supply Accuracy

MAX1722X

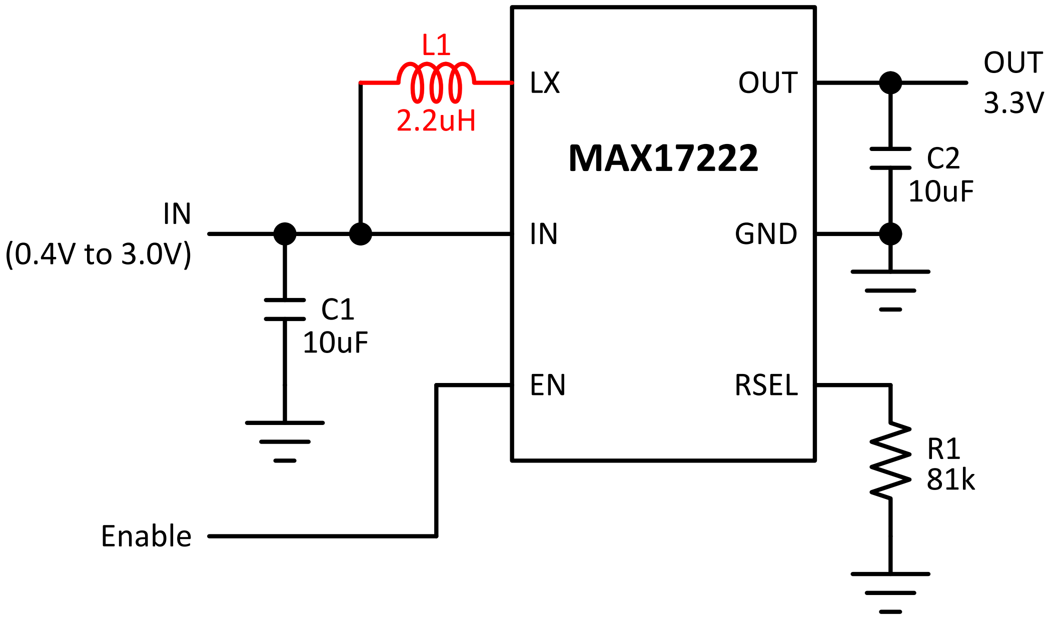


$$IOUT\_TRANSITION = \left(\frac{300ns^2}{2L}\right) \times \left(\frac{V_{IN}}{\frac{V_{OUT}}{V_{IN}} - 1}\right) \times \left(\frac{\eta}{17.5\mu s}\right)$$

Figure 4. ULPM, LPM, and HPM Waveforms (Part 1).

How Small Can the Inductor Be?

- Inductor Winding Resistance
  - > Increases I^2R Losses
  - > 0.1ohm to 0.3ohm Reduces **Efficiency** by ~3%
- Lower I_{SAT} Reduces Max Output Current
  - > $I_{LX}(peak) < I_{SAT}$
  - > $I_{OUT}(max) = [I_{LX}(peak) - dI_{LX}/2]*V_{IN}/V_{OUT}*Efficiency$
- Lower Inductance Reduces Max Output Current
  - > $dI_{LX} = toff*(V_{IN}-V_{OUT})/L$
  - > $I_{OUT}(max) = [I_{LX}(peak) - dI_{LX}/2]*V_{IN}/V_{OUT}*Efficiency$



Inductor Relationships

- Larger inductors – lower DCR
- Use a simulation tool

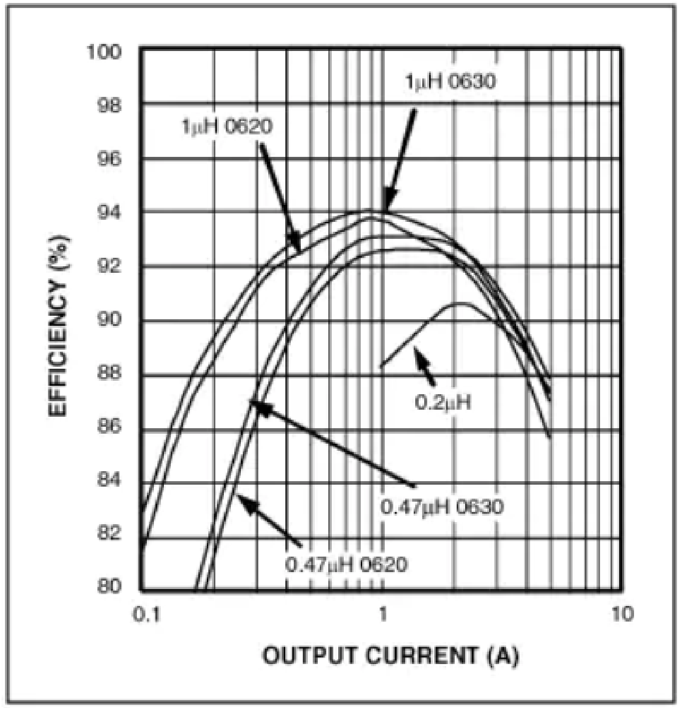


Figure 2. Efficiency vs. output current for various inductors operating in the Figure 1 circuit.

