Overview

A golden power supply that will satisfy every design requirement does not exist. Size, cost, and efficiency are the driving factors for selecting a design, causing each design to be different. This application note covers real-world circuit designs by showing a collection of the most commonly used power supply circuits. Some of the application circuits utilize low-profile surface mount components, while others employ low-cost components.

Every circuit in this application note has been designed, built, and evaluated for stability, temperature, component life, and tolerance (see Figure 1). Judicious design practices have been followed to ensure that the solutions are robust.

Efficiency is often a main concern with switching regulators. To allow a preliminary performance evaluation, efficiency plots for various input and output conditions accompany most circuits.

If the components specified in the schematic are not readily available, alternative components can be found in the cross-reference list in Appendix A. The components in the list are not exact replacements. Their electrical characteristics and physical sizes may be slightly different, but the electrical performance in the circuits will be the same. Appendix A also provides detailed electrical specifications for each power component, making the selection of alternate components easy.

Instead of publishing the operating equations for the buck (step-up), buck-boost (inverting), boost (step-up) and flyback topologies in this application note, Micrel chose to put them into easy-to-use Microsoft® Excel spreadsheets. This dramatically speeds up the design time when there is a need to modify one of the existing circuits.

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6V–24V to 3.3V/0.5A Buck Converter
Through Hole

Figure 1a. Schematic

Figure 1b. Efficiency

8V–24V to 5V/0.5A Buck Converter
Through Hole

Figure 2a. Schematic

Figure 2b. Efficiency

16V–24V to 12V/0.5A Buck Converter
Through Hole

Figure 3a. Schematic

Figure 3b. Efficiency

6V–24V to 3.3V/1A Buck Converter
Through-Hole

Figure 4a. Schematic

Figure 4b. Efficiency

Note 1 (General):  For IC electrical specifications, see the MIC4574, MIC4575, or MIC4576 data sheet.

Note 2:  Surface-mount component
8V–24V to 5V/1A Buck Converter
Through Hole

Figure 5a. Schematic

Figure 5b. Efficiency

16V–24V to 12V/1A Buck Converter
Through-Hole

Figure 6a. Schematic

Figure 6b. Efficiency

6V–24V to 3.3V/3A Buck Converter
Through Hole

Figure 7a. Schematic

Figure 7b. Efficiency

6V–36V to 3.3V/3A Buck Converter
Through Hole

Figure 8a. Schematic

Figure 8b. Efficiency

Note 2: Surface-mount component
**Application Note 15**

**Micrel**

**8V–24V to 5V/3A Buck Converter**

Through Hole

- **C1**: Nichicon UPL1J471MPH, ESR = 0.046Ω
- **C2**: Nichicon UPL1C102MPH, ESR = 0.047Ω
- **D1**: Motorola MBR5822
- **L1**: Coiltronics PL52C-33-1000, DCR = 0.036Ω, Bi HM77-30006, DCR = 0.045Ω

*Note 2: Surface-mount component*

**Figure 9a. Schematic**

**Figure 9b. Efficiency**

**16V–36V to 12V/3A Buck Converter**

Through Hole

- **C1**: Nichicon UPL1J471MPH, ESR = 0.039Ω
- **C2**: Nichicon UPL1C102MPH, ESR = 0.047Ω
- **D1**: Motorola MBR360
- **L1**: Bi HM77-29006, DCR = 0.08Ω

*Note 2: Surface-mount component*

**Figure 11a. Schematic**

**Figure 11b. Efficiency**

**6V–24V to 3.3V/0.5A Buck Converter**

Low-Profile Surface Mount

- **C1**: AVX TPSD106M035R0300, ESR = 0.3Ω
- **C2**: AVX TPSE337M006R0100, ESR = 0.1Ω
- **D1**: Motorola MBRS130LT3
- **L1**: Coiltronics CTX100-2P, DCR = 0.541Ω

*Note 2: Surface-mount component*

**Figure 12a. Schematic**

**Figure 12b. Efficiency**
8V–24V to 5V/0.5A Buck Converter
Low-Profile Surface Mount

C1 AVX TPSD106M035R0300, ESR = 0.3Ω
C2 AVX TPS6106M020R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX100-2P, DCR = 0.541Ω

