MSP430 Power Solutions
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Powering the MSP430

Power Supply
30uA – 5mA

MSP430
0.5 uA
MSP430 Power Requirements

• Typical Input Voltage Range (MSP430F2111)

<table>
<thead>
<tr>
<th></th>
<th>MIN</th>
<th>NOM</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCC</td>
<td>1.8</td>
<td>3.6</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

- Typical Operating Current (MSP430F2111)
  - Active mode 300μA to 5mA
  - Sleep mode 100nA

• Regulation required for Flash programming
  - 2.7V to 3.6V

• Regulation required for ADC
  - 2.2V to 3.6V

• Not all inputs are 1.8V to 3.6V
  - 5V bus
  - 110VAC
  - Single AA,AAA – 0.9V to 1.6V
  - CR2032 Manganese Dioxide Lithium– 2.0V to 3.0V
  - Solar Cell
Performance vs Voltage

- If you need to run fast, you need regulation
- Higher performance requires higher Vin

Note: This graph includes line, load, temp, ripple, transients, etc.

Minimum Operating Voltage

MSP430F2111

\[
F = m \cdot V_{cc} + b
\]

\[
m = \frac{\Delta F}{\Delta V}
\]

\[
\Delta F = F_2 - F_1 = 16MHz - 6MHz
\]

\[
\Delta V = V_2 - V_1 = 3.3V - 1.8V
\]

\[
V_{min} = \frac{F + 6MHz}{b} \cdot \frac{MHz}{V}
\]
10MHz Design Example

To operate at 10MHz, you must guarantee Vcc greater than

\[
V_{\text{min}} = \frac{F + \text{6MHz}}{\text{6.667MHz/V}} = 2.4V
\]

With 1% LDO and 0% ripple, Vcc\_nom = 2.4V + 1% = 2.42V

With 3% switcher and 2% ripple, Vcc\_nom = 2.4V + 3% + 2% = 2.52V

System Level Power Management

- Optimize code
  - Reduce memory accesses
  - Reduce clock cycles needed to complete a task
- Shutdown unused circuits
  - Partition the system into different power islands
- Dynamic voltage and frequency scaling
  - Reducing the voltage and frequency
Dynamic voltage and frequency scaling

- Reduce the frequency to the lowest clock rate that gets the job done and meets system requirements
- Reduce the voltage to the minimum required to meet the IC requirements

\[ P \propto C \cdot V_{DD}^2 \cdot F + V_{DD} \cdot I_{leakage} \]

### MPS430 Operating Current vs Frequency

**Versus frequency**

Current consumption of active mode versus system frequency, F-version

\[ I_{AM} = I(AM) \cdot (1 \text{ MHz}) \cdot (\text{System [MHz]}) \]

\[ I_{AM} = \left( 175 \frac{\mu A}{V \cdot V_{cc}} - 105 \mu A \right) \cdot \text{Freq} \]

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Voltage (V)</th>
<th>Active Mode Current (\mu A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3.6</td>
<td>3150</td>
</tr>
<tr>
<td>1</td>
<td>3.6</td>
<td>525</td>
</tr>
<tr>
<td>1</td>
<td>2.2</td>
<td>280</td>
</tr>
</tbody>
</table>

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Dynamic Frequency Scaling

Vcc = 3.3V @ 16 MHz
Vcc = 3.3V @ 8 MHz

Task A    Task B    Task C

Power

Time

Cumulative Energy

Vcc = 3.3V @ 16 MHz
Vcc = 3.3V @ 8 MHz

Task A    Task B    Task C

Time
Dynamic Voltage Scaling

- Discrete implementation

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Dynamic Voltage Scaling

- Discrete implementation

DVS - Discrete Example

Fall time is set by decay of load current from TPS62200 output capacitor

For a detailed explanation, including design equations, please refer to:
DVS - Discrete Example

Disadvantages of discrete DVS

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Dynamic Voltage Scaling

- Integrated implementation

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Modify internal feedback network

