Keywords: Current limit, foldback, fold back, linear regulator, lead-acid battery

Nov 16, 2005

APPLICATION NOTE 3654

Current Limiting for the MAX1864 Auxiliary Regulator

Abstract: The MAX1864 is a low-cost, multiple-output converter consisting of a switching buck circuit and two positive linear regulators. Although this integrated circuit's basic application circuit offers a low cost multiple output supply, designs that require current limited linear regulator outputs (the switching buck is already current limited) need to consult this application note. If shorts are expected at the linear regulator outputs, or where mishaps can cause the power dissipation of the external pass element to be exceeded, current limiting should be employed. Further protection can be had with a foldback current-limiting circuit. This application note details the design and implementation of current limiting for the MAX1864 positive linear regulators.

Figure 1 shows the basic linear regulator circuit available in the MAX1864. In this circuit, an open-drain MOSFET that drives the external PNP transistor Q1 follows an error amp. This, along with other external components, forms a linear regulator for up to 2A output current at a maximum of 30V. This basic circuit is current limited only by the base drive current and the beta of Q1. The maximum current Q1 can source is limited by the drive current from the open-drain MOSFET times the beta of Q1. This, however, is not very accurate, because the open-drain MOSFET base driver can deliver anywhere from 10mA to 35mA, and the beta for Q1 (KSH30) is specced from 15 to 100. Assuming that the pass element is not saturating, Q1 can deliver anywhere from 150mA to 3.5A. In this application, a heat sink is required if a short is expected for any duration. This is because the worst-case 3.5A times 15.8V amounts to 55W of dissipation, while the normal worst-case power dissipation is 150mA times 2.2V, or 330mW.

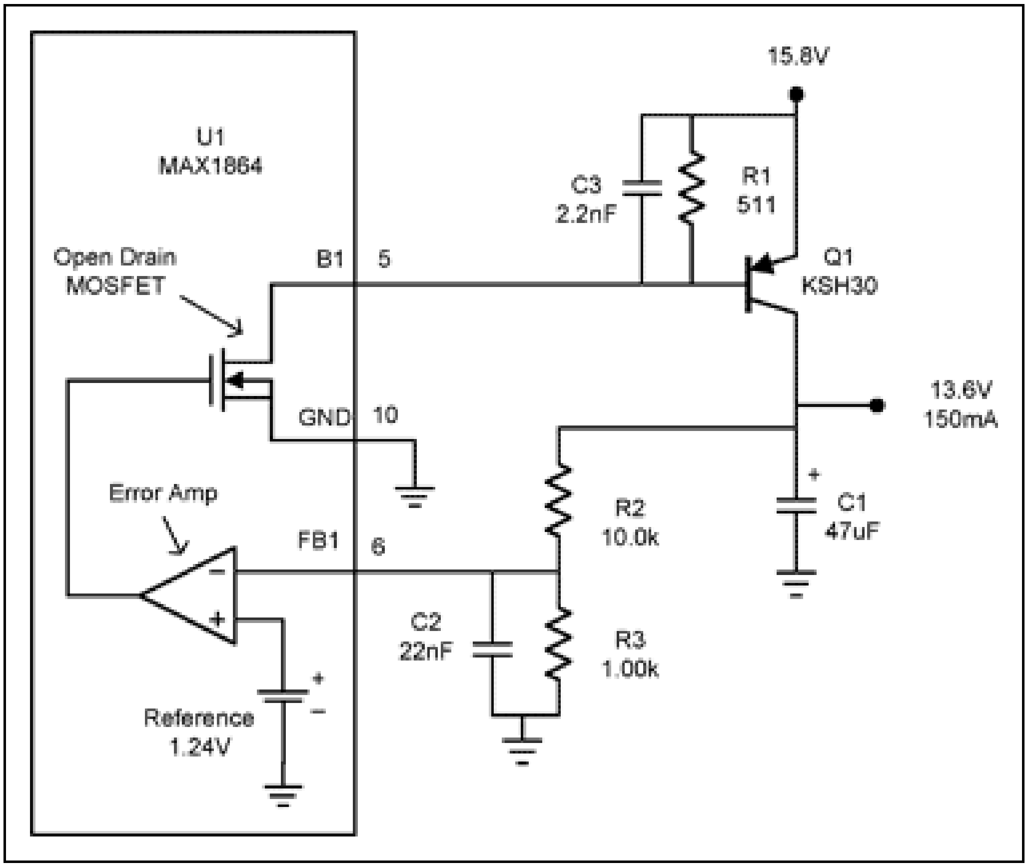


Figure 1. This circuit shows the basic MAX1864 linear regulator.