Figure 13a. Schematic

Figure 13b. Efficiency

6V–24V to 3.3V/1A Buck Converter
Low-Profile Surface Mount

C1 AVX TPSE226M035R0300, ESR = 0.3Ω
C2 AVX TPSE337M060R0100, ESR = 0.11Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX69-4P, DCR = 0.238Ω

Figure 15a. Schematic

Figure 15b. Efficiency

16V–24V to 12V/0.5A Buck Converter
Low-Profile Surface Mount

C1 Tokin C55Y5U1H106Z
C2 AVX TPSE226M035R0150, ESR = 0.15Ω
D1 General Instruments SS16
L1 Coiltronics CTX250-4P, DCR = 0.434Ω

Figure 14a. Schematic

Figure 14b. Efficiency

8V–24V to 5V/1A Buck Converter
Low-Profile Surface Mount

C1 AVX TPS6106M020R0100, ESR = 0.1Ω
C2 AVX TPSE337M060R0100, ESR = 0.11Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX69-4P, DCR = 0.238Ω

Figure 16a. Schematic

Figure 16b. Efficiency
16V–24V to 12V/1A Buck Converter
Low-Profile Surface Mount

8V–24V to 5V/0.5A Buck Converter
Lower-Cost Surface Mount

6V–24V to 3.3V/0.5A Buck Converter
Lower-Cost Surface Mount

16V–24V to 12V/0.5A Buck Converter
Lower-Cost Surface Mount

Figure 17a. Schematic

Figure 17b. Efficiency

Figure 18a. Schematic

Figure 18b. Efficiency

Figure 19a. Schematic

Figure 19b. Efficiency

Figure 20a. Schematic

Figure 20b. Efficiency
6V–24V to 3.3V/1A Buck Converter
Lower-Cost Surface Mount

C1 Sanyo 35CV150GX, ESR = 0.17Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 Motorola MBRS130LT3
L1 Coilcraft DO3316P-683, DCR = 0.16Ω
L1 Bi HM77-11003, DCR = 0.233Ω

8V–24V to 5V/1A Buck Converter
Lower-Cost Surface Mount

C1 Sanyo 35CV150GX, ESR = 0.17Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 Motorola MBRS130LT3
L1 Coilcraft DO3316P-683, DCR = 0.16Ω
L1 Bi HM77-11003, DCR = 0.233Ω

16V–24V to 12V/1A Buck Converter
Lower-Cost Surface Mount

C1 Nichicon UUX11470M1G, ESR = 0.4Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 General Instruments SS26
L1 Coilcraft DO5022P-15A, DCR = 0.218Ω

8V–18V to –5V/0.2A Buck-Boost Converter
Through Hole

C1 Nichicon UPL1VS1MPH
C2 Nichicon UPL1CS81MPH
D1 Motorola 1N5819
L1 Coiltronics PL52A-10-500
DCR = 0.045Ω

Figure 21a. Schematic
Figure 21b. Efficiency
Figure 22a. Schematic
Figure 22b. Efficiency
Figure 23a. Schematic
Figure 23b. Efficiency
Figure 24a. Schematic
Figure 24b. Efficiency
5V to –5V/0.3A Buck-Boost Converter
Through Hole

Figure 25a. Schematic

Figure 25b. Efficiency

Parallel Switching Regulators

Figure 26.
Low Output-Noise Regulator (5mV Output Ripple)

![Diagram of Low Output-Noise Regulator](image)

C1 AVX TPSE226M035R0300, ESR = 0.33Ω
C2 AVX TPSE227M010R0100, ESR = 0.1Ω
C4 AVX TPSE227M010R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
D2 Motorola MBRS130LT3
T1 Coiltronics CTX68-4P, DCR = 0.238Ω
L1 Coilcraft DO1608C-102

Figure 27.

Split ±5V Supply

![Diagram of Split ±5V Supply](image)

C1 AVX TPSE226M035R0300, ESR = 0.33Ω
C2 AVX TPSE227M010R0100, ESR = 0.1Ω
C4 AVX TPSE227M010R0100, ESR = 0.1Ω
C5 AVX TPSE227M010R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
D2 Motorola MBRS130LT3
T1 Coiltronics CTX68-4P, DCR = 0.238Ω

DC ≥ 40% then $-I_{OUT} \leq I_{OUT} \times (1-DC)$

Figure 28.