App note: https://www.maximintegrated.com/en/app-notes/index.mvp/id/3988

maxim integrated™

nanoPower Devices

- DC-DC converters
- Supervisors
- Comparators
- Current sense amps
- Op amps
- Real time clocks
- Microcontrollers

NOT nanoPower Devices

- Microprocessors
- Data converters
- RF devices
- Interface
- Light and sound emitting

Maxim's Latest nanoPower Portfolio

Power, Signal Conditioning, Supervisory - www.maximintegrated.com/nanoPower

Category	Part Number	Description
Power	MAX17220-MAX17225	300nA IQ, 0.4V to 5.5V **Boost Converter** with True Shutdown
	MAX17270- MAX17273	**Single Inductor Multiple Output Buck Boost** Converter
	MAX38640	300nA IQ 1.8V to 5.5V **Buck Converter**
Signal Conditioning	MAX9634	500nA IQ, precision **current sense amplifier**
	MAX40000 – MAX40001	900nA IQ **comparator** with built-in references
	MAX40002 – MAX40005	500nA IQ **comparator**
	MAX40007	700nA IQ **Op-amp**
	MAX6069	1µA WLP **Shunt Reference** for Sensors
Supervisory	MAX16056 – MAX16059	125nA supervisory circuit with capacitor adjustable reset and watchdog
	MAX16072 – MAX16074	700nA nanoPower supervisory circuit in tiny WLP package
	MAX16140A	350nA IQ Power Supervisory Reset IC in WLP
RTC	MAX31341	180nA **real time clock** w/power management

nanoPower Signal Chain and Supervisory ICs

Supervisor

Features

- 350nA Supply Current
- Edge/Level MR Input
- OD/PP Reset Output
- WLP & 5-SOT23 Packages

Op amp

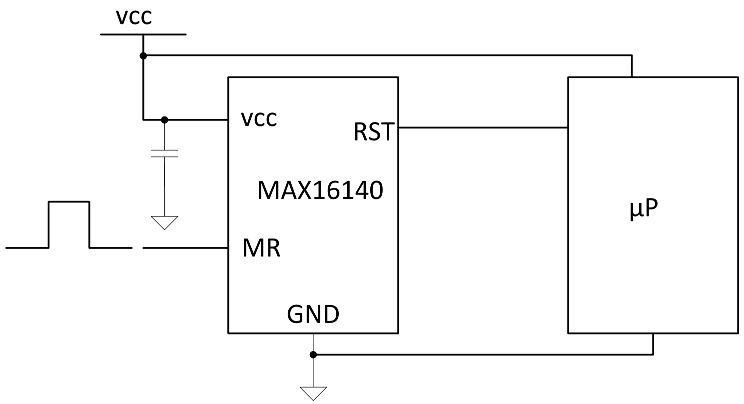
Features

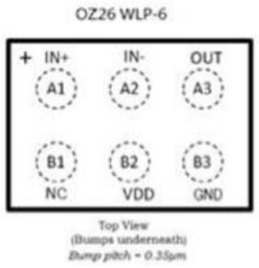
- 1.7V to 5.5V supply range
- 700nA quiescent current (typ), 900nA (max)
- 6-Pin WLP with 0.35mm pitch

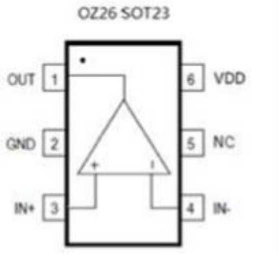
Comparator

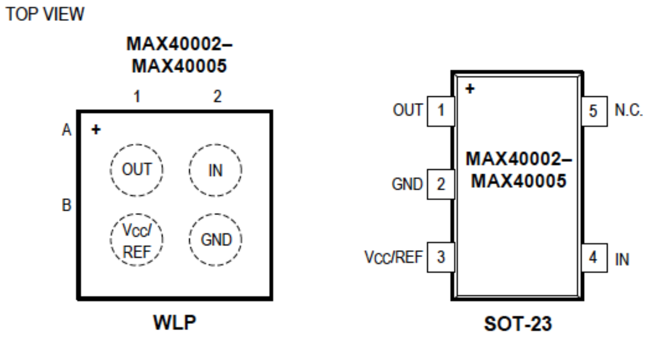
Features

- 1.7V to 5.5V supply range
- 450nA supply current
- 9ms propagation delay
- 4-Pin 0.73mm x 0.73mm WLP with 0.35mm pitch and SOT23 packages