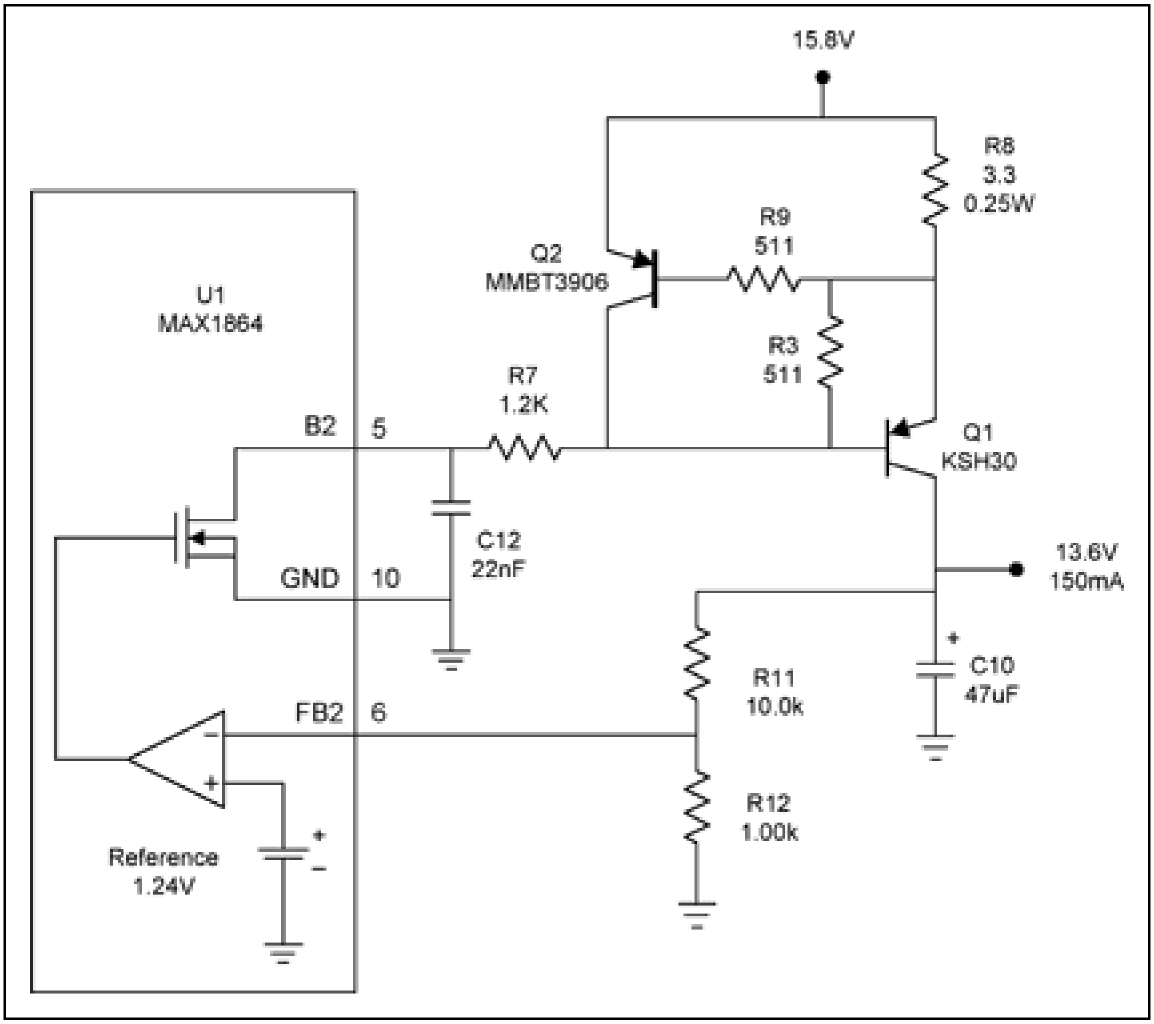


Figure 2. The addition of a current-sense resistor R8 and transistor Q2 provides current limiting.