Adjustable Output-Voltage Regulator (0V–12V)

![Diagram of Adjustable Output-Voltage Regulator](image)

C1 Nichicon UPL1V151MPH, ESR = 0.12Ω
C2 Nichicon UPL1C331MPH, ESR = 0.12Ω
D1 Motorola 1N5819
L1 Coiltronics PL52B-68-500, DCR = 0.095Ω
U2 Micrel LM4041CIZ-1.2

Figure 29.
Low Output-Voltage Regulator (1V)

C1 Nichicon UPL1V151MPH, ESR = 0.12Ω
C2 Nichicon UPL1C331MPH, ESR = 0.12Ω
D1 Motorola 1N5819
L1 Coiltronics PL52B-68-500, DCR = 0.095Ω
U2 National LM358

C1 150µF 35V
D1 1N5819
GND
FB
SW
MIC4575BT
V IN 4V to 15V
V OUT 1V/1A

Figure 30.

1A Battery Charger (6–8 cells)

C1 Nichicon UPL1V151MPH, ESR = 0.12Ω
C2 Nichicon UPL1C331MPH, ESR = 0.12Ω
D1 Motorola 1N5819
L1 Coiltronics PL52B-68-500, DCR = 0.095Ω
Q1 Siliconix VN2222LL

C1 150µF 35V
D1 1N5819
GND
FB
SW
MIC4575-BT
V IN 9V to 24V
V IN 8V to 24V
V IN min ≥ V BATT / 0.9 + 2.5V
Ilout = (1.23V / R2) R5 / R1

Figure 31.

0.1A–1A Variable-Current Battery Charger

C1 Micrel MIC4575BT
U2 National LM358
U3 Micrel LM4041CIZ-1.2
C1 Nichicon UPL1V151MPH, ESR = 0.12Ω
C2 Nichicon UPL1C331MPH, ESR = 0.12Ω
D1 Motorola 1N5819
D2 Motorola 1N5819
D3 Motorola 1N4148
L1 Coiltronics PL52B-68-500, DCR = 0.095Ω
R1 KRL SP-1-A1-0R100J
Q1 Siliconix VN2222LL

C1 150µF 35V
D1 1N5819
GND
FB
SW
MIC4575-BT
V IN 8V to 24V
V IN min ≥ V BATT / 0.9 + 2.5V

Figure 32.
1A Battery Charger (2–8 Cells)

**Figure 33.**

Remote-Sensing Regulator

**Figure 34.**
6V–18V to Split ±12V/100mA Supply

Figure 35.

1A Battery Charger

Figure 36.
Improved Adjustable Output-Voltage (0V–12V) Regulator

\[ V_{\text{IN}} = \frac{V_{\text{OUT}}}{0.9} + 2.5V \]

\[ V_{\text{OUT}} = 1.23V \left( 1 + \frac{R_1}{R_2} \right) \]

Figure 37.

Switchable Battery-Pack Charger

\[ I_{\text{OUT}} = 1A \]

Figure 38.
Lithium-Ion Battery Charger with End-of-Charge Flag

\[ I_{OUT} = \frac{1.24V}{R_3} \times \frac{R_2}{R_1} \]

\[ I_{OUT} = 1.02A \]

\[ V_{IN min} = \frac{V_{BATT}}{0.9} + 2.5V \]

\[ I_{OUT END} = 60mA \]

\[ I_{OUT END} = 1.23V \times \left( \frac{R_2}{R_3} - \frac{R_5}{R_4} \right) \]

**Figure 39.**

Low Output-Noise Regulator (<1mV)

\[ V_{OUT} = 1.23 \times \left( 1 + \frac{R_2}{R_1} \right) \]

**Figure 40.**
Appendix A

Component Cross-Reference List

Micrel provides this cross-reference list to make it easier to choose alternate power components. This becomes necessary when the standard components are not readily available or the manufacturer is not an approved vendor.

The components in this list are not exact replacements. Their electrical characteristics and physical sizes may be slightly different, but their performance in the circuit will be the same. Also, detailed electrical specifications are provided for each power component so that if you need an alternate component, you can choose it intelligently.

