The Infinite Bandwidth Company™

Application Note 15

Practical Switching Regulator Circuits

by Brian Huffman

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.

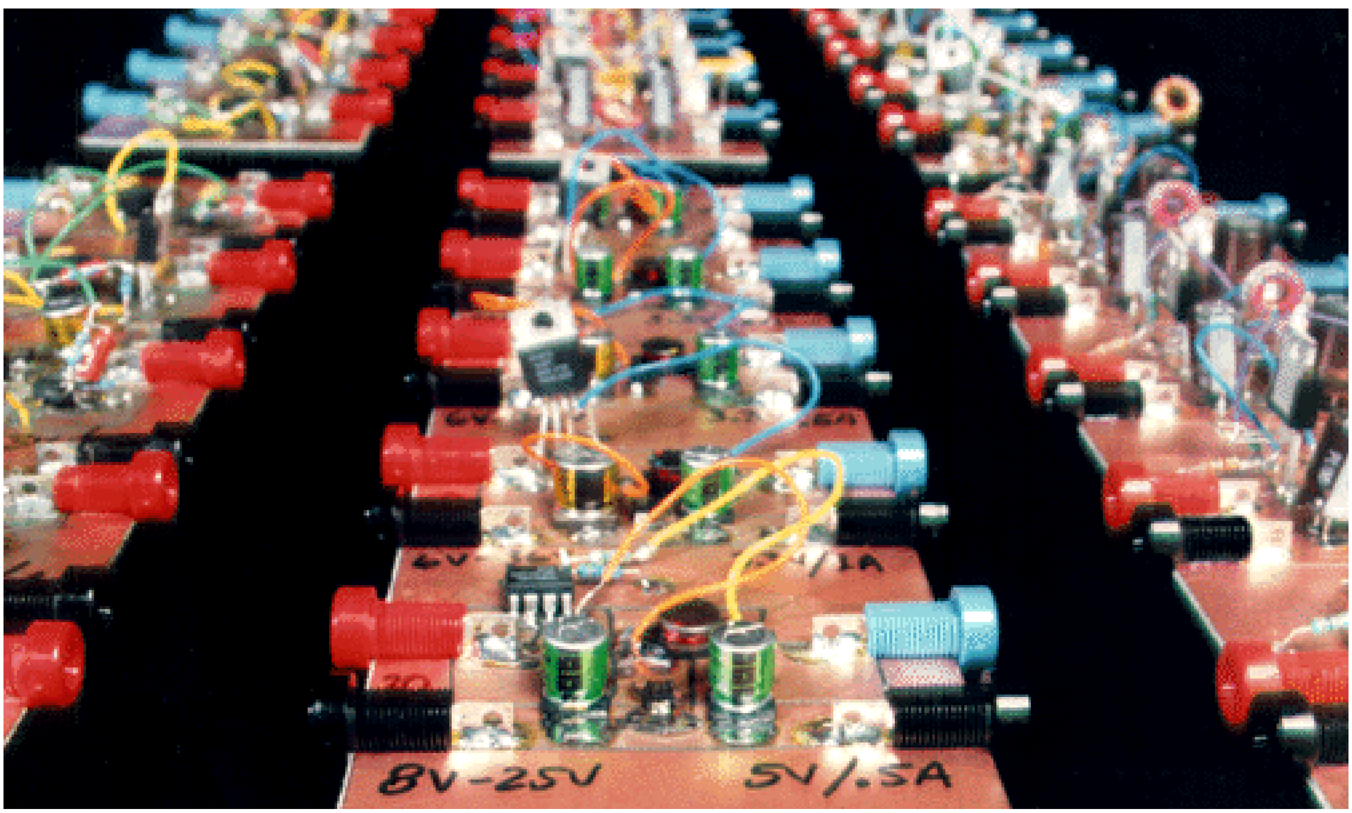

Figure 1. Designed, Built, and Tested

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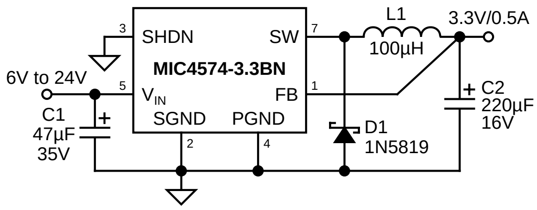
Application Note Contents

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



C1	Nichicon	UPL1V470MEH, ESR = 0.34Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	1N5819
L1	Sumida	RCH875-101K, DCR = 0.28Ω

Figure 1a. Schematic

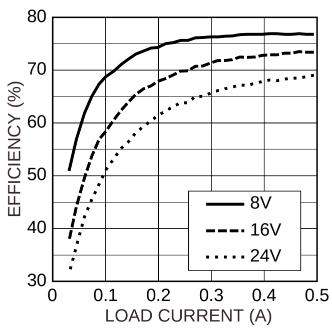
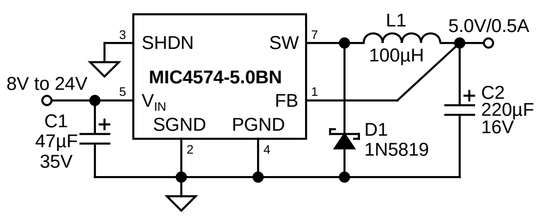


Figure 1b. Efficiency

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



C1	Nichicon	UPL1J470MEH, ESR = 0.34Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	1N5819
L1	Sumida	RCH875-101K, DCR = 0.28Ω

Figure 2a. Schematic

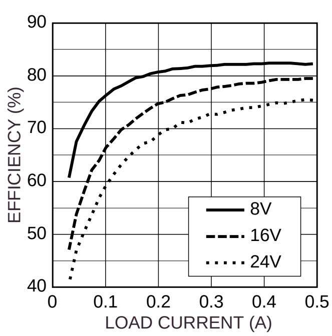
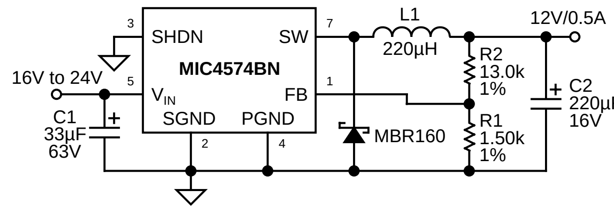


Figure 2b. Efficiency

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



C1	Nichicon	UPL1J330MEH, ESR = 0.35Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.16Ω
D1	Motorola	MBR160
L1	Sumida	RCH106-221K, DCR = 0.78Ω

Figure 3a. Schematic

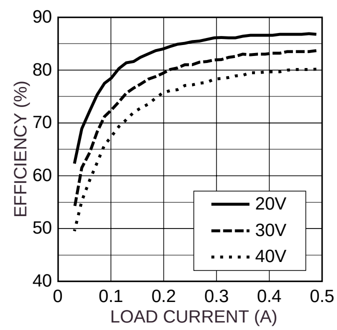
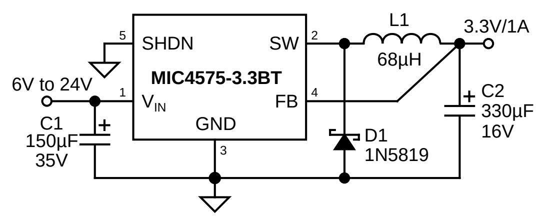


Figure 3b. Efficiency

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



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Sumida	RCH106-680K, DCR = 0.22Ω
L1	Bi	HM77-11003, DCR = 0.233Ω, **Note 2**

Figure 4a. Schematic

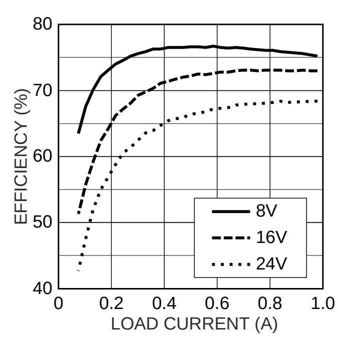
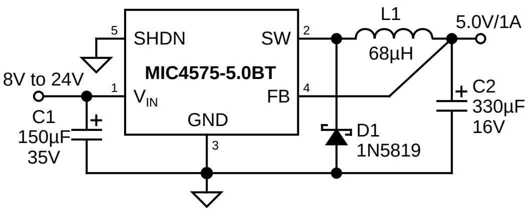


Figure 4b. Efficiency

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



C1	Nichicon	UPL1J151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
L1	Sumida	RCH106-680K, DCR = 0.22Ω
L2	Bi	HM77-11003, DCR = 0.233Ω, **Note 2**

Figure 5a. Schematic

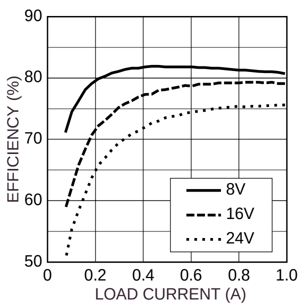
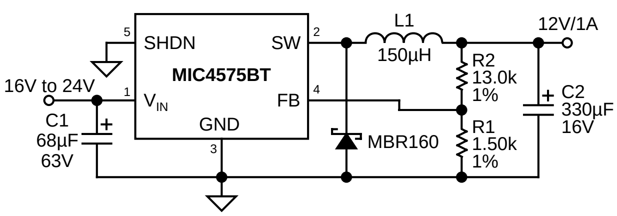


Figure 5b. Efficiency

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



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	MBR160
L1	Sumida	RCH110-151K, DCR = 0.23Ω

Figure 6a. Schematic

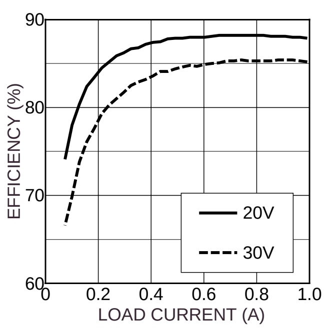
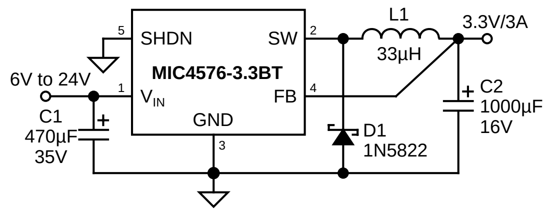