For an application such as a battery charger, where long-duration shorts are expected, several improvements can be made. The first level of protection comes from a simple current-limit circuit shown in **Figure 2**. In this circuit, when the voltage across R8 exceeds the bias voltage of approximately 0.7V, Q2 (MMBT3906) turns on and the base drive current for Q1 is shunted through the collector of Q2. If the Q2 turns on at 0.7V, then this circuit will limit at 212mA. There are two limitations to this approximation. First, Q2 starts to turn on at 0.5V, and second, the voltage loop is still active. Even though Q2 starts to conduct, the voltage loop will provide more base drive current when the output voltage falls below the regulation set point. R9 limits the Q2 base current to approximately 400µA during current limiting. The measured output-current limit for this circuit is 200mA at room temperature, and there is a -700µA/°C (-0.47%/°C) temperature coefficient due to the Vbe characteristics of Q2. Figure 1 also shows a noise-reduction capacitor, C3. This capacitor reduces switching noise amplified by the linear loop. In Figure 2, R7 in conjunction with C12 provide the same function as C3 and also replace C2 from Figure 1.

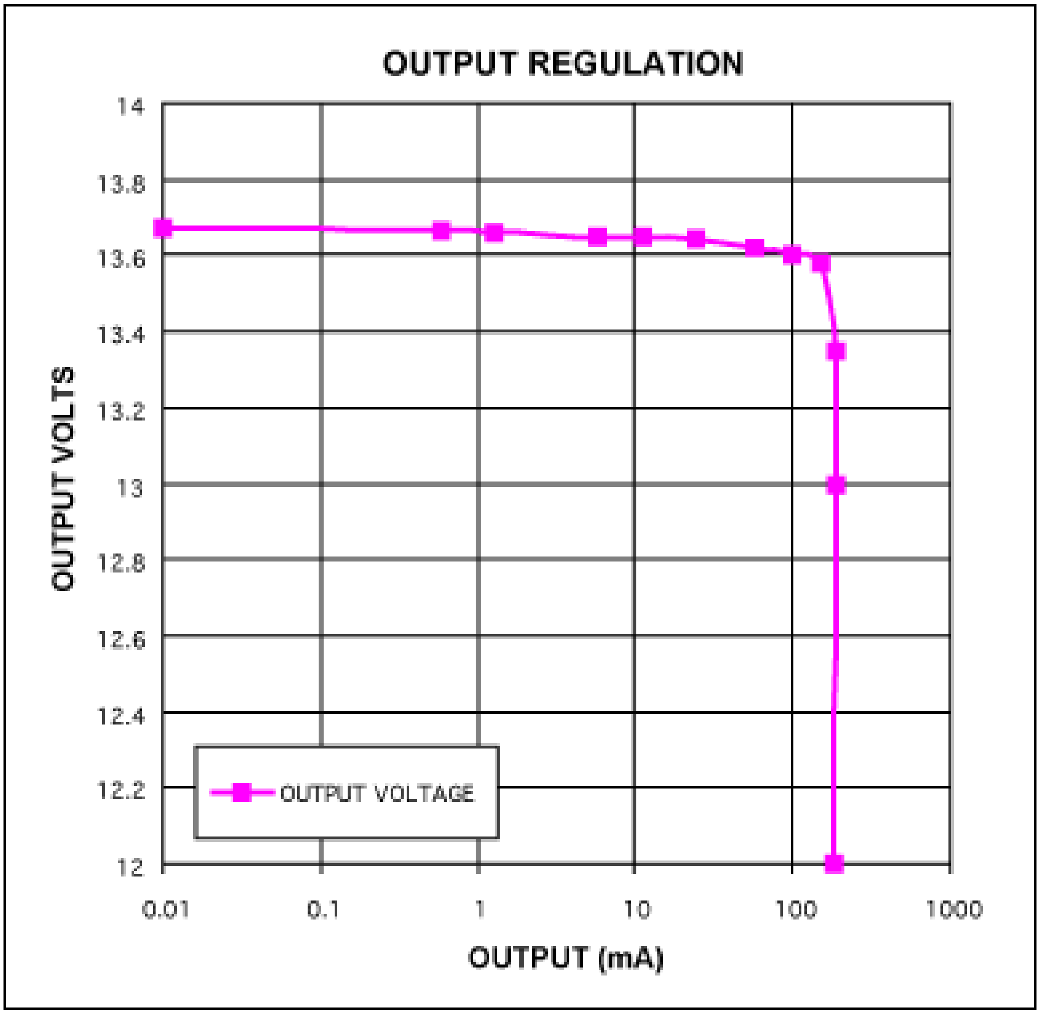


Figure 3. Output voltage vs. output current for the circuit in Figure 2.