Through-Hole Components

Capacitors

<table>
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<tr>
<th>Value</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Model</th>
<th>Part Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>220µF/16V/0.16Ω/0.460A</td>
<td>Electrolytic</td>
<td>Nichicon</td>
<td>UPL1C221MPH</td>
<td>16MV220GX</td>
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<tr>
<td>330µF/16V/0.12Ω/0.595A</td>
<td>Electrolytic</td>
<td>Sanyo</td>
<td>UPL1C331MPH</td>
<td>16MV330GX</td>
</tr>
<tr>
<td>680µF/16V/0.065Ω/1.02A</td>
<td>Electrolytic</td>
<td>Panasonic</td>
<td>UPL1C681MPH</td>
<td>16MV560GX</td>
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<tr>
<td>1000µF/16V/0.047Ω/1.41A</td>
<td>Electrolytic</td>
<td>United Chemi-Con</td>
<td>UPL1C102MPH</td>
<td>16MV1000GX</td>
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<tr>
<td>47µF/35V/0.34Ω/0.27A</td>
<td>Electrolytic</td>
<td>Nichicon</td>
<td>UPL1V470MEH</td>
<td>35MV68GX</td>
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<tr>
<td>150µF/35V/0.12Ω/0.595A</td>
<td>Electrolytic</td>
<td>Sanyo</td>
<td>UPL1V151MPH</td>
<td>35MV150GX</td>
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<td>470µF/35V/0.046Ω/1.42A</td>
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<td>Panasonic</td>
<td>UPL1V471MPH</td>
<td>35MV680GX</td>
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<td>Motorola</td>
<td>UPL1J330MEH</td>
<td>63MV82GX</td>
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<tr>
<td>68µF/63V/0.17Ω/0.5A</td>
<td>Schottky</td>
<td>GI</td>
<td>UPL1J680MPH</td>
<td>63MV150GX</td>
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<td>470µF/63V/0.039Ω/1.42A</td>
<td>Schottky</td>
<td>IR</td>
<td>UPL1J471MRH</td>
<td>63MV680GX</td>
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Diodes

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<td>1A/40V</td>
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<td>Motorola</td>
<td>1N5819</td>
<td>1N5819</td>
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<tr>
<td>1A/60V</td>
<td>Schottky</td>
<td>GI</td>
<td>MBR160</td>
<td>SB160</td>
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<td>Schottky</td>
<td>IR</td>
<td>UPL1J330MEH</td>
<td>1N5822</td>
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<tr>
<td>3A/60V</td>
<td>Schottky</td>
<td>GI</td>
<td>MBR360</td>
<td>SB360</td>
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Inductors

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<td>PL52A-10-500</td>
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<td>33µH/3A</td>
<td>Rod Cores</td>
<td>Renco</td>
<td>PL52C-33-1000</td>
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<tr>
<td>68µH/1A</td>
<td>Toroidal Cores</td>
<td>Sumida</td>
<td>PL52B-68-500</td>
<td>RL-1283-68-43</td>
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<tr>
<td>68µH/3A</td>
<td>Rod Cores</td>
<td>Sumida</td>
<td>PL52D-68-2000</td>
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<tr>
<td>100µH/0.5A</td>
<td>Rod Cores</td>
<td>PL52A-100-250</td>
<td>RL-1284-100-43</td>
<td>RCH875-101K</td>
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<td>150µH/1A</td>
<td>Rod Cores</td>
<td>PL52B-150-500</td>
<td>RL-1283-150-43</td>
<td>RCH110-151K</td>
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<td>RCH106-221K</td>
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## Surface-Mount

### Capacitors

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<th>Sprague (Tantalum)</th>
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<td>330µF/6.3V/0.1Ω/1.149A</td>
<td>TPSE337M006R0100</td>
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<td>593D337X06R3E2W</td>
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<tr>
<td>220µF/10V/0.1Ω/1.149A</td>
<td>TPSE227M010R0100</td>
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<td>593D227X0010E2W</td>
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<tr>
<td>68µF/20V/0.15Ω/0.938A</td>
<td>TPSE686M020R0150</td>
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<td>593D686X0020EZW</td>
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<td>10µF/35V/0.3Ω/0.663A</td>
<td>TPSD106M035R0300</td>
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<td>593D106X0035E2W</td>
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<td>22µF/35V/0.3Ω/0.632A</td>
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Appendix B
Suggested Manufacturers List
Micrel supplies this list of manufacturers to save you time in selecting components. Micrel makes no claims about these companies except that they provide components necessary in switching power supplies.