Modify internal bandgap

VOUT

Digital input

Control

VIN

Power Supply

VFB

VOUT

Modify internal feedback network

VOUT

Modify internal bandgap

VFB

VIN
DVS - Integrated Example

- **Saves parts**
- **Saves board space**
- **Saves cost**
- **Reduces resistor current to GND**

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**DVS - Integrated Example**

- **TPS780330220**
  - 3.3V for high frequency MSP430 operation
  - 2.2V for low frequency MSP430 operation

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DVS - Integrated

- TPS62400
  - Easyscale digital interface
    - uP control
    - Internal registers
    - 5 bits → 32 discrete output voltage setpoints
      - 25mV to 100mV steps
- TPS6502x
  - I2C digital interface
    - uP control
    - Internal registers
    - 5 bits → 32 discrete output voltage setpoints
      - 25mV to 300mV steps

Component Level Power Management

- Power Supply Efficiency
  - Topology (sync buck, charge pump ratio)
  - Component selection (inductor)
    - Important when operating time is long
- Quiescent current
  - Component selection (feedback resistors)
  - IC selection (quiescent/standby currents)
    - Important when standby times are long
Where to Start?

- Do I need a power supply?
- Examine your performance requirements
  - Clock speed?
  - Programming Flash?
  - Running A/D?
- Examine your system power
  - Operate from battery
  - Buck
  - Boost
  - Charge Pump
  - LDO

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Buck Converter

**Features**
- High efficiency, up to 96%
- Low ripple - 5mV-20mV
- Low quiescent current

**Limitations**
- Vout<Vin
- Higher parts count if not integrated

**Best choice when:**
- Large Vin to Vout difference
- Higher currents
- Efficiency is important
Boost Converter

• **Features**
  - High efficiency, up to 96%
  - Low quiescent current

• **Limitations**
  - Vout>Vin
  - Higher parts count if not integrated

• **Best choice when:**
  - Large Vin to Vout difference
  - Higher currents
  - Efficiency is important

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TPS6102x: 96%-efficient, 1.5-A Switch Boost Converter with LDO Down-Mode

- 0.9V to 5.5V input voltage range
- 200mA (500mA) from 0.9V (3.3V) Vin
- 1.2A/1.5A (min/typ) switch current limit
- 25-ua (typ) quiescent current, 0.1-µA shutdown
- LDO down-mode

- Low-battery comparator
- Load disconnect during shutdown
- 3x3 mm² QFN-10 package, TPS6102EVM (4Q)

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**Why Use**

- Highly efficient, single-cell alkaline boost converter with LDO down-mode in small package

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TPS61200 Boost Converter, 0.5V input

**Features**
- Input voltage: 0.3V to 5.5V
- Startup into full load at 0.5V input voltage
- Switch Current Limit: 1.5A (max)
- More than 90% efficiency
- Quiescent Current: < 55µA
- Package: 3x3 mm2 QFN

**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

**Special Features**
- Integrated ‘Down Mode’ enables continuous operation during Vin > Vout conditions
- Automatic transition between Boost mode and Down Conversion mode
- Programmable undervoltage lockout threshold, down to almost 0.0V possible
- Load disconnect during shutdown

Charge Pump

**Features**
- Buck, boost, or buck-boost
- High efficiency, up to 90%
- Low external component count (no inductor)
- Low ripple - 5mV
- Low quiescent current

**Limitations**
- Limited output current (300mA max)

**Best choice when:**
- Low - Medium current
- Low voltage batteries are used
- Efficiency is important
- EMI is important
Recommended Charge Pumps

- **Boost**: TPS6030x – Input 0.9 to 1.8V, Output 3.0V or 3.3V, 35 micro-Amps Supply Current, Power Good Function. (1-Cell Alkaline, Nickel Metal Hydride)

- **Boost**: TPS6031x – Input 0.9 to 1.8V, Output 3.0V or 3.3V, 2 micro-Amps Supply Current, Power Good Function. (1-Cell Alkaline, Nickel Metal Hydride)