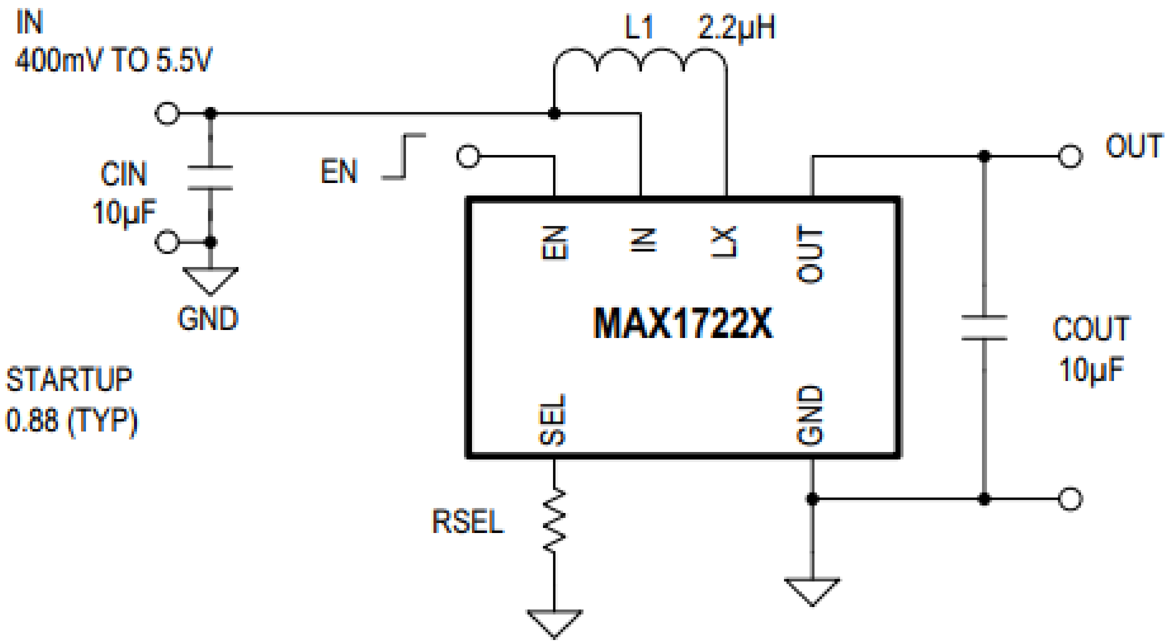




MAX17220/2/3/4/5 nanoPower Boost Converter

Features

- 0.4V to 5.5V Input, 0.88V Start up voltage
- 300nA Low IQ, 0A reverse current from during True Shutdown
- Package options:
  - 0.88mm x 1.4mm 6-WLP
  - 2mm x 2mm 6-pin uDFN Packages
- 225mA/500mA/1A IIN Limit Allows Small Inductor Options (1.6 x 0.8 x 0.6 or 2.0 x 1.5 x 1.0)
- 33 Output Voltages by a Single Resistor (RSEL)



Lowest I_Q in the smallest possible form factor

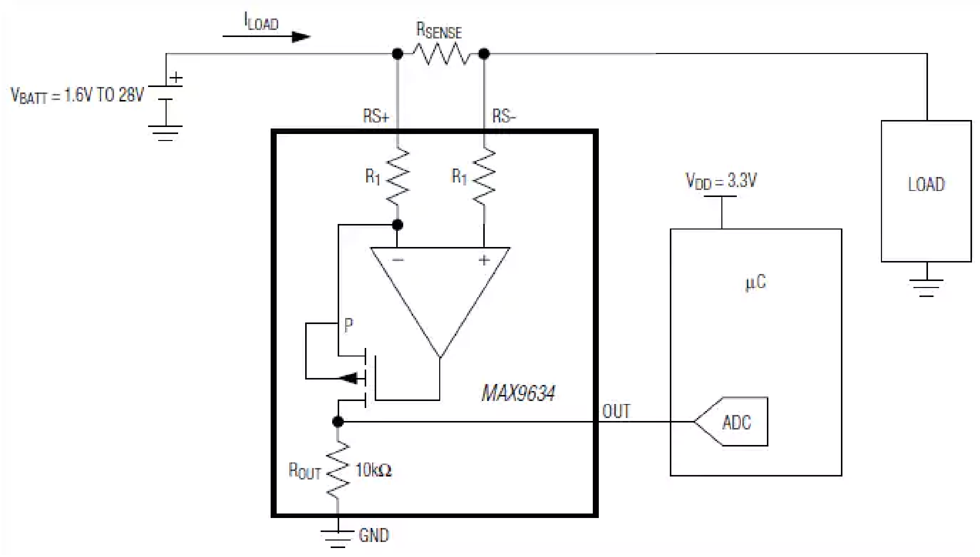
maxim integrated™

nanoPower Precision Current-Sense Amplifier

Save system power with < 1µA quiescent current

MAX9934

- Low 250µV Input Offset Voltage
- Low < 0.5% (max) Gain Error
- Four Gain versions:
  - •25V/V
  - •50V/V
  - •100V/V
  - •200V/V
- 1.6V to 28V Input Common Mode
- 5-Pin SOT & 4-Bump 1mm x 1mm uCSP