Figure 6b. Efficiency

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



C1	Nichicon	UPL1V471MPH, ESR = 0.046Ω
C2	Nichicon	UPL1C221MPH, ESR = 0.047Ω
D1	Motorola	1N5822
L1	Coiltronics	PL52C-33-1000, DCR = 0.036Ω
L1	Bi	HM77-30004, DCR = 0.045Ω, **Note 2**

Figure 7a. Schematic

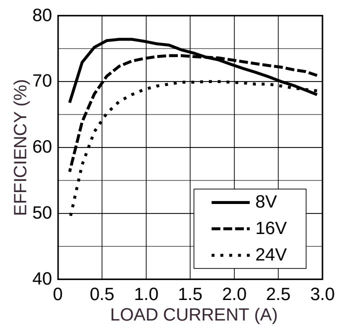
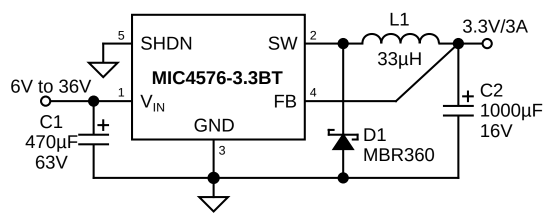


Figure 7b. Efficiency

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



C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PL52C-33-1000 DCR = 0.036
L1	Bi	HM77-30004, DCR = 0.045Ω, **Note 2**

Figure 8a. Schematic

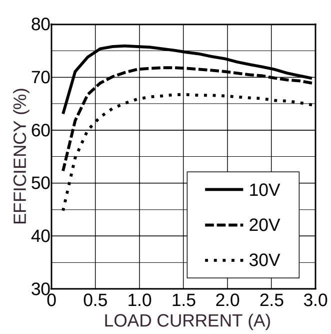
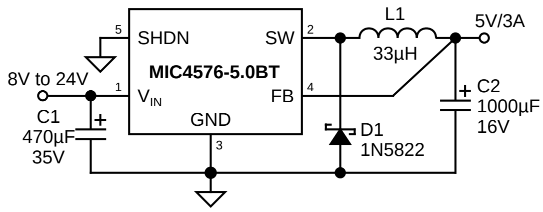


Figure 8b. Efficiency

Note 2: Surface-mount component

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 = 0.036
L1	Bi	HM77-30004, DCR = 0.045Ω, **Note 2**

Figure 9a. Schematic

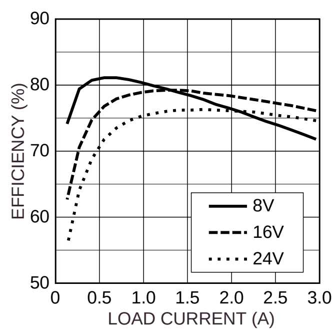
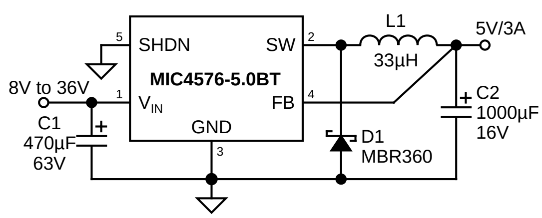


Figure 9b. Efficiency

8V–36V to 5V/3A Buck Converter Through Hole



C1	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	MBR360
L1	Coiltronics	PLS2C-33-1000, DCR = 0.036
L1	Bi	HM77-30004, DCR = 0.045Ω, **Note 2**

Figure 10a. Schematic

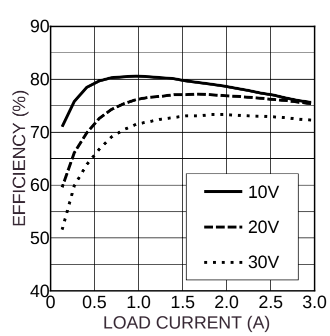
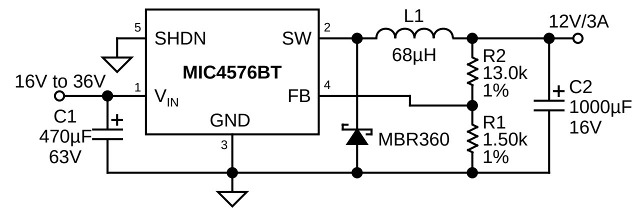


Figure 10b. Efficiency

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

Figure 11a. Schematic

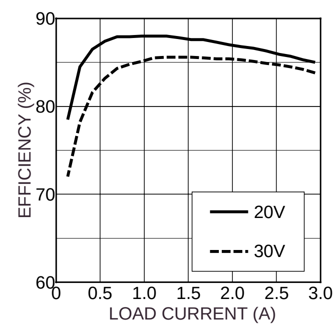
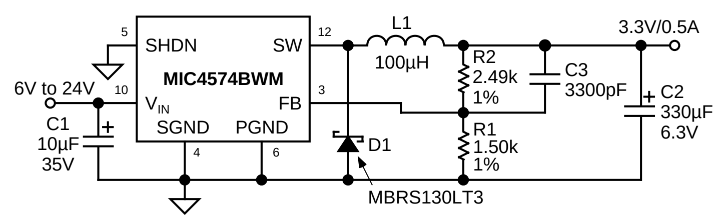


Figure 11b. Efficiency

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

Figure 12a. Schematic

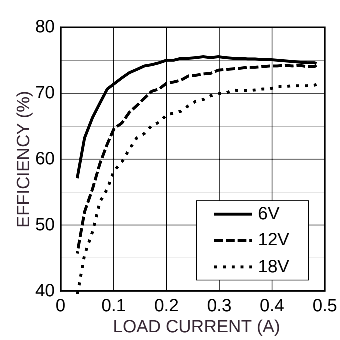
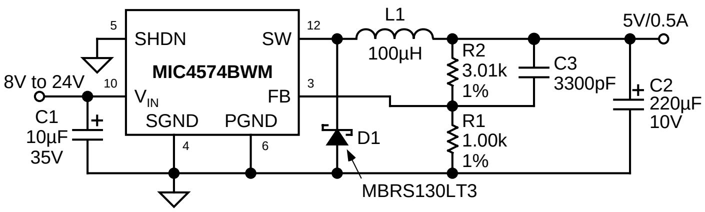


Figure 12b. Efficiency

Note 2: Surface-mount component

8V–24V to 5V/0.5A Buck Converter Low-Profile Surface Mount



C1 AVX TPSD106M035R0300, ESR = 0.3Ω
C2 AVX TPSE227M010R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX100-2P, DCR = 0.541Ω

Figure 13a. Schematic

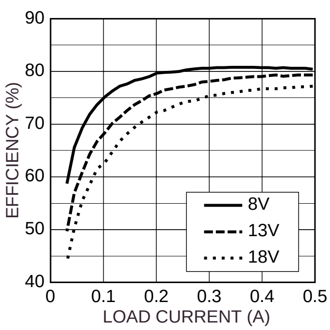
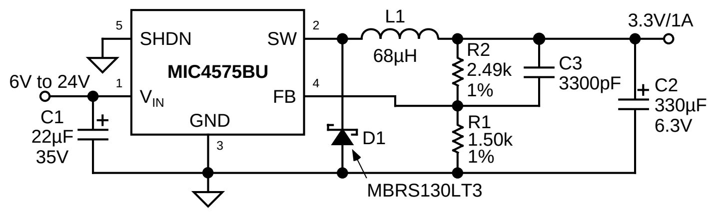


Figure 13b. Efficiency

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



C1 AVX TPSE226M035R0300, ESR = 0.3Ω
C2 AVX TPSE337M006R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX68-4P, DCR = 0.238Ω

Figure 15a. Schematic

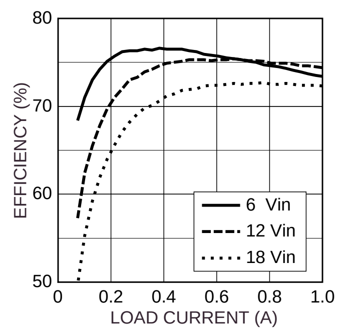
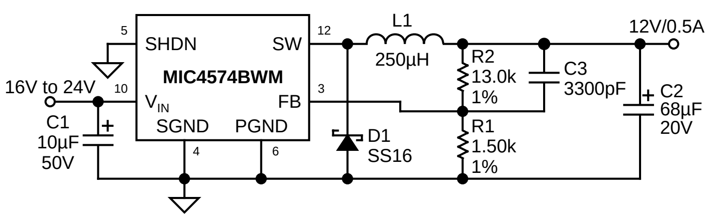


Figure 15b. Efficiency

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



C1 Tokin C55Y5U1H106Z
C2 AVX TPSE686M020R0150, ESR = 0.15Ω
D1 General Instruments SS16
L1 Coiltronics CTX250-4P, DCR = 0.434Ω

Figure 14a. Schematic

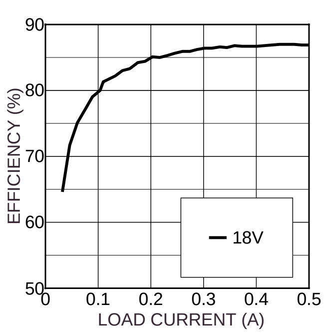
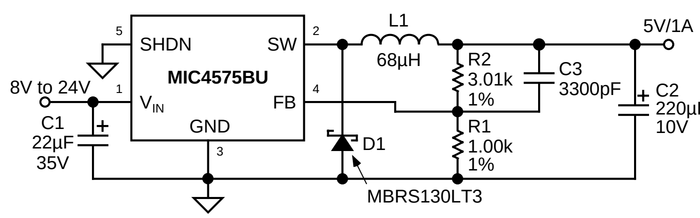


Figure 14b. Efficiency

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



C1 AVX TPSE226M035R0300, ESR = 0.3Ω
C2 AVX TPSE227M010R0100, ESR = 0.1Ω
D1 Motorola MBRS130LT3
L1 Coiltronics CTX68-4P, DCR = 0.238Ω