Capacitors

**AVX Corp.**
801 17th Ave. South
Myrtle Beach, SC 29577
Tel: (803) 448-9411
Fax: (803) 448-1943

**Nichicon (America) Corporation**
927 East State Parkway
Schaumburg, IL 60173
Tel: (708) 843-7500
Fax: (708) 843-2798

**Panasonic**
6550 Katella Avenue
PANAZIP 17A-11
Cypress, CA 90630
Tel: (714) 373-7857
Fax: (714) 373-7102

**Sanyo Video Components (USA) Corp.**
2001 Sanyo Avenue
San Diego, CA 92173
Tel: (619) 661-6835
Fax: (619) 661-1055

**Sprague Electric**
Lower Main Street
60005 Sanford, ME 04073
Tel: (207) 324-4140

**Tokin America, Inc.**
155 Nicholson Lane
San Jose, CA 95134
Tel: (408) 432-8020
Fax: (408) 434-0375

**United Chemi-Con Inc.**
9801 West Higgins Road, Suite 430
Rosemount, IL 60018
Tel: (708) 696-2000
Fax: (708) 696-9278

Diodes

**General Instruments (GI)**
10 Melville Park Road
Melville, NY 11747
Tel: (516) 847-3222
Fax: (516) 847-3150

**International Rectifier Corp.**
233 Kansas Street
El Segundo, CA 90245
Tel: (310) 322-3331
Fax: (310) 322-3332

**Motorola Inc.**
3102 North 56th St., MS 56-126
Phoenix, AZ 85018
Tel: (800) 521-6274
Fax: (602) 952-4190

Heat Sinks

**Aavid Engineering, Inc.**
67 Primrose Drive
Laconia, NH 03246
Tel: (603) 528-3400
Fax: (603) 528-1478

**Thermalloy**
2021 West Valley View Lane
P.O. Box 810839
Dallas, TX 75381
Tel: (214) 243-4321
Fax: (214) 241-4656

Inductors

**Bi Technologies**
4200 Bonita Place
Fullerton, CA 92635
Tel: (714) 447-2345
Fax: (714) 447-2500

**Coilcraft**
1102 Silver Lake Road
Cary, IL 60013
Tel: (708) 639-2361
Fax: (708) 639-1469

**Coiltronics**
6000 Park of Commerce Boulevard
Boca Raton, FL 33487
Tel: (407) 241-7876
Fax: (407) 241-9335

**Dale Electronics**
East Highway 50
Yankton, SD 57078
Tel: (605) 665-9301
Fax: (605) 665-0817

**Renco**
60 Jefryn Boulevard East
Deerpark, NY 11729
Tel: (516) 586-5566
Fax: (516) 586-5562

**Sumida Electric**
5999 New Wilke Road
Suite 110
Rolling Meadows, IL 60008
Tel: (708) 956-0666
Fax: (708) 956-0702

Resistors

**KRL/Bantry Components, Inc.**
160 Bouchard Street
Manchester, NH 03103
Tel: (603) 668-3210
Fax: (603) 624-0634
Appendix C

Microsoft® Excel Spreadsheet Summary

Determining the operating conditions for a switching regulator requires dozens of calculations. Doing this with a handheld calculator can take hours, but when the equations are put into a spreadsheet, this takes only a few seconds. Micrel provides Microsoft® Excel spreadsheets for buck (step-up) and buck-boost (inverting), boost (step-up) and flyback switching regulator topologies. The spreadsheets perform computer aided design, not computer generated design. It is the responsibility of the user to verify spreadsheet results by building the circuit and measuring component stress under all expected operating conditions.

Figure C1 shows the buck regulator spreadsheet. It is divided into three columns. The first column contains all the input variables. You can change any variable in this column, such as input voltage, switching frequency, and inductor value. You might change these variables to observe the sensitivity of the circuit, to test for worst-case conditions, or to set a tolerance on component characteristics.