- **Buck**: TPS60500/1/2/3 – Input 1.8 to 6.5V, Output 0.9 to 3.3V, 40 micro-Amps Supply Current, Shutdown of .05uA, Power Good, Low Battery, Current Limit, Thermal Limit. (1-Cell Li+, 2-Cell or 3-Cell Alkaline, Nickel Metal Hydride)

- **Buck/Boost**: REG710 – Input 1.8 to 5.5V, Output 2.5, 2.7, 3.0, 3.3, 5.0, 5.5V; 65 uA supply current, Shutdown. (1-Cell Li+, 2-Cell or 3-Cell Alkaline, Nickel Metal Hydride)

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**TPS6031x:**

Single cell (0.9V – 1.8V) to 3.3V / 20mA

- Regulated 3.3V output from a 0.9V to 1.8V input voltage
- 20mA output current (Dual output)
- Quiescent Current of 35uA
- Only 5 small 1uF ceramic capacitors required
- Power Good Detector
- Snooze mode (2uA)
- 10 pin MSOP package
- EVM available
**TPS60310 – Using with MSP430**

![Diagram](image)

**Figure 25. Application With MSP430; PG as Supply for Analog Circuits**

**LDO - Low Drop Out Regulator**

**Features**
- Simple low-cost design
- Uses few external components
- No switching noise
- Fast transient response
- Low quiescent current

**Limitations**
- Use only to generate a lower voltage
- Poor efficiency: Efficiency = $\frac{V_{out}}{V_{in}}$
- Power dissipation may be a concern

**Best When**
- $V_{in}$ - $V_{out}$ is small
- Low-to-medium current applications
- Low output ripple is important
  - Audio and RF transceiver power
- Space and cost are important
**TPS797xx**  
10-mA, μ-power LDO with ‘Power Good’ in SC-70

**Features:**
- 10-mA low-dropout regulator
- 1.2-μA quiescent current (typ)
- Fixed 1.8-V, 3.0-V, 3.3-V versions
- Power Good function
- Dropout (typ) 100mV at 10mA (‘79730)
- Over-current limitation
- 5-Pin SC-70 (SOT-323)

**Benefits:**
- Meets μC power supply requirements
- Ideal for battery-powered applications
- Design flexibility
- Minimizes board-space

**Applications**
- Powering MSP430 applications
- PDA, notebook, digital camera, internet audio

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**TPS715xx**  
High Input Voltage, μ-power, Any-Cap, in SC70

**Features:**
- Input Voltage range 2.5V to 24V
- Low 3.2uA quiescent current at 50mA load
- 50-mA rating with 125mA current limit
- Fixed (2.5V, 3.3V) and Adjustable (1.2 to 15V) Versions
- Stable with any capacitor (>0.47uF)
- SC-70 package is 1/2 the size of SOT-23

**Applications**
- Battery Management
- MSP430 Low Power Processors
- Internet Audio and Digital Camera
**TPS780xx/781xx**
Low IQ LDO with Dual-Level Outputs

**Features**
- Rated Output Current: 150mA
- Ultra-Low IQ: 500nA typ (TPS780xx)
- 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

**Runtime Calculations**
- **Input Power**
  - CR2032 Lithium Coin Cell
- **MSP430**
  - Clock 6MHz
  - $VCC > 2V$ for 6MHz clock

**Specifications for CR2032**
- Nominal Voltage (V): 3
- Nominal Capacity (mAh): 220
- Continuous Drain (mA): 0.2
- Operating Temp (°C): -30 ~ +60

**Temperature Characteristics**
- Load: 19kΩ (190mA)
Runtime Calculations

**System A**

- CR2032
- MSP430
- Efficiency = 100%
- Freq=6MHz

**System B**

- CR2032
- Regulator
- MSP430
- Efficiency = 66%
- (assuming LDO)
- Freq=6MHz

---

**Input Bus**

- $V_{bus} = 3.0V$
- Capacity = 220mAh

**Power Supply**

- Efficiency of the power supply ($0.5\% = 50\%$ efficient)
  - $\text{Efficiency}_1 = 1$
  - $\text{Efficiency}_2 = 0.733$