Figure 16a. Schematic

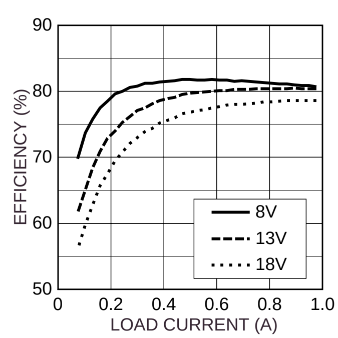
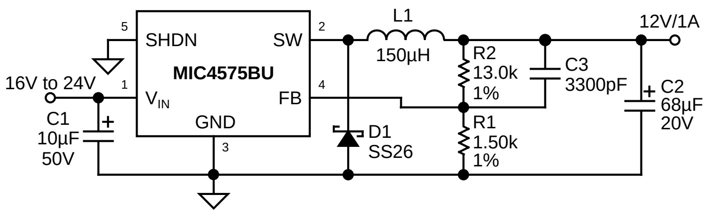


Figure 16b. Efficiency

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



C1 Tokin C55YU1H106Z
C2 AVX TPSE686M020R0150, ESR = 0.15Ω
D1 General Instruments SS26
L1 Coiltronics CTX150-4, DCR = 0.372Ω

Figure 17a. Schematic

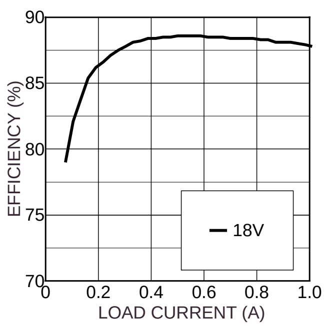
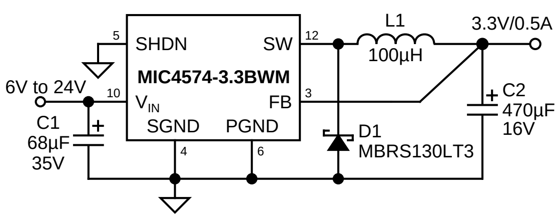


Figure 17b. Efficiency

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



C1 Sanyo 35CV168GX, ESR = 0.34Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 Motorola MBRS130LT3
L1 Coilcraft DO3316P-104, DCR = 0.23Ω

Figure 18a. Schematic

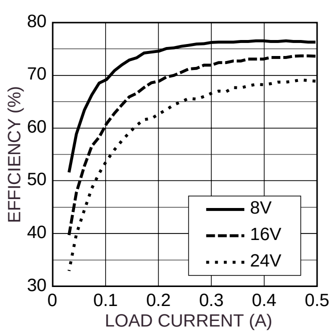
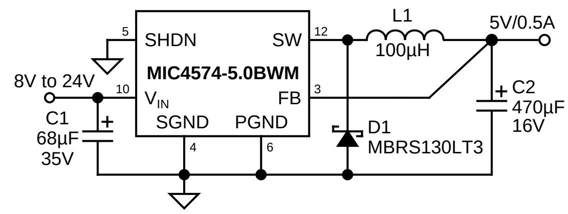


Figure 18b. Efficiency

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



C1 Sanyo 35CV168GX, ESR = 0.34Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 Motorola MBRS130LT3
L1 Coilcraft DO3316P-104, DCR = 0.23Ω

Figure 19a. Schematic

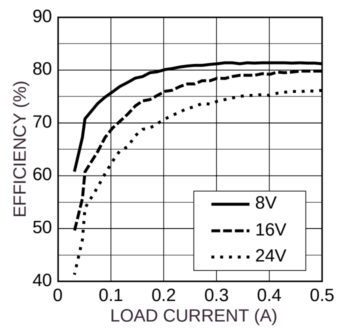
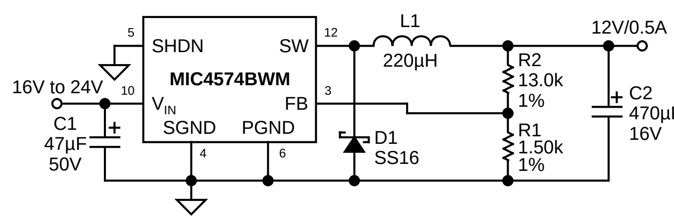


Figure 19b. Efficiency

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



C1 Nichicon UUX1H470MNT1GS, ESR = 0.4Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 General Instruments SS16
L1 Coilcraft DO3316-224, DCR = 0.53Ω

Figure 20a. Schematic

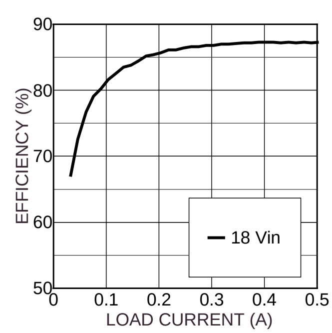
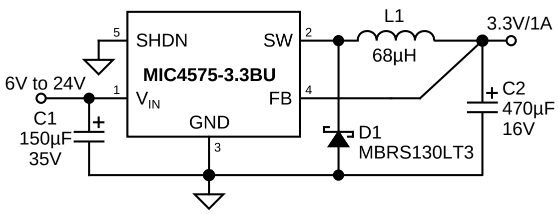


Figure 20b. Efficiency

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

Figure 21a. Schematic

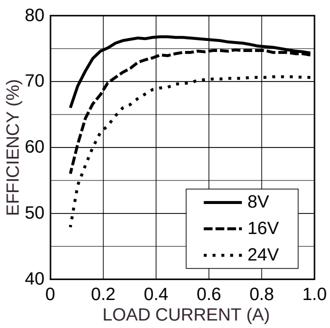
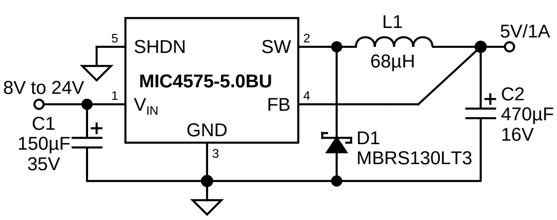


Figure 21b. Efficiency

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

Figure 22a. Schematic

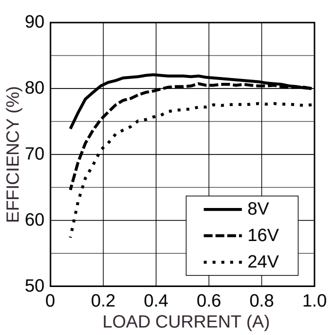
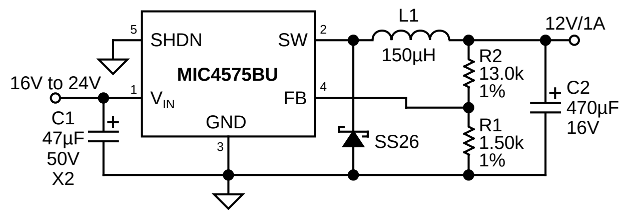


Figure 22b. Efficiency

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



C1 Nichicon UUX1H470MT1GS, ESR = 0.4Ω
C2 Sanyo 16CV470GX, ESR = 0.17Ω
D1 General Instruments SS26
L1 Coiltcraft DO5022P-154, DCR = 0.218Ω

Figure 23a. Schematic

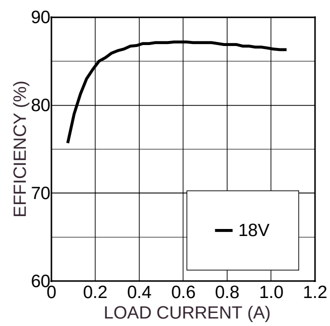


Figure 23b. Efficiency

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

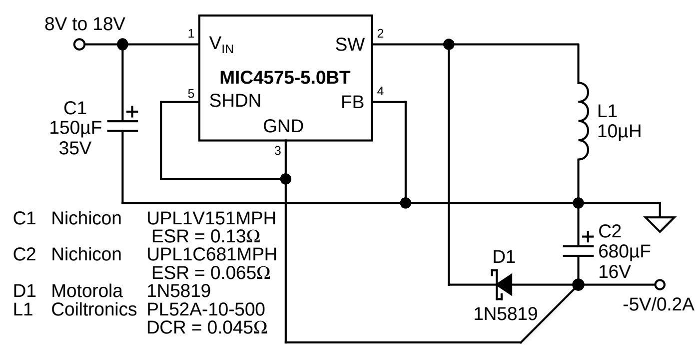


Figure 24a. Schematic

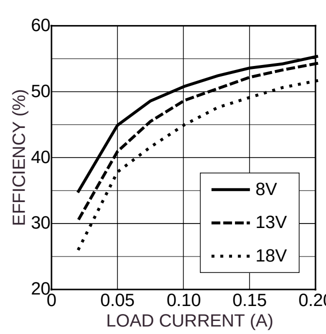
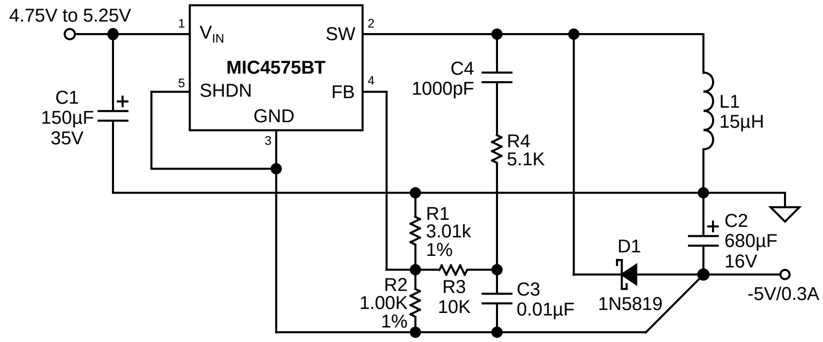


Figure 24b. Efficiency

5V to –5V/0.3A Buck-Boost Converter Through Hole



C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C681MPH, ESR = 0.065Ω
D1	Motorola	1N5819
L1	Coiltronics	PL52A-15-500, DCR = 0.054Ω