The second column contains the resulting operating conditions for all power components. You select the power components based upon these values. Most worst-case operating conditions occur at the minimum input voltage, but not in every case. To ensure a reliable design, vary the input voltage over its entire operating range and use the worst-case value to select components.

The third column itemizes the power losses. The largest contributors to efficiency losses are the IC switch (Pd_IC_Switch) and diode (Pd_Diode). For heat sink design, the IC’s power dissipation result (Pd_IC) makes sizing of the heat sink quick and easy.

There are three pull-down menus: one for selecting a Micrel IC, one for selecting an inductor core material, and one for doing worst-case analysis on a selected parameter. The Micrel parts list shows all the devices that are available for a design. The list includes both the 52kHz (LM257X) and the 200kHz (MIC457X) parts. The operating warning window uses the selected IC’s peak switch current, input voltage range, and output voltage range to determine if an operating condition exceeds its limit.

The second pull-down menu has two core materials to choose from, either a powdered iron type 52 (#52) or a ferrite (Fe). The inductor core material has a minuscule effect on the overall efficiency and was included only for completeness.

Worst case analysis has been automated for user convenience. The program sweeps the input voltage from the minimum input voltage (Vin_Min) to the maximum input voltage (Vin_Max). The output current is fixed at its original value. Once the calculation is complete the results are displayed in a graph.

Note that the list box exhibits a strange behavior. The program will not rerun if you select the same item in the list box two times in a row. To rerun a parameter, you must select the

<table>
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<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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</table>

Figure C1. Buck Regulator Excel Spreadsheet
None item first and then click on the desired parameter.

Efficiency varies widely for various input voltages and load conditions. Therefore, a macro has been written that sweeps both the input voltage and the output current over the entire operating region. The resulting efficiency is then automatically displayed in a graph. To run the macro, click the efficiency button.

Equations in the second and third columns are protected and cannot be inadvertently changed. You can defeat the protection feature, however, by selecting the Tools button from the top menu bar, clicking the protection menu item, selecting the unprotect sheet option, and entering "Micrel" for the password. Now any equation or formatting in the active spreadsheet can be changed. It is advisable to make a backup copy of the spreadsheet program prior to removing the protection.

The spreadsheets were created in Microsoft® Excel 5.0 for Windows™ and run under Windows™3.1, Windows NT™, and Windows 95™.

The diskette and spreadsheets can also be used with Microsoft® Excel 5.0 for the Macintosh® or newer. For System 7.5 or later, the PC Exchange control panel must be "on." System 7.1 or earlier requires Apple® File Exchange (included on the System Software disks) to mount the DOS-formatted diskette and copy the file to the hard disk.

### Definition of Terms

**Input & Output**

Vin: input voltage  
Vout: output voltage  
Iout: output current

**Component Parameters**

L: inductance  
L_DCR: inductor DC resistance  
Diode_Vf: catch diode forward voltage drop  
Cin: input capacitor value  
Cin_ESR: input capacitor equivalent series resistance  
Cout: output capacitor value  
Cout_ESR: output capacitor equivalent series resistance

**IC Parameters**

IC_fs: switching frequency  
IC_Rsw: internal switch equivalent resistance  
IC_Vs: internal switch equivalent voltage  
IC_Iq: quiescent current  
IC_ton: switch turn-on time  
IC_toff: switch turn-off time

**Inductor Core Loss Constants**

Ci: core loss contant  
d: core loss frequency exponent  
p: core loss flux density exponent  
U: permeability of core

**Resulting Power Dissipation**

Pd_IC_Iq: power loss due to quiescent current  
Pd_IC_AC: power loss due to switching times  
Pd_IC_Switch: switch conduction loss  
Pd_IC: total IC loss  
Pd_Diode: diode power loss  
Pd_Cin: input capacitor power loss  
Pd_Cout: output capacitor power loss  
Pd_L_Cu: power loss due to the DCR of the inductor  
Pd_L_Core: power loss due to core material  
Pd_L: total inductor loss  
P_loss: sum of all the power losses  
Efficiency: output power divided by input power