Figure 3 shows the performance of the current-limit circuit in Figure 2. This graph shows a hard current limit at 200mA where the output voltage begins to drop very fast. While the circuit in Figure 2 provides current limiting, with a short there will still be 3.16W of dissipation in the output pass element (200mA * 15.8V). This is because the pass element Q1 has the full 15.8V input across it. This is a great improvement over the circuit in Figure 1.

Further reduction in short current power dissipations can be had with the circuit in **Figure 4**. This circuit implements a foldback current limit where the current limit is also a function of the voltage drop on the pass element, Q1. When the voltage across Q1 exceeds 5.6V, D5 begins to conduct through Q2's base, which turns off Q1. **Figure 5** shows the performance of this circuit, where the current drops with lowered output voltage. In fact, when the output voltage is 0V, the output current is only 20mA. An added bonus is that the foldback circuit will continue to work even if the output voltage is driven negative. One application where this would prove effective is for a battery charger where the battery could be connected in reverse.

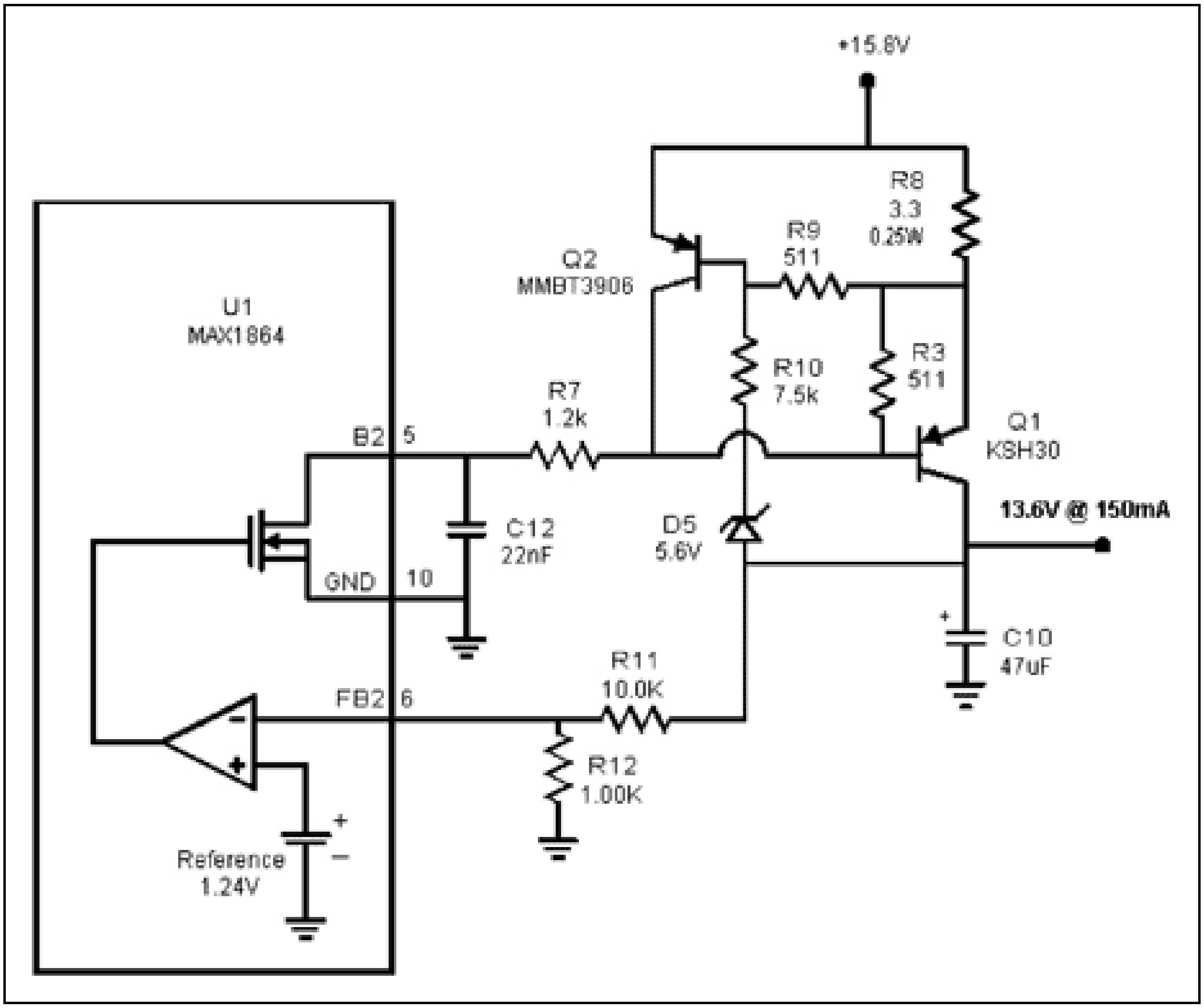


Figure 4. Foldback current limiting is added. The Zener diode, D5, limits the voltage drop on the pass element, Q1, to 5.6V. This helps reduce the power dissipation on Q1 during short circuits.

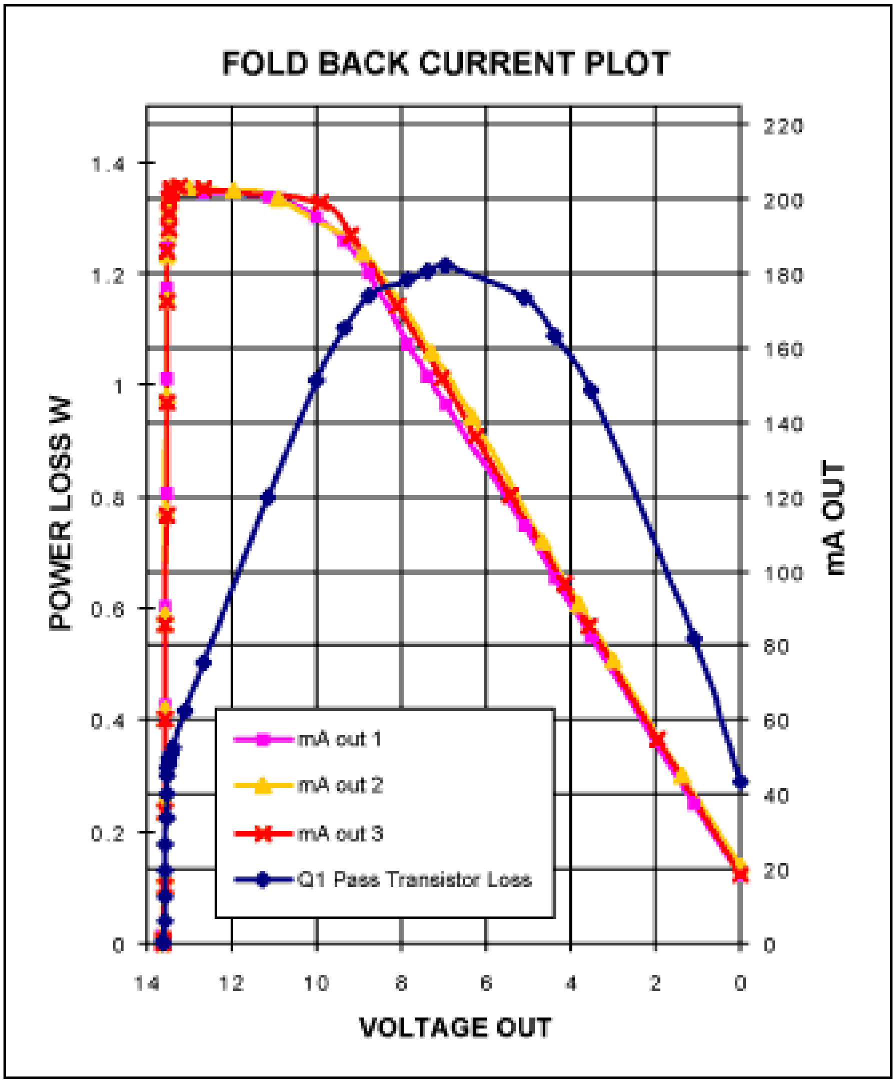


Figure 5. The performance of the foldback current limit circuit in Figure 4. Note that the output current drops with lower output voltage; this limits the power dissipation on Q1 to 1.2 Watts.

A practical application circuit using foldback current limiting is the dual gel-cell/lead-acid battery charger shown in **Figure 6**. Here, the MAX1864 operates as a constant voltage charger, which is attractive because it provides high current for a fast charge when the battery voltage is low, and no current when the battery becomes fully charged to 13.6V.