Figure 25a. Schematic

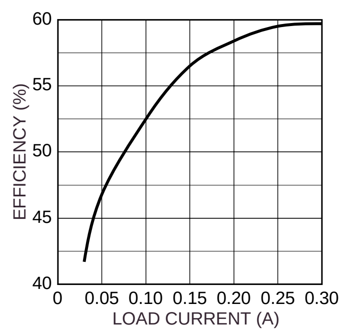
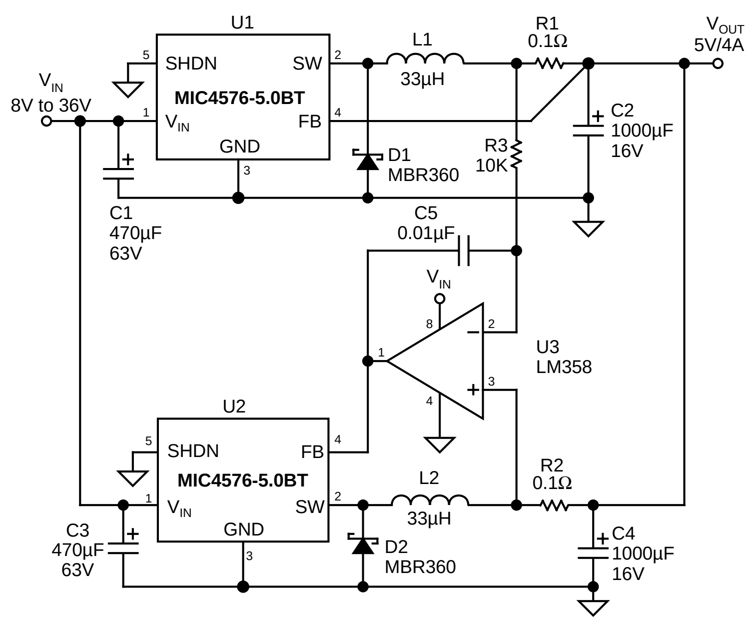


Figure 25b. Efficiency

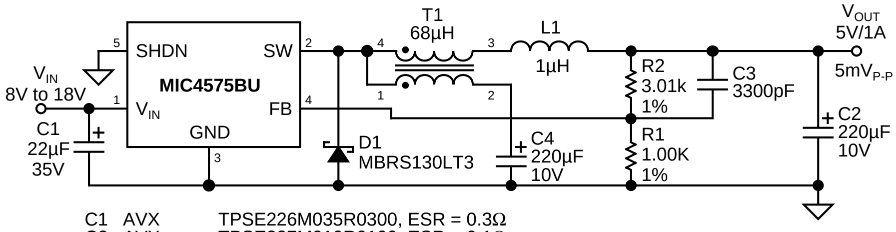
Parallel Switching Regulators



C1, C3	Nichicon	UPL1J471MRH, ESR = 0.039Ω
C2, C4	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1, D2	Motorola	MBR360
L1, L2	Coiltronics	PL52C-33-1000, DCR = 0.036
R1, R2	KRL	SP-1-A1-0R100J
U3	National	LM358

Figure 26.

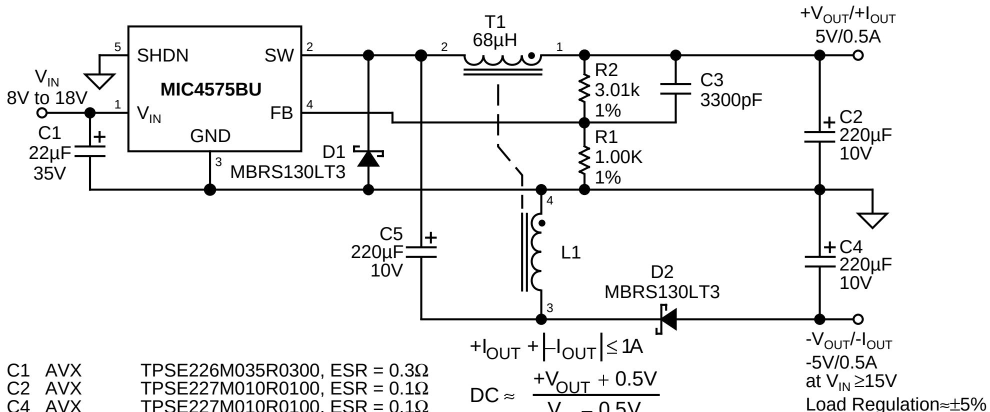
Low Output-Noise Regulator (5mV Output Ripple)



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE227M010R0100, ESR = 0.1Ω
C4	AVX	TPSE227M010R0100, ESR = 0.1Ω
D1	Motorola	MBRS130LT3
T1	Coiltronics	CTX68-4P, DCR = 0.238Ω
L1	Coilcraft	DO1608C-102

Figure 27.

Split ±5V Supply



C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
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

$$+I_{OUT} + \left|-I_{OUT}\right| \le 1A$$

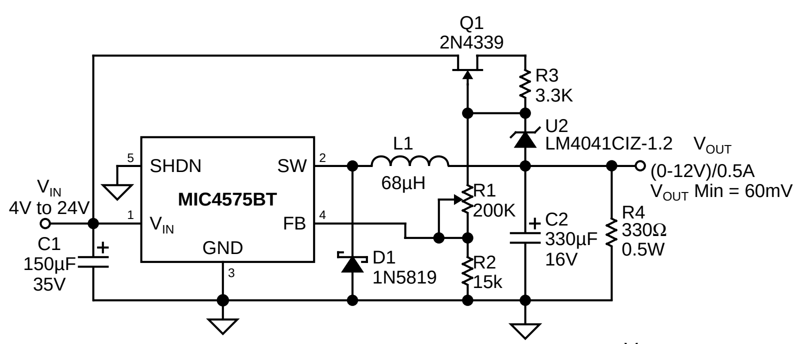
$$DC \approx \frac{+V_{OUT} + 0.5V}{V_{IN} - 0.5V}$$

$$DC \le 40\% \text{ then } -I_{OUT} \le +I_{OUT}$$

$$DC \ge 40\% \text{ then } -I_{OUT} \le +I_{OUT} \times (1 - DC)$$

Figure 28.

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



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

$$V_{IN\ min} \ge \frac{V_{OUT}}{0.9} + 1.5V$$

and

$$V_{IN\ min} \ge V_{OUT} + 2.5V$$

Figure 29.

Low Output-Voltage Regulator (1V)

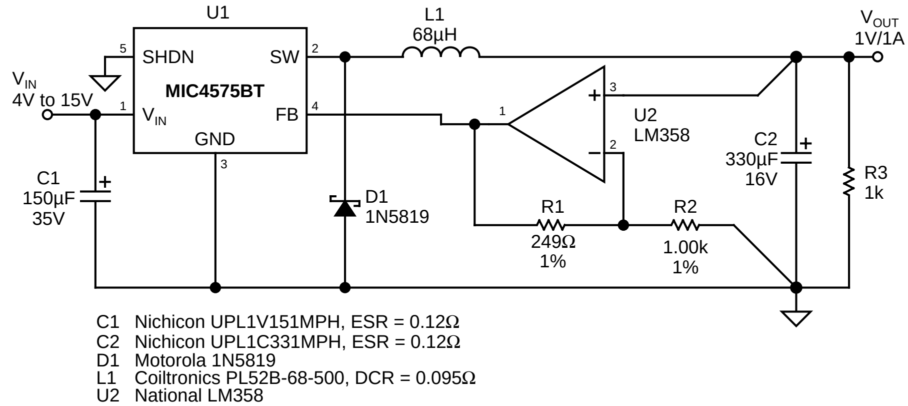


Figure 30.

1A Battery Charger (6–8 cells)

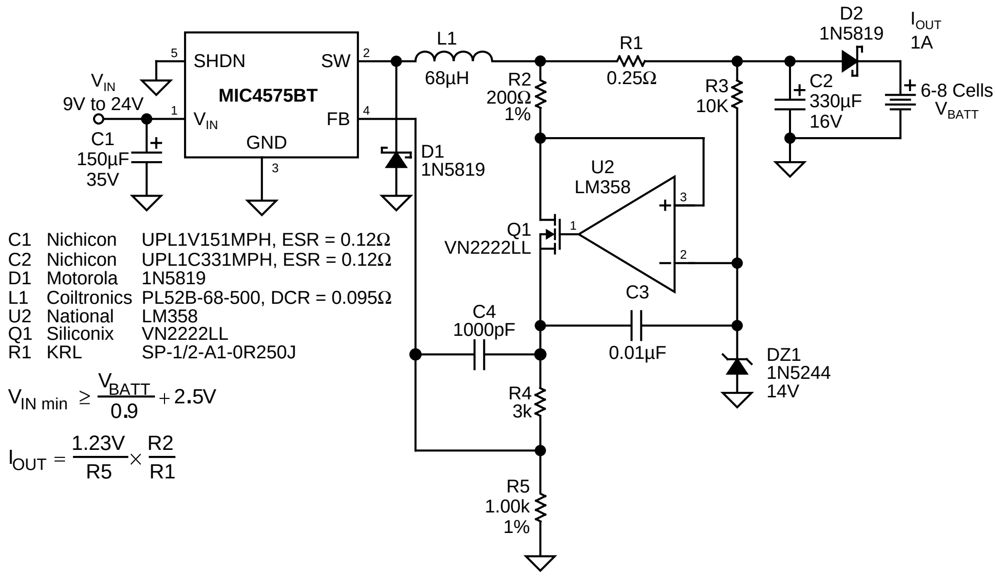


Figure 31.