Applications

- Smart Phones & Tablets
- Portable Battery Systems
- Notebooks

nanoPower Comparator - Smallest Package (0.73 x 0.73mm)

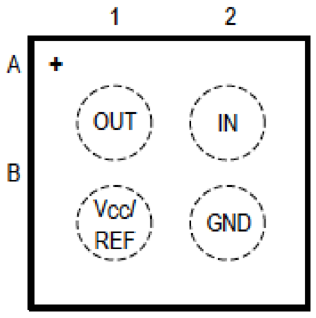
MAX40002-05

Features

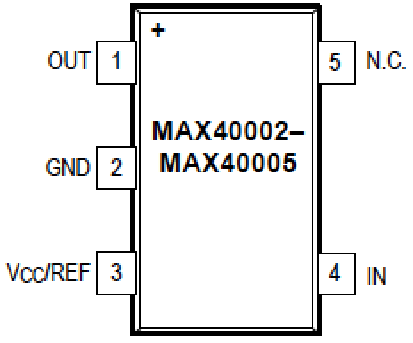
- 1.7V to 5.5V supply range
- 450nA supply current
- 9µs propagation delay
- 4-Pin 0.73mm x 0.73mm WLP with 0.35mm pitch and SOT23 packages

TOP VIEW

MAX40002–MAX40005



WLP



SOT-23

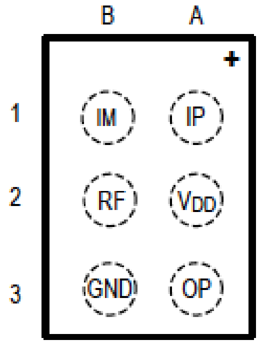
nanoPower Comparator: Tiny Size and Internal 1% Reference

MAX40000-01

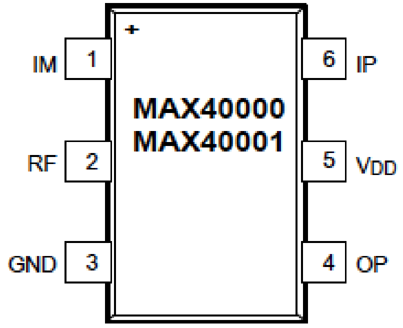
Features

- 1.7V to 5.5V supply range
- 900nA supply current
- 6µs propagation delay
- 6-Pin 0.73mm x 1.07mm WLP with 0.35mm pitch and SOT23 packages

MAX40000
MAX40001



6-WLP



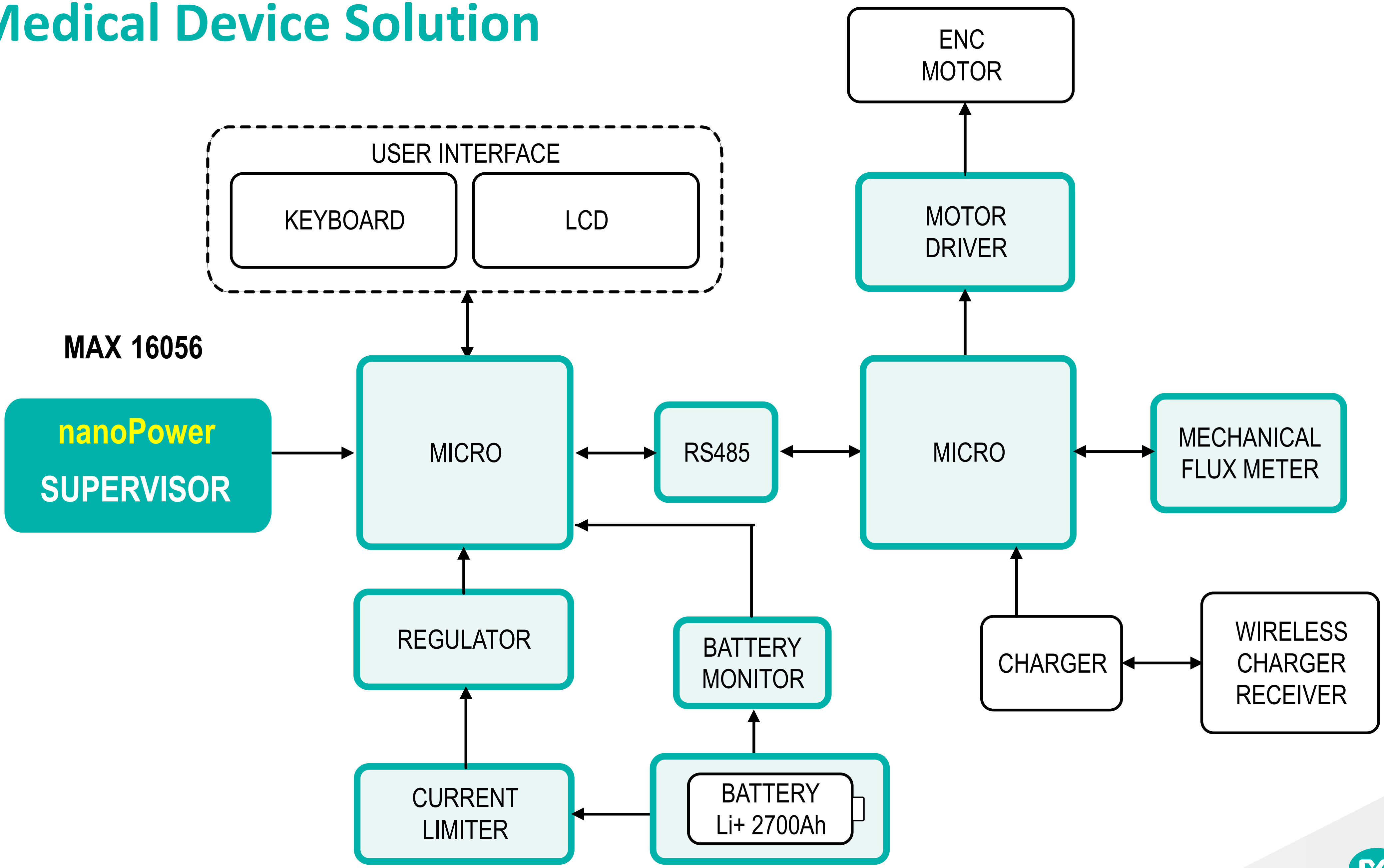
SOT23-6
(TOP VIEW)