Large variations in line input voltage can require that the charger step up and/or down. This requirement is usually met with SEPIC topology. MAX1864 solves this problem by using a tapped inductor to generate a regulated 3.3V. Then the tapped inductor/transformer (T1) in Figure 6 steps the voltage up to 15.8V. This allows the circuit to generate a 13.6V output from an 8V to 25V input. Although this circuit has the appearance of a buck converter, it is best modeled as a half-bridge circuit. To explain this, at the beginning of the switch cycle N1A turns on and charges C8 through T1. Assuming that C8 is duty regulated at 3.3V when N1A turns off and N1B turns on, 3.3V shows up on each of the six windings of T1. By noting the polarity of the dots on T1, T1-7 will have five times 3.3V, or 16.5V. After rectification, C9 sees 15.8V.

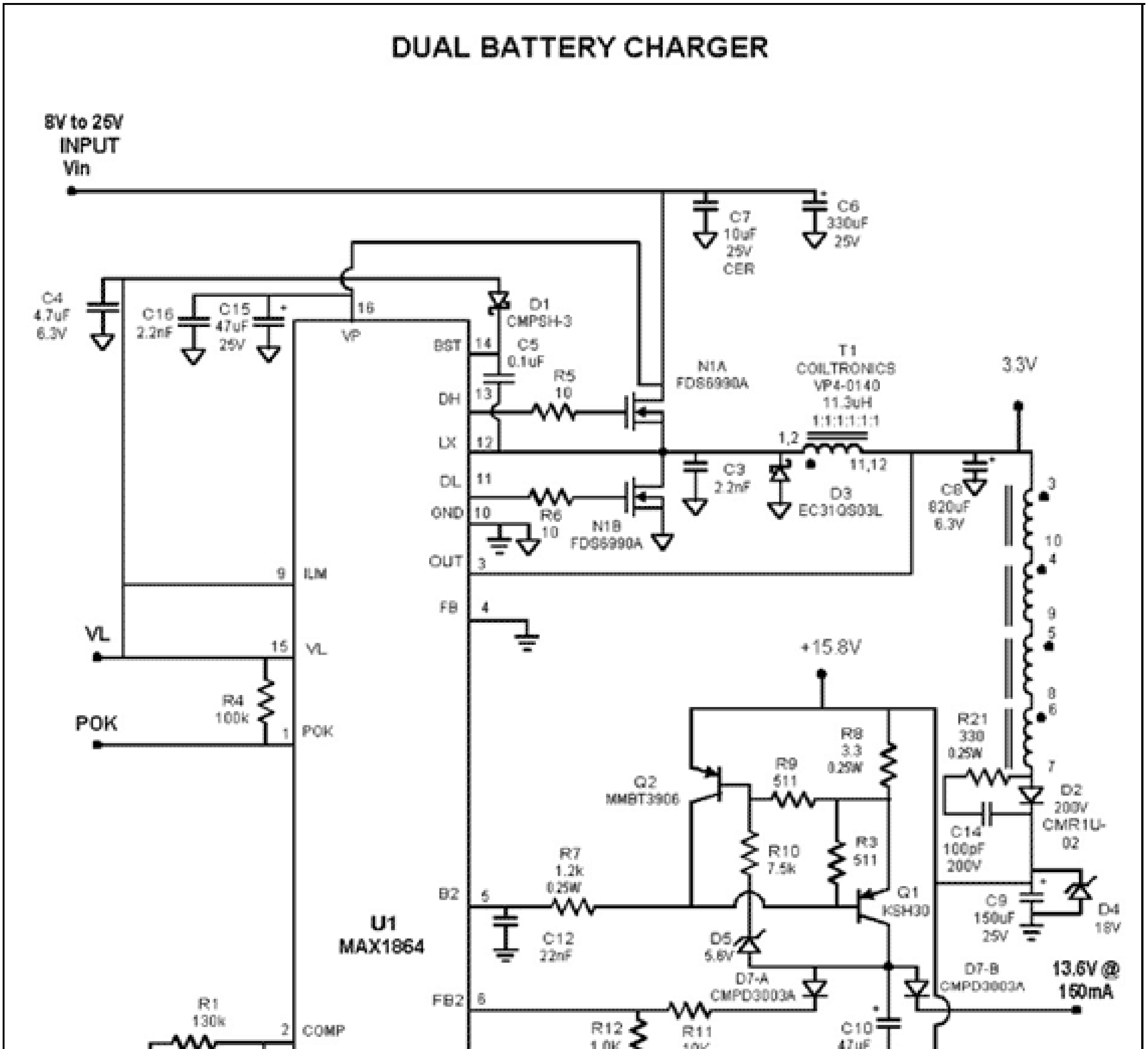
The MAX1864 is cost effective because it uses low-cost PNP transistors as the regulating elements. Furthermore, the output voltages can be set independently using resistors and the internal 1.24V reference. By using a tapped inductor, good efficiency coupled with low cost make MAX1864 a good choice for many multiple-output power-supply applications.