0.1A–1A Variable-Current Battery Charger

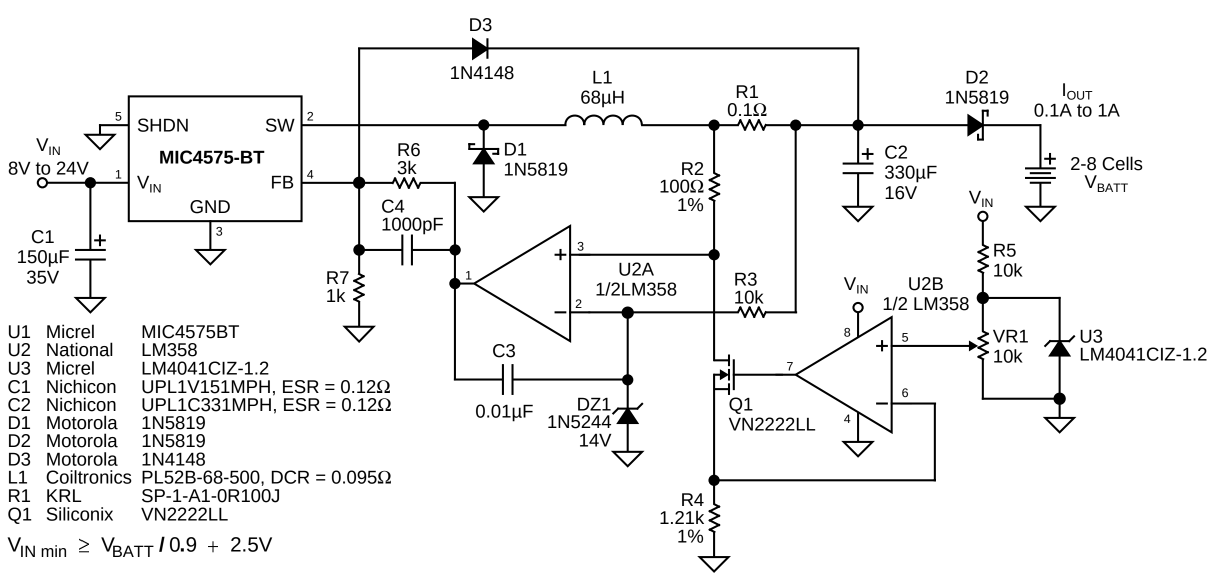
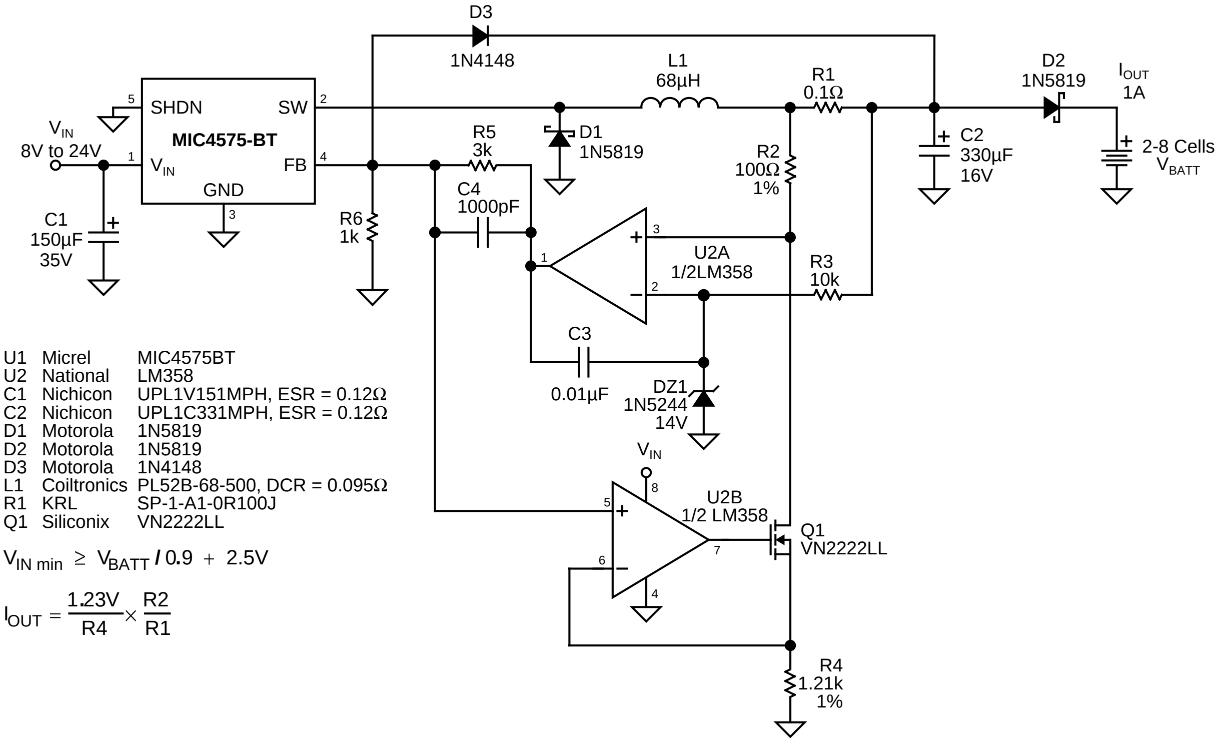


Figure 32.

1A Battery Charger (2–8 Cells)



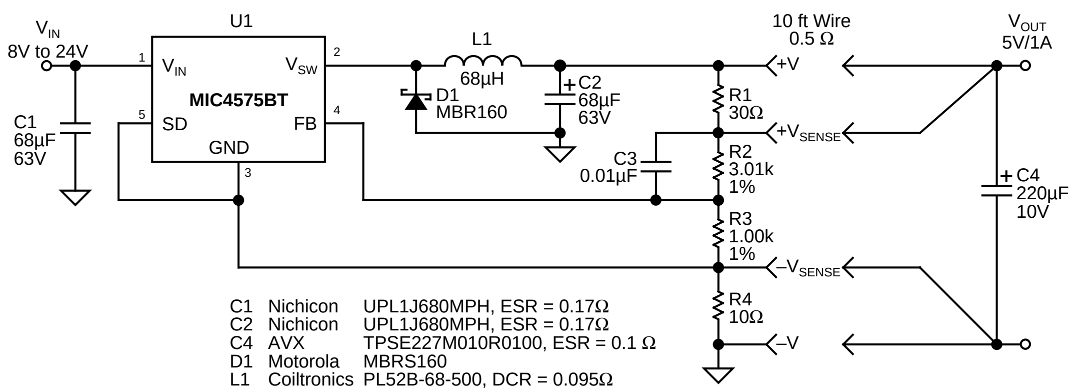
U1	Micrel	MIC4575BT
U2	National	LM358
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
D3	Motorola	1N4148
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω
R1	KRL	SP-1-A1-0R100J
Q1	Siliconix	VN2222LL

$$V_{IN\ min} \geq V_{BATT} / 0.9 + 2.5V$$

$$I_{OUT} = \frac{1.23V}{R4} \times \frac{R2}{R1}$$

Figure 33.

Remote-Sensing Regulator



C1	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C2	Nichicon	UPL1J680MPH, ESR = 0.17Ω
C4	AVX	TPSE227M010R0100, ESR = 0.1 Ω
D1	Motorola	MBRS160
L1	Coiltronics	PL52B-68-500, DCR = 0.095Ω

Figure 34.

6V–18V to Split ±12V/100mA Supply

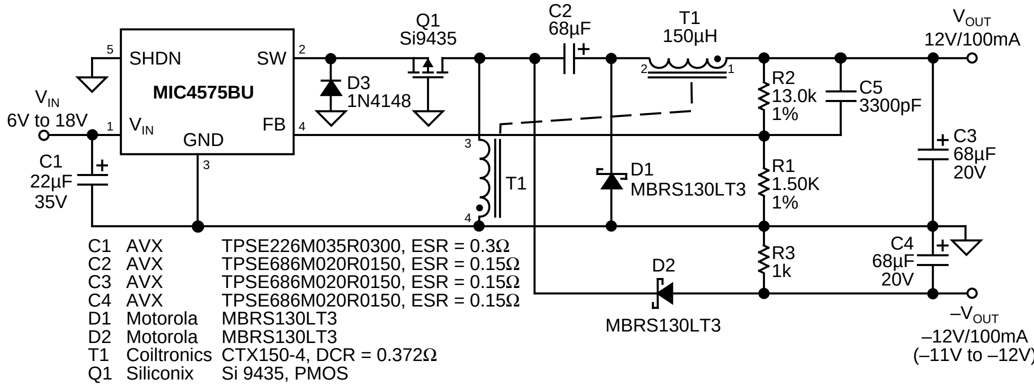
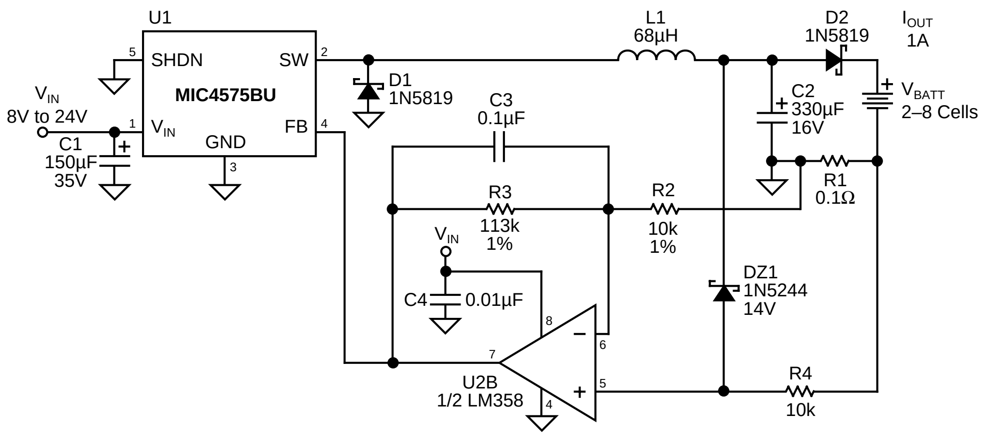


Figure 35.