- Quiescent Current of the power supply
  - $I_{q\_supply1} = 0\mu A$
  - $I_{q\_supply2} = 0.5\mu A$

- Output voltage of the power supply
  - $V_{cc1} = 3.0V$
  - $V_{cc2} = 2.2V$

---

**Battery**

- TPS780xx LDO

- LDO Efficiency = $\frac{V_{out}}{V_{in}}$
Runtime Calculations

**MSP430 current in active mode**

\[ I_{CC_{AM\_sys1}} = \frac{187.5 \mu A}{V_{CC1}} \cdot 47.5 \mu A \cdot \text{Efficiency}_{1\text{MHz}} \]

\[ I_{CC_{AM\_sys2}} = \frac{187.5 \mu A}{V_{CC2}} \cdot 47.5 \mu A \cdot \text{Efficiency}_{1\text{MHz}} \]

**MSP430 current in low power mode**

\[ I_{CC\_LPM3\_sys1} = 0.125 \mu A/V_{CC1} + 0.125 \mu A/V_{CC1} \]

\[ I_{CC\_LPM3\_sys2} = 0.125 \mu A/V_{CC2} + 0.125 \mu A/V_{CC2} \]

Duty cycle, or percentage of time that MSP430 stays in active mode

\[ h_{bus1}(D1) = I_{supp1} + \left( \frac{I_{CC\_AM\_sys1} \cdot V_{CC1}}{\text{Efficiency}_{1\text{MHz}}} \right) \cdot D1 + \left( I_{CC\_LPM3\_sys1} \cdot V_{CC1} \cdot (1 - D1) \right) \]

\[ h_{bus2}(D2) = I_{supp2} + \left( \frac{I_{CC\_AM\_sys2} \cdot V_{CC2}}{\text{Efficiency}_{1\text{MHz}}} \right) \cdot D2 + \left( I_{CC\_LPM3\_sys2} \cdot V_{CC2} \cdot (1 - D2) \right) \]

**Runtime system1 D1()**

\[ 3600 \times 24 \cdot 73\% \text{ efficient solution has longer run time than a } 100\% \text{ efficient solution} !!!!!!! \]

Battery Life vs. Duty Cycle

A 73% efficient solution has longer run time than a 100% efficient solution !!!!!!
Iq is critical in low duty cycle applications

Use same example
Assume you are aware of TI’s TPS780xx with 0.5uA quiescent current
Assume your competitor uses a std LDO with 20uA of quiescent current

<table>
<thead>
<tr>
<th></th>
<th>TPS780</th>
<th>Std LDO</th>
<th>% increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>0.7333</td>
<td>0.7333</td>
<td></td>
</tr>
<tr>
<td>Iq</td>
<td>0.5uA</td>
<td>20uA</td>
<td></td>
</tr>
<tr>
<td>MSP430 Active current</td>
<td>2190uA</td>
<td>2190uA</td>
<td></td>
</tr>
<tr>
<td>MSP430 Low Power current</td>
<td>0.5uA</td>
<td>0.5uA</td>
<td></td>
</tr>
<tr>
<td>Active Mode 1 sec/hour</td>
<td>5704 days</td>
<td>434 days</td>
<td>1214%</td>
</tr>
<tr>
<td>Active Mode 10 sec/hour</td>
<td>1297 days</td>
<td>345 days</td>
<td>275%</td>
</tr>
<tr>
<td>Active Mode 100 sec/hour</td>
<td>148 days</td>
<td>113 days</td>
<td>31%</td>
</tr>
<tr>
<td>Active Mode 1000 sec/hour</td>
<td>15.1 days</td>
<td>14.6 days</td>
<td>3.4%</td>
</tr>
<tr>
<td>Active Mode 3600 sec/hour</td>
<td>4.18 days</td>
<td>4.16 days</td>
<td>0.48%</td>
</tr>
</tbody>
</table>