The MAX1864 has two linear gain blocks that can accurately regulate and reduce noise on the boosted output voltage. The optional dual diode (D7, D8) shown in Figure 6 provides reverse-leakage protection to prevent the batteries from discharging when the charger is turned off. Although there is some regulation error due to the D7 diode drop, at 1mA the error is small because D7-A and D7-B are on the same die and have the same forward current, so they have very similar voltage-drop characteristics.

While the tapped inductor does complicate the design of the MAX1864, it provides a cost-effective solution for many multiple-output power-supply applications. Even though the linear pass regulators are lossy, because the tapped inductor can regulate the raw voltage for these circuits, the losses across the transistor can be minimized.

One drawback to this circuit is the variation of the discrete transistor parameters. Beta and the Vbe drop are often specced with a wide variance in the data sheets, so the design can be somewhat dependent on these parameters. Care must be taken to use the minimum beta and the worst-case Vbe for designs that must guarantee current-limit performance over the production life of the circuit and its components. The graph in Figure 5 presents the current-limit performance for the Figure 6 circuit with three different transistors sets, and shows that it tracks very well from device to device.

The MAX1864 is a versatile integrated circuit that can provide a cost-effective multiple-output converter. The MAX1865 has extra positive and negative gain blocks in addition to the features of the MAX1864, providing the capability to generate quintuple-output power supplies. The MAX1964 and MAX1965 add power-up sequencing and tracking. The MAX8513 and MAX8514 can also benefit from the current-limiting techniques presented in this note. The MAX1865, MAX1965 and MAX8514 all have negative output regulators and, although this is not presented in this note, the PNP transistor can be replaced with equivalent NPN transistors to facilitate the same current-limit functions. These multiple-output supplies are of much greater value to the engineer, with current-limit and foldback circuits that can be implemented when needed.