1A Battery Charger

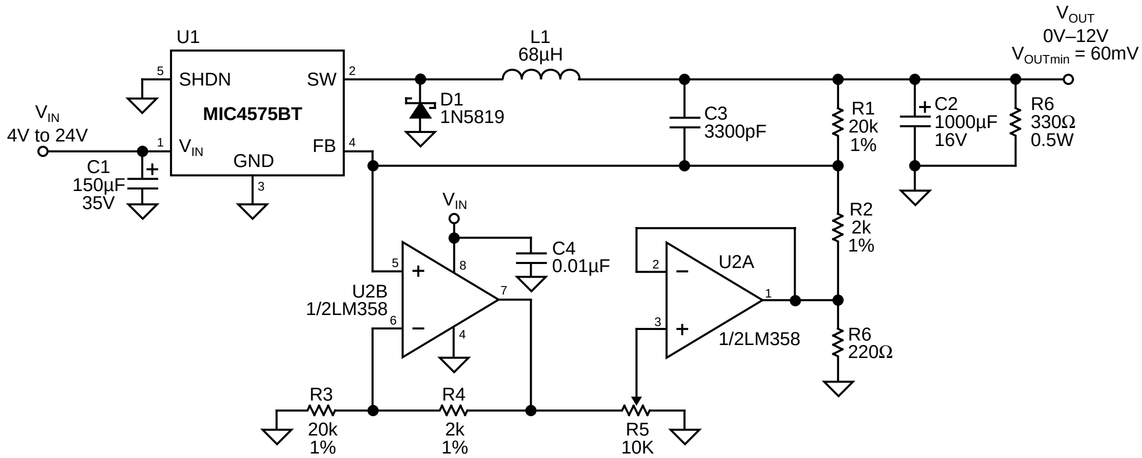


$$V_{IN\ min} > = \frac{V_{BATT}}{0.9} + 2.5V$$

$$I_{OUT} = \frac{1.23V}{R1} \times \frac{R2}{R2 + R3}$$

Figure 36.

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



U1	Micrel	MIC4575BT
U2	National	LM358
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C2	Nichicon	UPL1C102MPH, ESR = 0.047Ω
D1	Motorola	1N5819
L1	Bi	HM77-11003, DCR = 0.233Ω

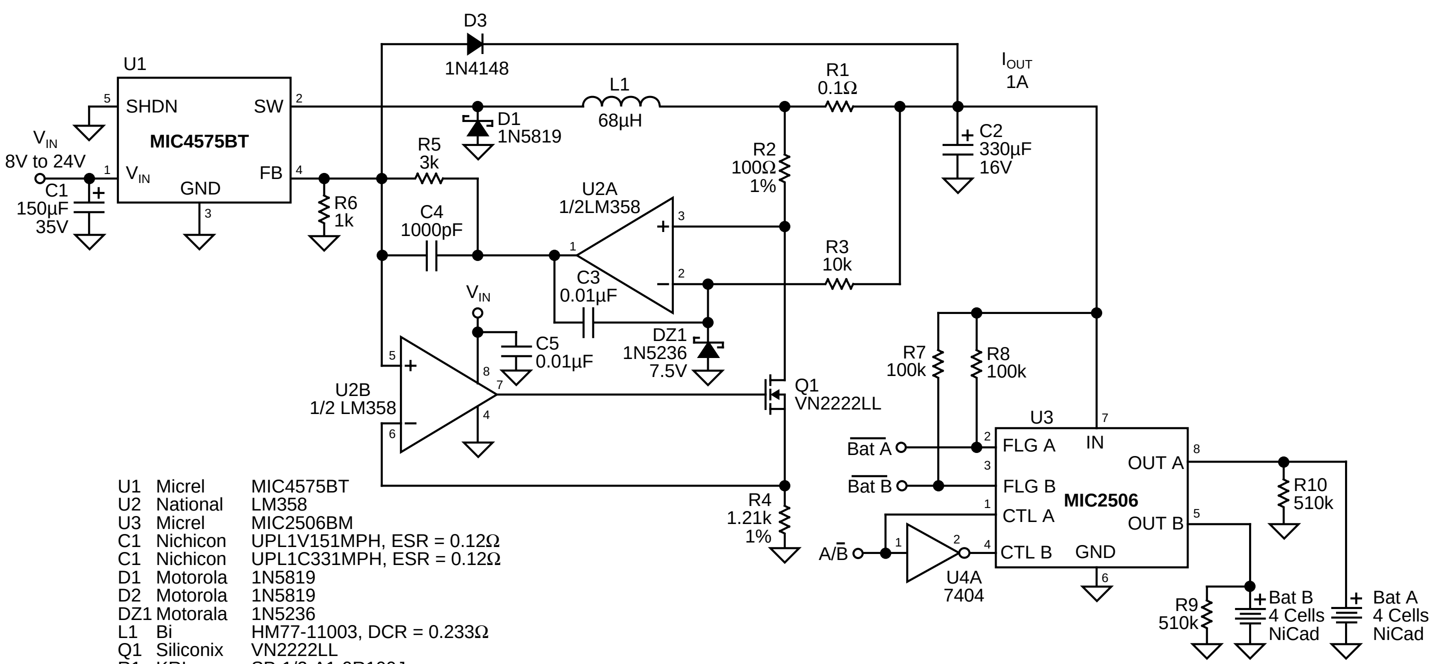
$$V_{IN\ min} > = \frac{V_{OUT}}{0.9} + 2.5V$$

$$V_{OUT\ max} = 1.23V \times \left(1 + \frac{R1}{R2}\right)$$

R1 = R3 and R2 = R4

Figure 37.

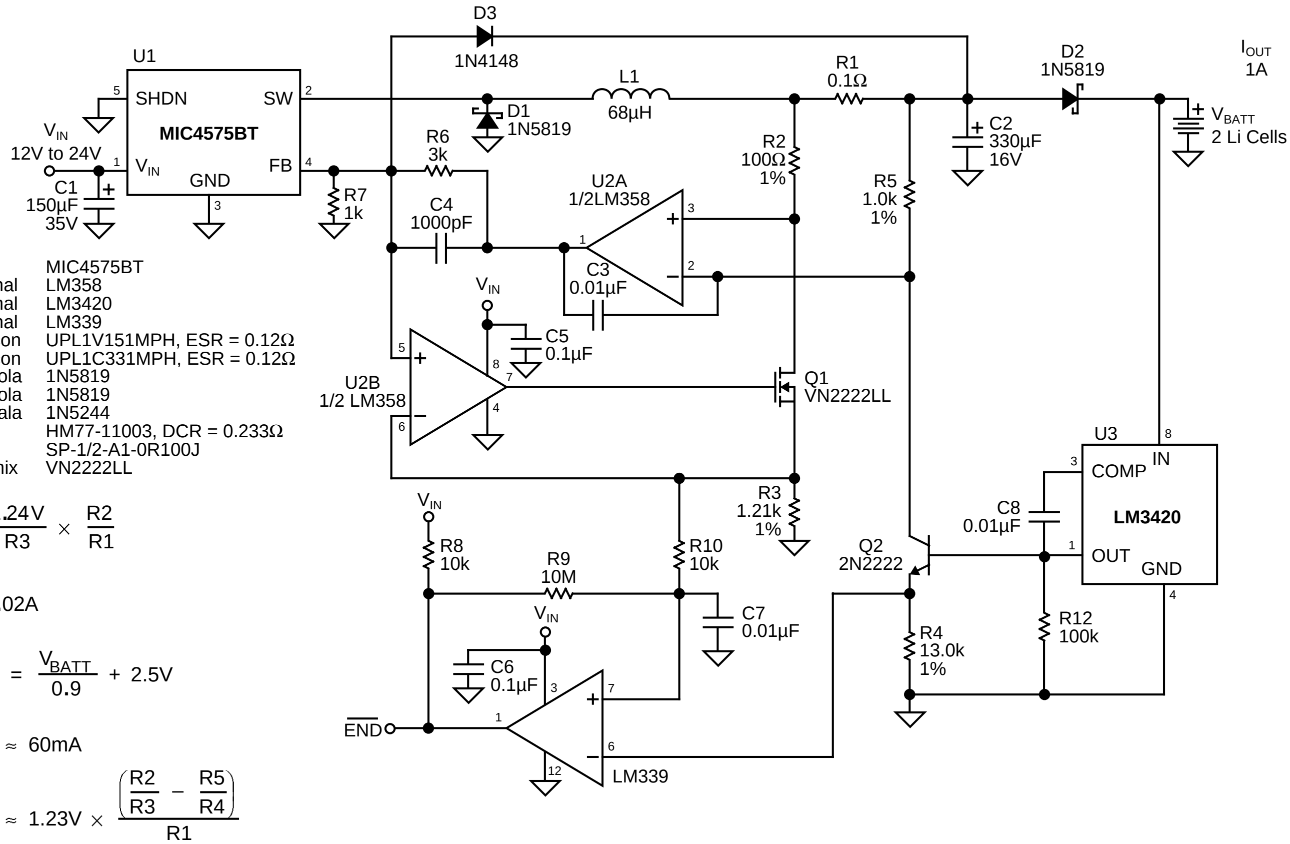
Switchable Battery-Pack Charger



U1	Micrel	MIC4575BT
U2	National	LM358
U3	Micrel	MIC2506BM
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C1	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
DZ1	Motorala	1N5236
L1	Bi	HM77-11003, DCR = 0.233Ω
Q1	Siliconix	VN2222LL
R1	KRL	SP-1/2-A1-0R100J

Figure 38.