Battery Life vs. Duty Cycle

Using TPS780 with 0.5uA Iq
Using std LDO with 20uA Iq

Duty Cycle of Active Mode

System1
System2

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High Voltage Input

System A

9V Battery

→

Vbus

→

LDO TPS71501

→

MSP430

Vbus = 2.5V

System B

9V Battery

→

Vbus

→

Switcher TPS62110

→

MSP430

Vbus = 2.5V

Datasheet Efficiency includes quiescent current

Assume power stage efficiency at point where \( I_q \) is insignificant

\[ \Rightarrow I_{out} = 10mA, \text{ effic} = 90\% \]

\[ I_q = 20\mu A \text{ from parametric table} \]

\[ \text{Eff}_{\text{high current}} \equiv \frac{P_{out}}{P_{in}} \]

\[ \text{Eff}_{\text{low current}} \equiv \frac{V_{out} I_{out}}{V_{out} I_{out} + V_{in} I_q} \text{ Eff}_{\text{high current}} \]

Power stage dominated

Quiescent current dominated

Use high current efficiency and quiescent current in runtime calculations

Not datasheet efficiency at low current and quiescent current
High Voltage Input

TPS715 TPS62110
LDO Switcher

Power Supply
Efficiency of the power supply (0.5=50% efficient)

Note: includes resistor divider current

Efficiency1 = 0.33
Efficiency2 = 0.90

Quiescent Current of the power supply

I_q_supply1 = 4.7μA
I_q_supply2 = 20μA

Output voltage of the power supply

V_{cc1} = 2.5V
V_{cc2} = 2.5V

High Voltage Input

LDO

I_{cc_AM_sys1} = 5.055mA
I_{cc_LPM3_sys1} = 0.538μA
I_{bus1}(0.000) = 10.348μA
I_{bus1}(0.01) = 56.298μA
I_{bus1}(1) = 515.795μA

Switcher

I_{cc_AM_sys2} = 5.055mA
I_{cc_LPM3_sys2} = 0.538μA
I_{bus2}(0.000) = 22.071μA
I_{bus2}(0.01) = 38.919μA
I_{bus2}(1) = 207.401μA

Battery Life vs. Duty Cycle

Battery life (years)

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Texas Instruments
Solar Cell Application

Solar Cell Application

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Basic Solar Cell Current and Power Output

Output Current (mA)

Output Power (mW)

0 0.1 0.2 0.3 0.4 0.5 0.6
0 2 4 6
**Solar Cell Application**

SuperCap Voltage

TPS61200 Enable

**tx/rx enable**

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**Solar Cell Application**

\[ t_{\text{sleep}} \approx 100 \mu A \]

\[ t_{\text{tx_rx}} \approx 50 mA \]

\[ t_{\text{rx_rx}} \approx 100 ms \]

\[ t_{\text{charge}} \approx 5 mA \]

\[ I = \frac{C}{\Delta V/\Delta t} \]

\[ C_{\text{min}} \approx \frac{t_{\text{tx_rx}}}{V_{\text{min_charge}} - V_{\text{min_operate}}} \]

\[ t_{\text{charge}} \approx \frac{C_{\text{min}}(V_{\text{max_charge}} - V_{\text{min_charge}})}{I_{\text{charge}}} \]

\[ t_{\text{decay}} \approx \frac{C_{\text{min}}(V_{\text{max_charge}} - V_{\text{min_charge}})}{I_{\text{deep}}} \]

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**2AA with Boost and MSP430 Example**

Operation = 3.3V @ 50mA  
Standby = battery pass through @ 10uA

Nonsync boost  
low efficiency  
battery pass through

Sync boost  
high efficiency  
load disconnect

R=100mV/10uA=10kohm

**Conclusions**

- Proper utilization of MSP430 power capabilities requires careful consideration of both IC and system level issues.
- Dynamic voltage and frequency scaling can extend battery life (faster is not always better)
- Optimized system run time are a function of supply efficiency, quiescent current, and system run profile
- TI has the ICs and tools to provide all your MSP430 power solutions