Examples of nanoPower

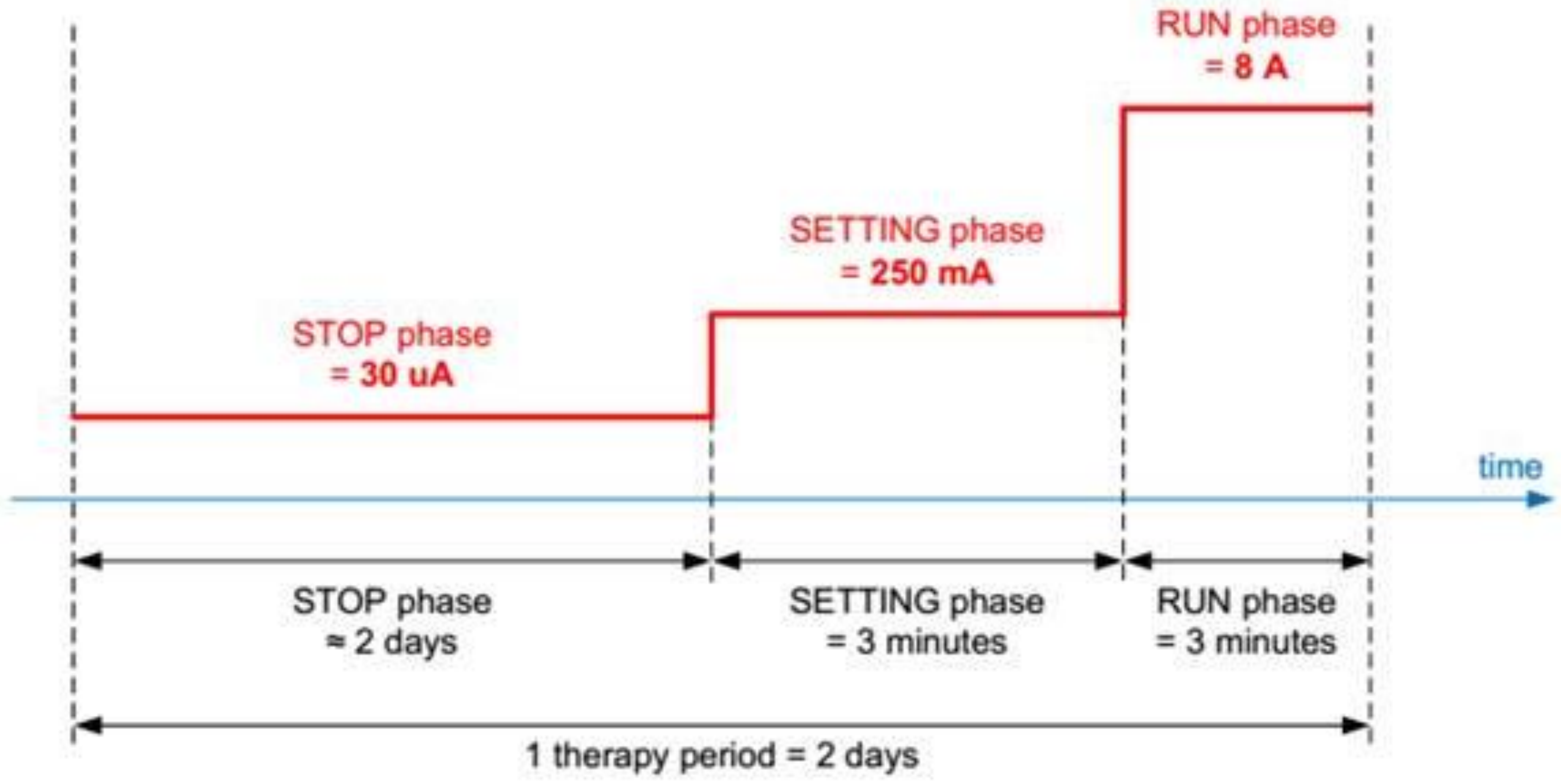
Examples of nanoPower

- Medical pump
- Security repeater
- Camera
- Wearable patch
- Gas meter

Medical Device Solution



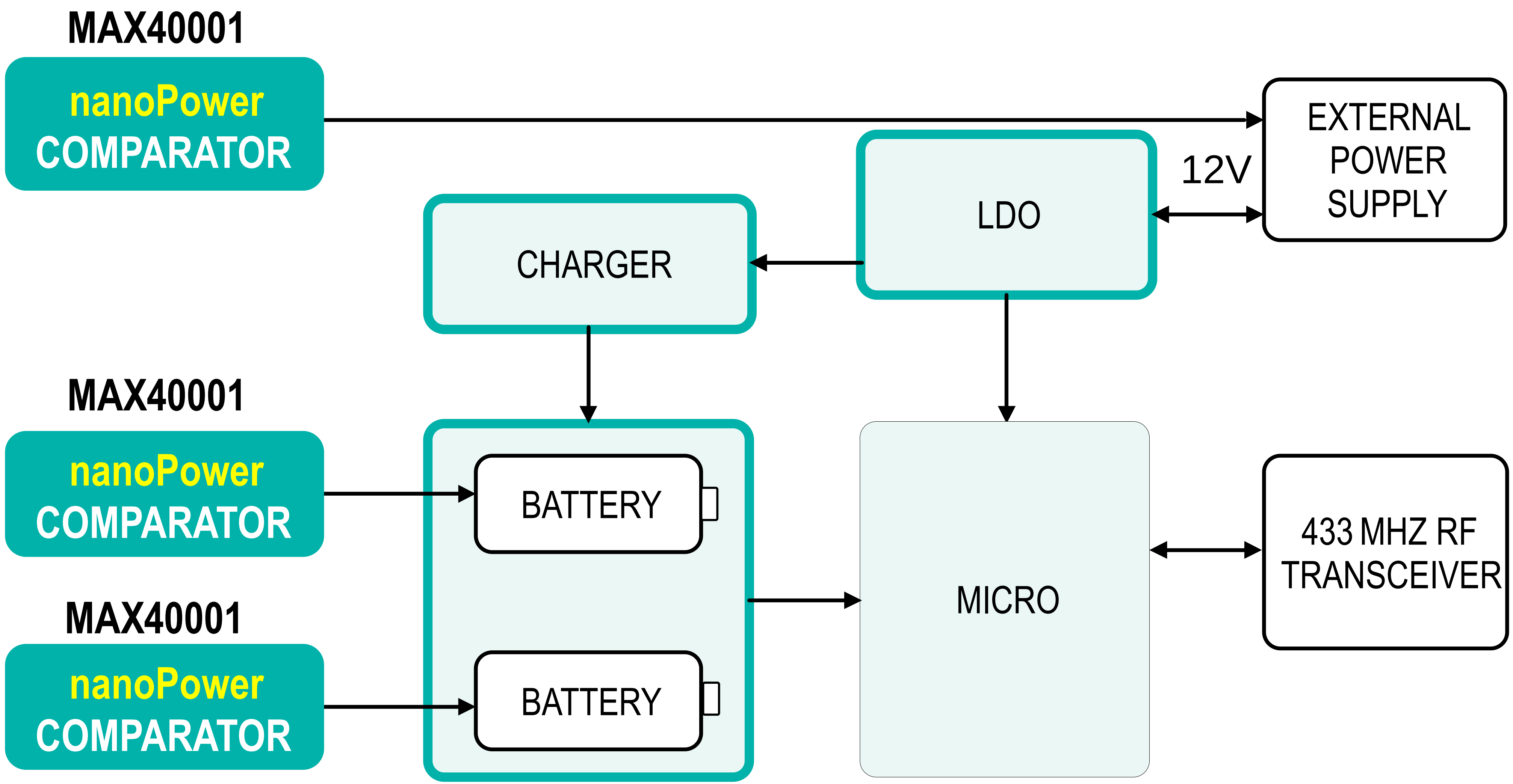