Lithium-Ion Battery Charger with End-of-Charge Flag



U1	Micrel	MIC4575BT
U2	National	LM358
U3	National	LM3420
U4	National	LM339
C1	Nichicon	UPL1V151MPH, ESR = 0.12Ω
C1	Nichicon	UPL1C331MPH, ESR = 0.12Ω
D1	Motorola	1N5819
D2	Motorola	1N5819
DZ1	Motorola	1N5244
L1	Bi	HM77-11003, DCR = 0.233Ω
R1	KRL	SP-1/2-A1-0R100J
Q1	Siliconix	VN2222LL

$$I_{OUT} = \frac{1.24V}{R3} \times \frac{R2}{R1}$$

$$I_{OUT} = 1.02A$$

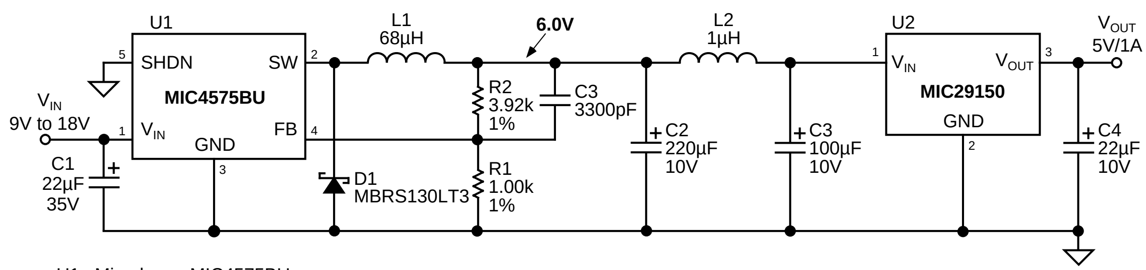
$$V_{IN\ min} > = \frac{V_{BATT}}{0.9} + 2.5V$$

$$I_{OUT}END \approx 60mA$$

$$I_{OUT}END \approx 1.23V \times \frac{\left(\frac{R2}{R3} - \frac{R5}{R4}\right)}{R1}$$

Figure 39.

Low Output-Noise Regulator (<1mV)



U1	Micrel	MIC4575BU
U2	Micrel	MIC29150-5.0BU
C1	AVX	TPSE226M035R0300, ESR = 0.3Ω
C2	AVX	TPSE227M010R0100, ESR = 0.1Ω
C3	AVX	TPSE106M010R0200, ESR = 0.2Ω
C4	Sprague	293D226X0010C2W
D1	Motorola	MBRS130LT3
D2	Motorola	MBRS130LT3
L1	Bi	HM77-11003, DCR = 0.233Ω
L2	Coilcraft	D016087C-102, DCR = 0.05Ω

$$V_{OUT} = 1.23 \times \left(1 + \frac{R2}{R1}\right)$$

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

	Nichicon (Electrolytic)	Sanyo (Electrolytic)	Panasonic (Electrolytic)	United Chemi-Con (Electrolytic)
220µF/16V/0.16Ω/0.460A	UPL1C221MPH	16MV220GX	ECA1CFQ271	LXF16VB271M10x12.5
330µF/16V/0.12Ω/0.595A	UPL1C331MPH	16MV330GX	ECA1CFQ331L	LXF16VB331M8x15
680µF/16V/0.065Ω/1.02A	UPL1C681MPH	16MV560GX	ECA1CFQ681L	LXF16VB681M10x20
1000µF/16V/0.047Ω/1.41A	UPL1C102MPH	16MV1000GX	ECA1CFQ122L	LXF16VB102M10x30
47µF/35V/0.34Ω/0.27A	UPL1V470MEH	35MV68GX	ECA1VFQ560	LXF35VB680M6.3x11.5
150µF/35V/0.12Ω/0.595A	UPL1V151MPH	35MV150GX	ECA1VFQ151L	LXF35VB181M8x15
470µF/35V/0.046Ω/1.42A	UPL1V471MPH	35MV680GX	ECA1VFQ561L	LXF35VB5611M10x30
33µF/63V/0.35Ω/0.33A	UPL1J330MEH	63MV82GX	ECA1JFQ390	LXF63VB33M6.3x15
68µF/63V/0.17Ω/0.5A	UPL1J680MPH	63MV150GX	ECA1JFQ680	LXF63VB820M8x20
470µF/63V/0.039Ω/1.42A	UPL1J471MRH	63MV680GX	ECA1JFQ471L	LXF63VB561M12.5x40

Diodes

	Motorola (Schottky)	GI (Schottky)	IR (Schottky)
1A/40V	1N5819	1N5819	11DQ04
1A/60V	MBR160	SB160	11DQ06
3A/40V	1N5822	1N5822	31DQ04
3A/60V	MBR360	SB360	31DQ06

Inductors

	Coiltronics (Toroidal Cores)	Renco (Rod Cores)	Sumida (Button Cores)
10µH/0.5A	PL52A-10-500		
15µH/0.5A	PL52A-15-500		
33µH/3A	PL52C-33-1000		
68µH/1A	PL52B-68-500	RL-1283-68-43	RCH106-680K
68µH/3A	PL52D-68-2000		
100µH/0.5A	PL52A-100-250	RL-1284-100-43	RCH875-101K
150µH/1A	PL52B-150-500	RL-1283-150-43	RCH110-151K
220µH/0.5A	PL52A-220-250	RL-1284-220-43	RCH106-221K

Surface-Mount

Capacitors

Low Profile	AVX (Tantalum)	Tokin (Ceramic)	Sprague (Tantalum)
330µF/6.3V/0.1Ω/1.149A	TPSE337M006R0100		593D337X06R3E2W
220µF/10V/0.1Ω/1.149A	TPSE227M010R0100		593D227X0010E2W
68µF/20V/0.15Ω/0.938A	TPSE686M020R0150		593D686X0020EZW
10µF/35V/0.3Ω/0.663A	TPSD106M035R0300		593D106X0035E2W
22µF/35V/0.3Ω/0.632A	TPSE226M035R0300		593D226X0035E2W
10µF/35V		C55Y5U1E106Z	
22µF/35V		C25Y5U1E226Z	
10µF/50V		C55Y5U1H106Z	

Lower-Cost	Sanyo (Electrolytic)	Nichicon (Electrolytic)
470µF/16V/0.17Ω/0.45A	16CV470GX	
68µF/35V/0.34Ω/0.28A	35CV68GX	
220µF/35V/0.17Ω/0.45A	35CV220GX	
47µF/50V/0.4Ω/0.18A		UUX1H470MNT1GS

Diodes

	Motorola (Schottky)	GI (Schottky)	IR (Schottky)
1A/30V	MBRS130LT3		
1A/40V	MBRS140T3	SS14/SS24	10MQ040
1A/60V		SS16/SS26	
3A/40V	MBRS340T3	SS34	330WQ04F
3A/60V	MBRS360T3	SS36	330WQ06F

Inductors

	Coiltronics (Toroidal Cores)	Coilcraft (Button Cores)	Bi (Toroidal Cores)
100µH/0.5A	CTX100-2P	DO3316P-104	
220µH/0.5A	CTX250-4P	DO3316P-224	
68µH/1A	CTX68-4P	DO3316P-683	HM77-11003
150µH/1A	CTX150-4	DO5022P-154	
33µH/3A			HM77-30004
68µH/3A			HM77-29006

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 Streeet
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 hand-held 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 it's 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

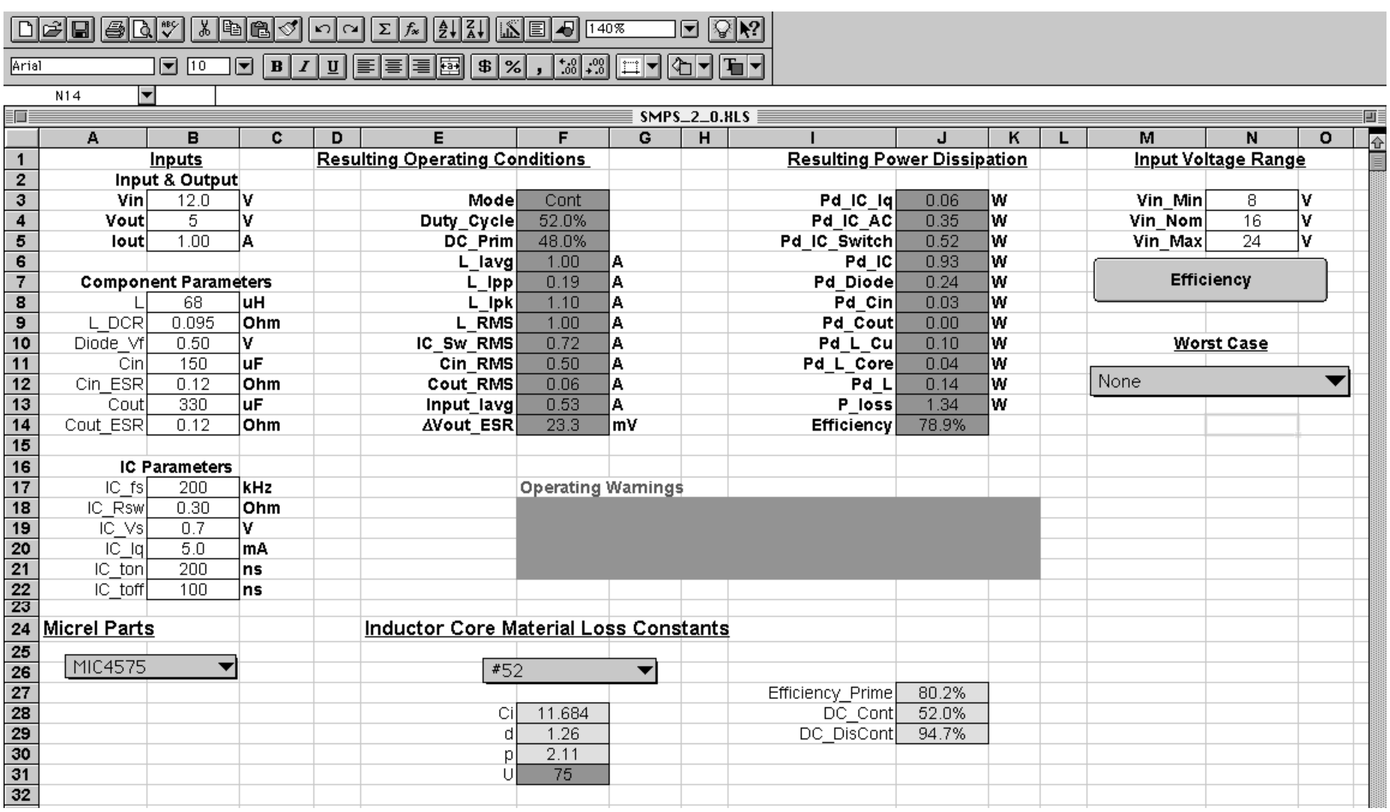


Figure C1. Buck Regulator Excel Spreadsheet

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 Operating Conditions

Mode: indicates whether the regulator is in continuous or discontinuous mode

DC: duty cycle

DC_Prim: (1 – 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

ΔVout_ESR: output ripple voltage caused by the ESR of the output capacitor

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

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.

