How to Select and Use Power Supplies and dc/dc Converters for Your Applications

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• Introduction to Power Supplies and dc/dc Converters
• Types & Technologies of Power Supplies and dc/dc Converters
• Circuit Selection and Design
• Thermal Requirements and Design Issues
Introduction to Power Supplies and dc/dc Converters

• Available/Raw Power Sources
  – AC or DC (frequency)
  – Un-regulated (changes with load, prime source, etc.)
  – Voltage (different level, polarity, isolation)
  – Non-protected (against over load, fault, temp., etc.)

• Load Demand
  – Different AC or DC (frequency)
  – Regulated (against load, prime source, etc.)
  – Voltage (different level, polarity, isolation)
  – Protected (against over load, fault, temp., etc.)
Specs, Performance and Protection

- Voltage ripple (+-50 mV, or 5%)
- Isolation (e.g., 1,500 V ac for 1 min.)
- Load regulation (e.g., 3%)
- Dynamic response (transients, wake-up time, etc.)
- Short circuit protection
- OC protection
- OV protection
- OT protection
Introduction to Power Supplies and dc/dc Converters –cont.

Raw power in
Battery
Fuel Cell
AC Outlet
Solar

Power & Electronic Circuits

Desired power out
(V, I, P, F)

To loads:
Electronic ckts
Motor
Computer Equipment

Control

Power Supply
Power Supplies and dc/dc Converters – Types & Technologies

• **AC-DC Power Supply (or AC Adapter)**
  – Change ac power into regulated dc power, e.g., a typical AC Adapter takes 120 V ac input and converts it to regulated 5 Vdc.

• **DC/DC Converters**
  – Change dc at one voltage potential to a dc at a different voltage potential

• **DC-AC Power Supply** (for example, UPS, 12Vdc-120Vac adapter)

• **AC-AC Power Supply/Regulator** (for example, line regulator)
AC-DC Power Supplies
-Circuit Selection and Design

- Using Linear Regulators
- Using LDO Regulator
  
  [Link to LM78M05](http://www.national.com/pf/LM/LM78M05.html)

- For low power (several watts or below) applications.
- Low efficiency, large size and weight (bulky step-down line transformer)
- Low cost
Linear Regulators

Active-mode operation of BJT

\[ V_O \approx V_{ref} \left( \frac{R_1}{R_2} + 1 \right) \]
LDO Regulator

Low drop-out voltage
**LDO Regulator**

Low drop-out voltage

![LDO Regulator Diagram](image)
Switching regulators

1. Buck Converter

\[
E_{out} = D \cdot E_{in}
\]

Duty Cycle: \[ D = \frac{T_{on}}{T_{sw}} \]
2. Boost Converter

\[ E_{out} = \frac{1}{1 - D} \cdot E_{in} \]
Power Supply Topologies

Texas Instruments, the Power Behind Your Designs

DC-DC Converter
AC-DC Power Supplies
-Circuit Selection and Design

• Using Switching-Mode
• High efficiency
• Small size and light weight
• For high power (density) applications

TI Power Supply Technologies Poster

http://www.electronicproducts.com/
http://www.linear.com/index.jsp
http://www.linear.com/3770
Charge Pump

- Inductor-less Boost, Buck
- Stray inductance enough to limit current
- TI, Linear Technology have several ICs
Charge Pump: 1X
Charge Pump: 2X

(a) Switching state I.

(b) Switching state II.
Charge Pump: 3X

(a) Switching state I.

(b) Switching state II.

(c) Switching state III.
Selecting the Right dc/dc Converter –cont.

**VBAT = 3.7 V nom, BIN_BB = 1.2 V**
Load Current = 600 mA
Power delivered to load = 600 mA * 1.2 V = 720 mW
Power converted to heat =
\[ 600 \text{ mA} \times (3.7-1.2) = 1,500 \text{ mW} \]
Total power consumed =
\[ 720 \text{ mW} + 1,500 \text{ mW} = 2,200 \text{ mW} \]

32% goes to work, 68% goes to heating user hand and ear when using a Linear Regulator for a mobile device.