Medical Device Power Profile



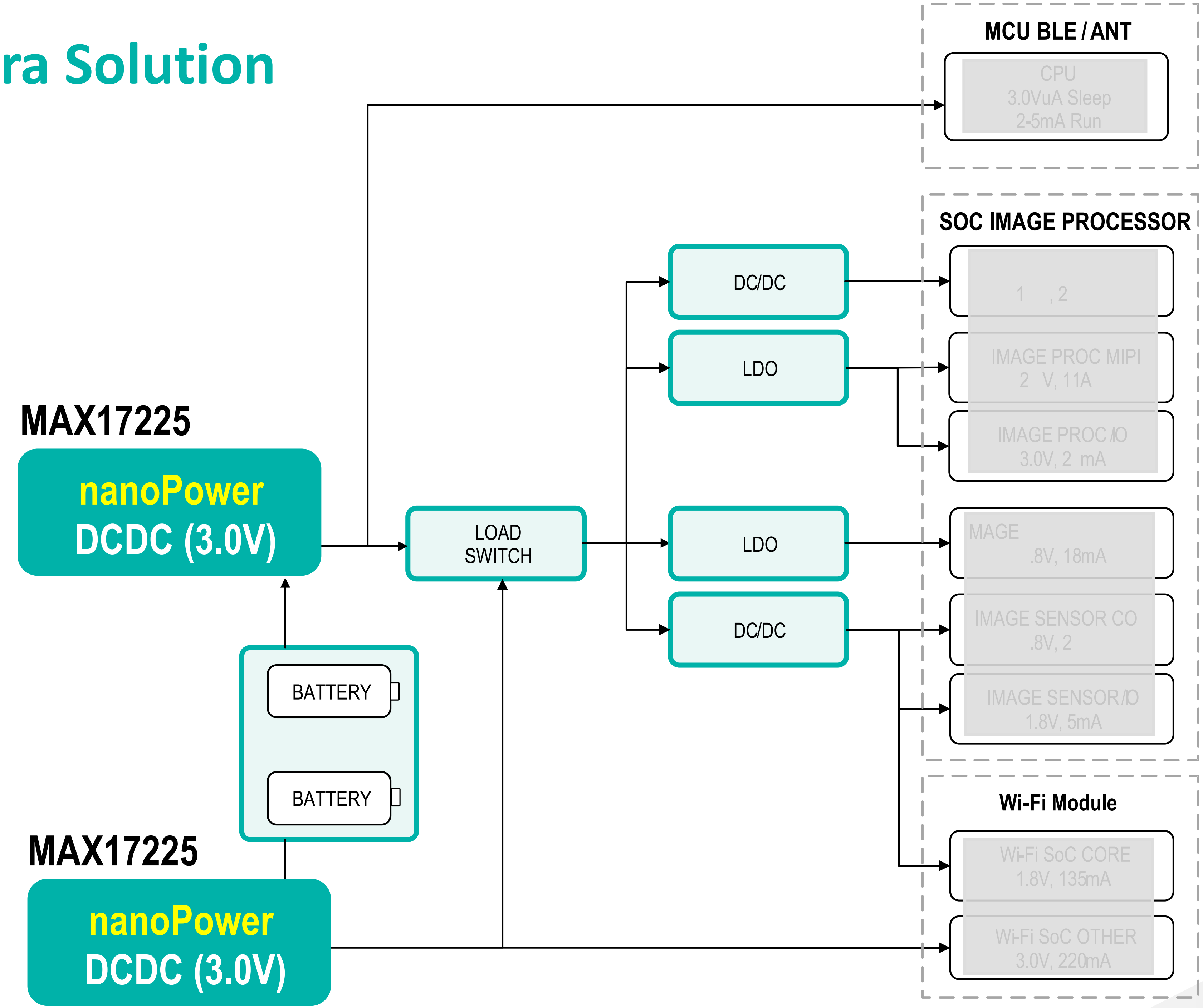
0.2% duty cycle

maxim integrated™

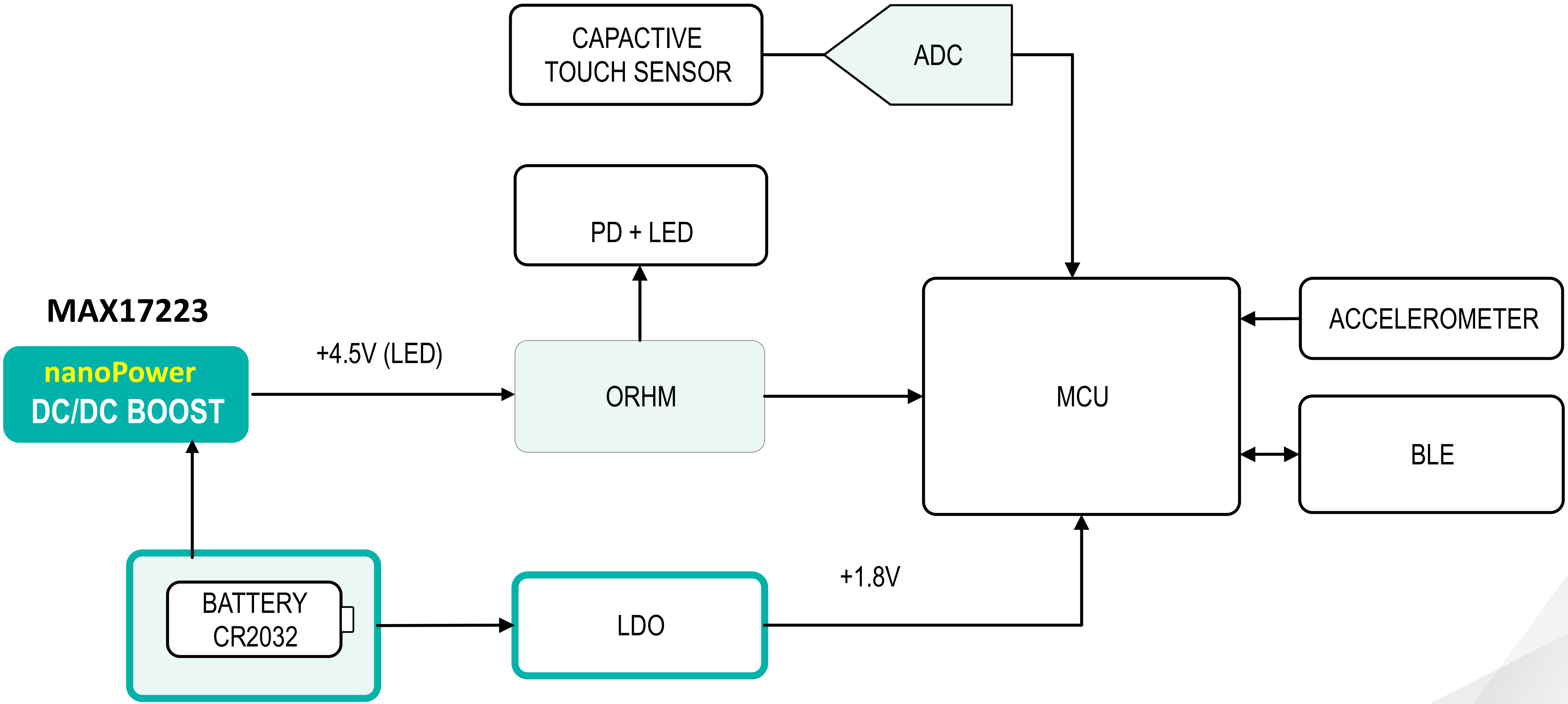
Security Repeater Solution



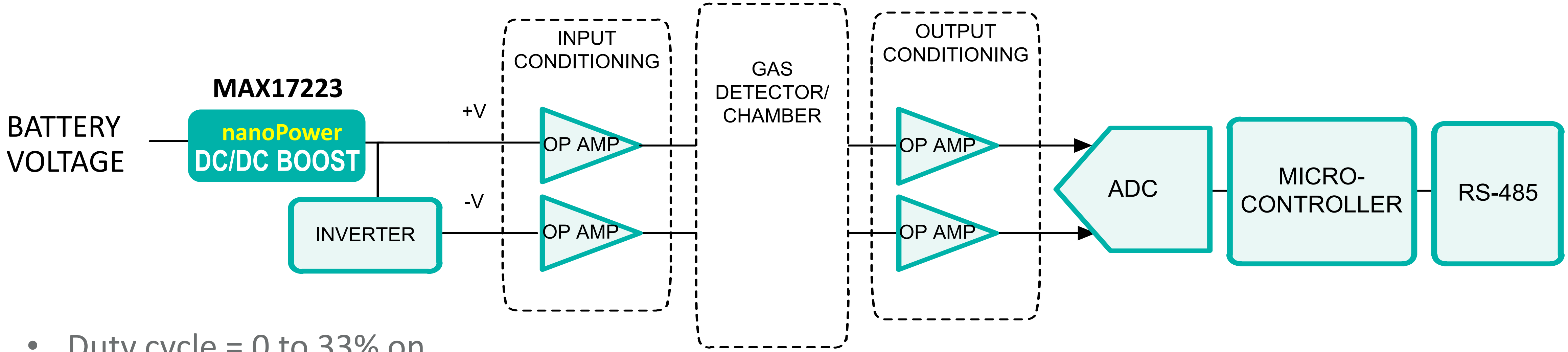
Camera Solution



Patch Solution



Gas Detector



- Duty cycle = 0 to 33% on
- 2V to 3V for two cells
- 3V at 100mA
- Battery life ~ a few thousand hours

nanoPower – in Conclusion

Devices with a quiescent current less than 1µA

- A technology that enables new applications
- A new generation of ultra low power devices/new design tool
- A set of features that minimize current consumption
- A set of energy free functions