Heat-Sink Style	Thermalloy No.	θ_{CA}
Clip on	6045	30°C/W
Screw mount	6099B	12°C/W

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 heat-sinking effect of the PC board. Table D1 gives a more reasonable junction-to-ambient thermal resistance for the various package types. Note that one square inch of PC board copper area was used to make these measurements. Additional copper area will lower the thermal resistance further.

Package Style	θ_{JA}
TO-220	50°C/W
TO-263	50°C/W
8-Pin DIP	90°C/W
16-Pin SO	100°C/W

Table D1. Package Thermal Coefficients (1 in^2 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

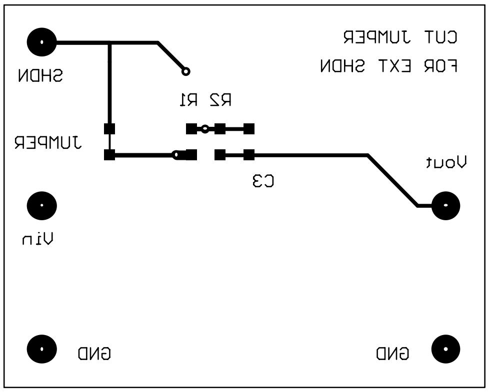
To achieve proper performance, printed circuit (PC) board layouts are provided for the various IC package types. Poor PC board layout can have dramatic effects on the operation of a power supply. Reduced efficiency, increased EMI, and spurious oscillations are just some of the results of a poor layout. 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.

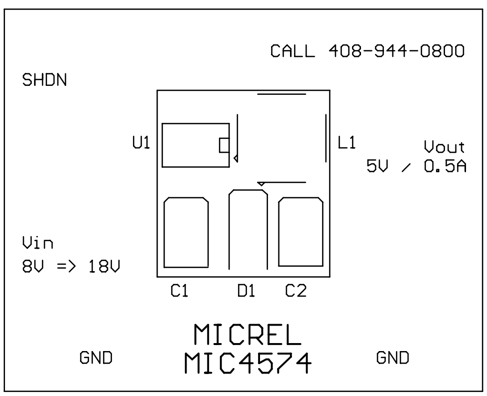
In 95 percent of the cases where a power supply is malfunctioning, the cause is more than likely that the inductor is physically too small rather than poor PC board layout.

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.

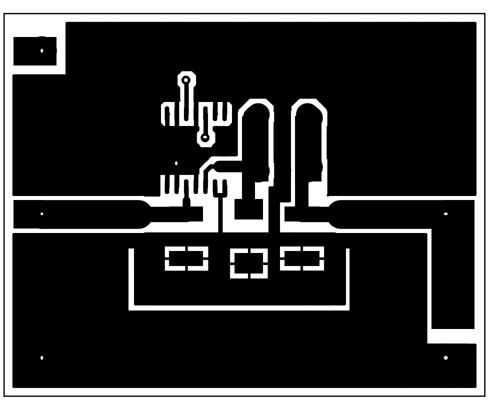
Figure 1.
MIC4574-5.0BWM
14-lead SOIC
(Layout for Figure 18a)



Solder Side

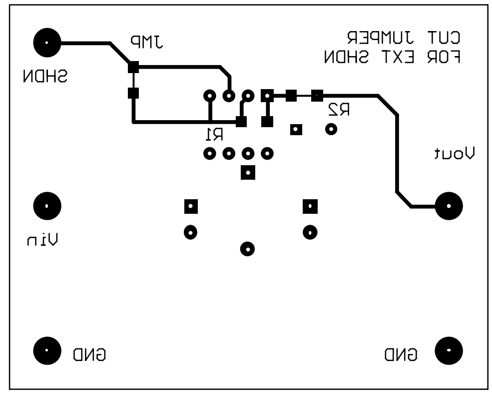


Silk Screen

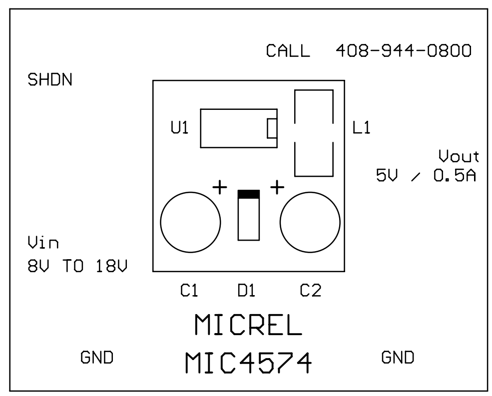


Component Side

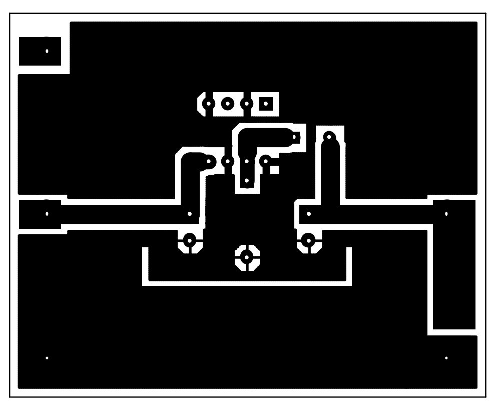
Figure 2.
MIC4574-5.0BN
8-pin DIP
(Layout for Figure 4a)



Solder Side

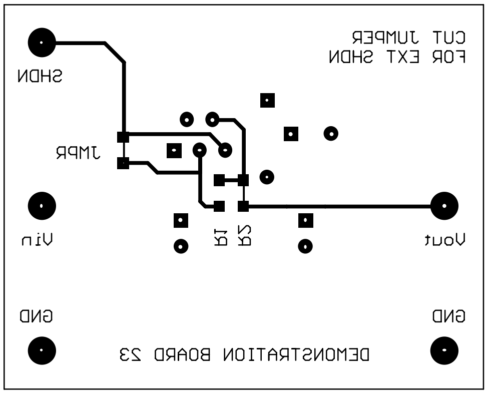


Silk Screen

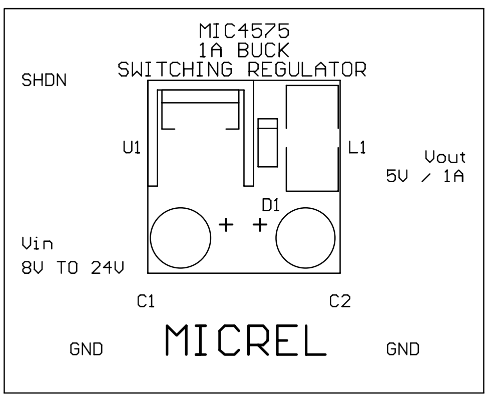


Component Side

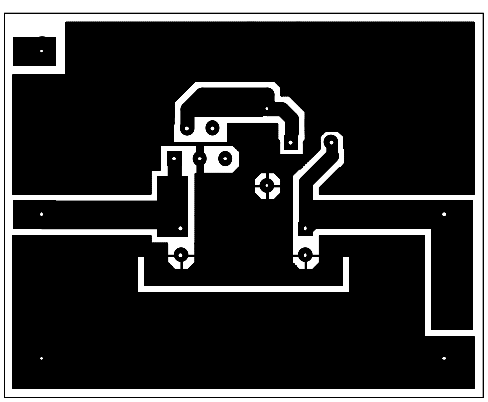
Figure 3.
MIC4575-5.0BT/MIC4576-5.0BT
5-lead TO-220
(Layout for Figure 9a)



Solder Side

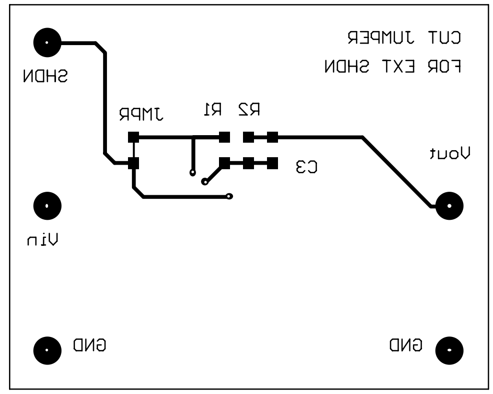


Silk Screen

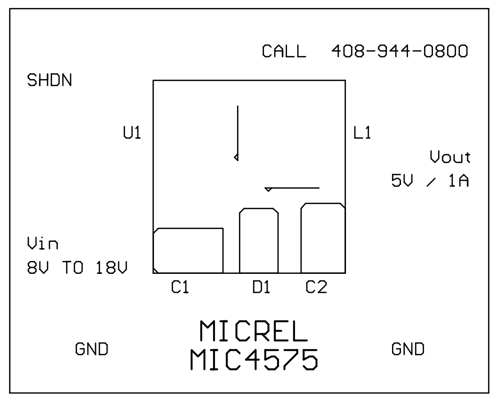


Component Side

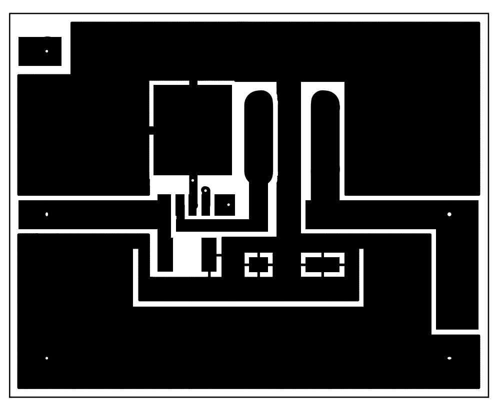
Figure 4.
MIC4575-5.0BU/MIC4576-5.0BU
5-lead TO-263
(Layout for Figure 22a)



Solder Side



Silk Screen



Component Side

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
Gaitherburg, 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)
Inseklammerstr. 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
Stadhampton 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 Ospiate 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

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