**Linear regulators:**
- Inexpensive
- Small footprint
- Low part count
- Low noise
- High ripple rejection

**Switching regulators:**
- A bigger footprint
- Higher part count,
- More cost
- Prone to conducted and radiated EMI.

**VBAT = 3.7 V nom; BIN_BB = 1.2 V**
Load Current = 600 mA
Converter efficiency = 90%
Power delivered to load = 600 mA * 1.2 V = 720 mW
Total power consumed = 720 mW * (1/0.9) = 800 mW
Power converted to heat = 800 mW - 720 mW = 80 mW

90% goes to work, 10% goes to heating user hand and ear
When using a Switch-mode regulator for a mobile device.
Selecting the Right dc/dc Converter

- **The Need for dc/dc Converters**
  - E.g., a single AA alkaline battery produces 1.5 V when fully charged and its voltage drops to as low as 0.9 V when becoming depleted.

- **Dc/dc Converter Types**
  - Buck
  - Boost
  - Buck-Boost

- **Dc/dc Converter Technologies**
  - Linear Regulators
  - Switching Regulators
  - Charge Pumps

*The MCP1703 LDO is one type of dc/dc linear regulator*
## Selecting the Right dc/dc Converter – cont.

### Dc/dc converter technology comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Linear regulator</th>
<th>Switching regulator</th>
<th>Charge pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>EMI Noise</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Output current</td>
<td>Low to medium</td>
<td>Low to High</td>
<td>Low</td>
</tr>
<tr>
<td>Boost (step-up)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Buck (step-down)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Solution size</td>
<td>small</td>
<td>Large</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Power Losses and Thermal Design

• For example, a 7815 linear regulator with input voltage of 20 V and output current of 1 A. The power loss is (20-15)Vx(1 A)=5 W.

• From the chip to the ambient, ΔTi can be calculated according to the thermal circuit using Ohm’s law (R=V/I), where R is the thermal resistance, V is the temperature and I is the power dissipation.

\[
R_{Th\text{case-ambient}} = \frac{T_{\text{case}} - T_{\text{ambient}}}{P_{\text{dissipation}}}
\]

\[
P_{\text{dissipation}} = P_{\text{in}} - P_{\text{out}} = \frac{P_{\text{out}}}{\eta_{\text{op}}} - P_{\text{out}}
\]

Where:
- \(T_{\text{case}}\) is case Temp.
- \(T_{\text{ambient}}\) is ambient Temp.
- \(P_{\text{dissipation}}\) is power loss
- \(P_{\text{in}}\) is input power
- \(P_{\text{out}}\) is output power
- \(\eta_{\text{op}}\) is efficiency under given operating conditions
Power Losses and Thermal Design
--A more detailed thermal circuit

- W: Device power loss
- Tj: Junction temperature of device
- Tc: Device case temperature
- Tf: Temperature of heatsink
- Ta: Ambient temperature
- $R_{th(j-c)}$: Thermal resistance between junction and case, specified in datasheet
- $R_{th(c-f)}$: Contact thermal resistance between case and heatsink, specified in datasheet
- $R_{th(f-a)}$: Thermal resistance between heatsink and ambient air, specified by the heatsink manufacturer
Power Losses and Thermal Design

\[ T_j = W \times \{ R_{th(j-c)} + R_{th(c-f)} + R_{th(f-a)} \} + T_a \]

\[ T_c = W \times \{ R_{th(c-f)} + R_{th(f-a)} \} + T_a \]
Example

- Device: 7815 (Linear regulator)
- $V_{in}=20\text{V}, \ V_{o}=15\text{V}, \ I_{o}=1\text{A}$
- $W: (20-15) \times 1 = 5\text{ watts}$
- $R_{th(j-c)}: 5\ ^\circ\text{C/W}$
- $R_{th(c-f)}: 0.5\ ^\circ\text{C/W}, \text{ Greased surface}$
- $R_{th(f-a)}: 20\ ^\circ\text{C/W}$
- $T_{a}=25\ ^\circ\text{C}$

\[
T_{c}=5 \times (0.5 + 20) + 25 = 127.5\ ^\circ\text{C}
\]
\[
T_{j}=5 \times 1 + 127.5 = 132.5\ ^\circ\text{C}
\]
\[
\Delta T_{j}=132.5-25=107.5\ ^\circ\text{C}
\]
Some Tips

- Fully understand your requirement. Make a spec sheet
- Carefully read datasheets and application notes
- Get multiple samples from vendors to try different circuits. Several ICs available for low and medium power apps.
- Simultaneously work on thermal design and chassis design (multi-task !)
- Pay attention to EMI issues **during** layout. Use shielded inductors, Low ESL capacitors, common mode and DM chokes, etc.