### Equations

- DC: duty cycle  
- DC_Prim: \((1 – \text{duty cycle})\)  
- L_Iavg: average inductor current  
- L_Ipp: peak-to-peak inductor ripple current  
- L_Ipk: peak inductor current  
- L_RMS: inductor RMS current  
- IC_Sw_RMS: IC Switch RMS current  
- Diode_RMS: diode RMS current  
- Cin_RMS: input capacitor RMS current  
- Cout_RMS: output capacitor RMS current  
- Input_Iavg: average input current  
- ∆Vout_ESR: output ripple voltage caused by the ESR of the output capacitor
Appendix D
Package Thermal Characteristics
Designing the proper heat sink requires defining the thermal resistance of the package and heat sink. This is relatively straightforward for a TO-220 package in which the heat sink is attached to the part, but not for DIP and SO packages in which the external heat sink is the PC board. The physical size of the PC board can dramatically affect the thermal dissipation of the package.

The heat sink manufacturers have thoroughly characterized their heat sinks for TO-220 packages. For these packages, you can choose either a clip-on or screw-mount heat sink. The clip-on heat sinks offer the lowest labor cost to mount, but they can attain only about a 15° to 30°C/W case-to-ambient thermal coefficient. Alternatively, screw-mount types can reach a 5° to 10°C/W case-to-ambient thermal coefficient. The following Thermalloy part numbers are examples of each mounting option.

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<th>Heat-Sink Style</th>
<th>Thermalloy No.</th>
<th>θ_{CA}</th>
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<tbody>
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<td>Clip on</td>
<td>6045</td>
<td>30°C/W</td>
</tr>
<tr>
<td>Screw mount</td>
<td>6099B</td>
<td>12°C/W</td>
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</tbody>
</table>

Most data sheets give the worst-case thermal resistance coefficients of TO-220, DIP, and SO packages. That is, the packages are characterized in free air, and the thermal resistance coefficients do not take into account the heatsinking effect of the PC board. The following measurements are examples of each mounting option.

<table>
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<th>Package Style</th>
<th>θ_{JA}</th>
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<td>TO-220</td>
<td>50°C/W</td>
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<td>50°C/W</td>
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<tr>
<td>8-Pin DIP</td>
<td>90°C/W</td>
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<tr>
<td>16-Pin SO</td>
<td>100°C/W</td>
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</table>

Table D1. Package Thermal Coefficients (1 in² Cu)

The numbers in Table C1 are a good starting point to determine the IC’s junction temperature rise, but they can vary widely. Many factors affect these numbers, including PC board size and thickness as well as the number of layers, copper area, and copper thickness. Furthermore, a component like the diode or inductor can either heat up the IC or act as a heat sink.

For best thermal performance use as much copper as possible. Every pin should have a generous amount of PC board copper, especially the ground (GND) and input pin (VIN). One exception to this rule is the switch pin (SW), which should be designed just wide enough to handle the switch current, minimizing the radiated EMI. Copper provides the best transfer of heat to the surrounding area. Even double-sided or multilayered boards help in removing the heat from the IC.

Appendix E
Suggested PC Board Layouts
To achieve proper performance, printed circuit (PC) board layouts are provided for the various IC package types. Poor PC board layout can have dramatic effects on the operation of a power supply. Reduced efficiency, increased EMI, and spurious oscillations are just some of the results of a poor layout. Here are a few recommendations that should be followed:

1) The inductor, filter capacitors, diode, and IC should be physically close to one another and on the same side of the PC board. Keep the trace length between these components below 0.25 inches.
2) All the high-current traces must be on the same PC board layer. Do not use vias to connect the power traces.
3) Use a single-point ground, not a ground plane.
4) For the adjustable parts, connect the center tap of the voltage divider network (R1, R2 in Figure 15a) as close to the feedback pin as possible. Stray capacitance and pickup on this node can cause erratic switching behavior.
5) Connect the ground return of the divider network as close to the ground pin as possible. Bizarre switching action can occur if the ground is returned through a high-current path.

In 95 percent of the cases where a power supply is malfunctioning, the cause is more than likely that the inductor is physically too small rather than poor PC board layout.

The inductor is a power component and is selected based upon its value and current rating. An inductor’s current-handling capability is directly related to its physical size. A physically large inductor can handle higher peak currents than a small one of the same value. Just like a 10Ω, 10W resistor can handle more current than a 10Ω, 1/4W resistor. A 100µH, 3A inductor should be at least the size of your thumb. If it is not, its value can rapidly decrease or even go to zero (saturate the core) when operated beyond its rated limit. When this occurs, the DC-DC converter can exhibit erratic behavior.
Figure 1.
MIC4574-5.0BWM
14-lead SOIC
(Layout for Figure 18a)

Solder Side

Silk Screen

Component Side

Figure 2.
MIC4574-5.0BN
8-pin DIP
(Layout for Figure 4a)

Solder Side

Silk Screen

Component Side
Figure 3. 
MIC4575-5.0BT/MIC4576-5.0BT 
5-lead TO-220 
(Layout for Figure 9a)

Figure 4. 
MIC4575-5.0BU/MIC4576-5.0BU 
5-lead TO-263 
(Layout for Figure 22a)
Appendix F

Manufacturer's Distributors List

Micrel provides this list of distributors to make it easier for you to acquire components. An attempt has been made to ensure that the information is accurate; however, this list is subject to change without notice.

Coiltronics Distributors

Armor Electronics (North-East Area)
1055 East Street
Tweksbury, MA 01876
Tel: (508) 640-1499
Fax: (506) 640-1570

Component Distributors Inc. (Alabama Area)
908 B Merchant Walk
Huntsville, AL 35801
Tel: (800) 888-0331
Tel: (205) 536-8850
Fax: (800) 808-2067
Fax: (205) 533-3919

(Georgia Area)
5950 Crooked Creek Road
Suite 150
Norcross, GA 30092
Tel: (800) 874-7029
Tel: (770) 441-3320
Fax: (770) 449-1712

(Texas Area)
710 East Park Blvd.
Suite 108
Plano, TX 75074
Tel: (800) 848-4234
Tel: (214) 578-2644
Fax: (214) 578-2208

(Colorado Area)
3979 East Arapahoe Road
Suite 102, Bidg. 1
Littleton, CO 80122
Tel: (800) 551-7357
Tel: (303) 770-6214
Fax: (303) 770-6057

(Florida Area)
2510 Kirby Ave. N.E.
Suite 109
Palm Bay, FL 32905
Tel: (800) 558-2351
Tel: (407) 724-9910
Fax: (800) 292-6579
Fax: (407) 729-6579

(Virginia Area)
1111 Knoll Mist Lane
Gaithersburg, MD 20879
Tel: (800) 293-2080
Tel: (301) 527-0113
Fax: (301) 527-0115

(California Area)
1028 Opal Street
San Diego, CA 92109
Tel: (800) 372-1580
Tel: (619) 272-1580
Fax: (619) 272-2362

Bravo Electronics (West Coast Area)
610 Palomar Ave.
Sunnyvale, CA 94086-2913
Tel: (800) 392-6318
Tel: (408) 733-9090
Fax: (408) 733-8555

Alcom Electronics (Belgium)
Singel 3
2550 Kontich
Tel: + 32 (34) 58.30.33
Fax: + 32 (34) 58.31.26

E V Johanssen Electronik (Denmark)
Titangade 15
2200 Copenhagen N
Tel: + 45 35 86 90 22
Fax: + 45 35 86 90 00

Hy-Line Power Components (Germany)
Insekammerstr. 10
82008 Unterhaching
Tel: + 49 (89) 6 14 90 10
Fax: + 49 (89) 6 14 09 60

Metl (United Kingdom)
Countax House
Haseley Trading Estate
Stathampton Road
Great Haseley
Oxford OX44 7PF
Tel: +44 (1844) 278781
Fax: +44 (1844) 278746

Westech Electronics (Pte.), Ltd. (Singapore)
12 Lorong Bakar BATU #05-07
Kolam Ayer Industrial Park
Singapore 1334
Tel: +65 743 63 55
Fax: +65 746 13 96

TCE Sel (Italy)
Nia Trento 59
20021 Osipate Di Bollate
Milano
Tel: + 39 (2) 3501203
Tel: + 39 (2) 3501205
Fax: + 39 (2) 3501924

Tritech Ltd. (Israel)
4, Ha'Yetzira St.
P.O. Box 2436
43100 Ra'Anana
Tel: +972 (9) 917277
Fax: +972 (9) 982616