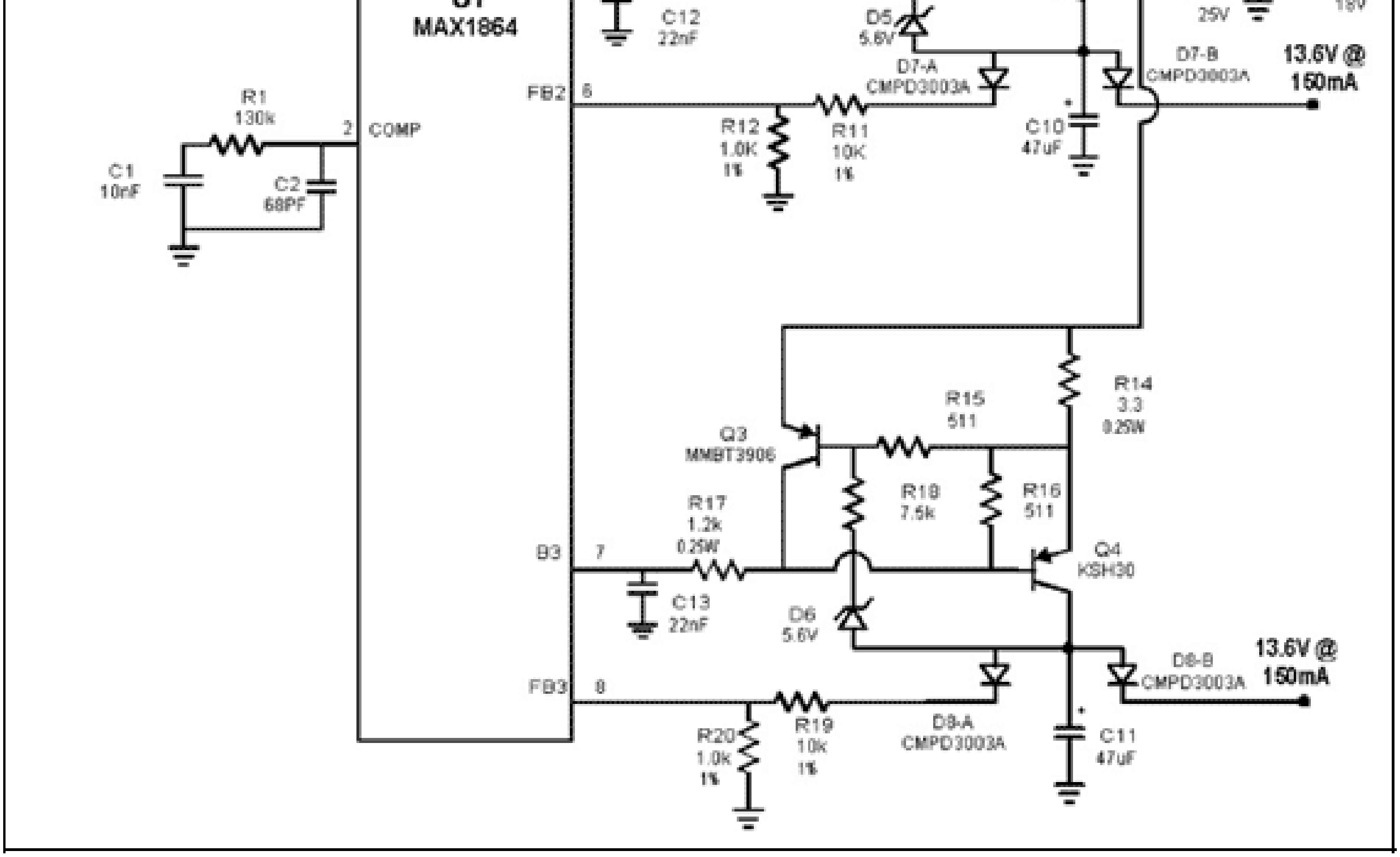


Figure 6. The MAX1864 forms a dual battery charger for a wide input-voltage range.

BILL OF MATERIALS
8V to 25V Input, 13.6V at 150mA Output

DESIGNATION	QTY	DESCRIPTION
C2	1	Cap 68pF 50V ceramic NPO 0603, Panasonic (ECJ-1VC1H680J)
C14	1	Cap 100pF 200V ceramic NPO 0805, Panasonic (ECJ-2YC2D101J)
C3, C16	2	Cap 2.2nF 50V ceramic X7R 0603, Panasonic (ECJ-1VB1H222K)
C1	1	Cap 10nF 50V ceramic X7R 0603, Panasonic (ECJ-1VB1H103K)
C12, C13	2	Cap 22nF 50V ceramic X7R 0603, Panasonic (ECJ-1VB1H223K)
C5	1	Cap 0.1uF 16V X7R ceramic 0603, Taiyo Yuden (EMK107BJ104MA)
C4	1	Cap 4.7uF 6.3V ceramic X5R 0805 Taiyo Yuden (JMK212BJ475MG)
C7	1	Cap 10uF 25V ceramic X5R 1210Taiyo Yuden (TMK325BJ106MM)
C10, C11, C15	3	Cap 47uF 25V electrolytic, Sanyo (25MV47HC)
C9	1	Cap 150uF 25V electrolytic, Sanyo (25MV150AX)
C6	1	Cap 330uF 25V electrolytic, Sanyo (25MV390WX)
C8	1	Cap 820uF 6.3V electrolytic, Sanyo (6.3MV820EXR)
D1	1	Diode 30V 0.1A Schottky SOT-23, Central Semi (CMPSH-3)
D2	1	Diode 200V 1A SMB, Central Semi (CMR1U-02)
D3	1	Diode 30V 3A Schottky SMA, Nihon (EC31QS30L)
D5, D6	2	Diode 5.6V Zener SOT-23, Central Semi (BZX84C5V6)
D7, D8	2	Diode 180V, 0.2A, dual low-leakage, SOT-23, Central Semi (CMPD3003A)
D4	1	Diode 18V Zener SOT-23, Central Semi (CMPZ5248B MPX)
N1A, N1B	1	NFET Dual 0.023Ω 30V SO-8, Fairchild (FDS6990A)
Q1, Q4	2	Transistor 40V PNP D-PAK, Fairchild (KSH30)

Q2, Q3	2	Transistor 40V PNP SOT-23, General Semiconductor (MMBT3906)
R8, R14	2	Resistor 3.3Ω 1% 1210Panasonic (ERJ14NF3R3V)
R5, R6	2	Resistor 10Ω 5% 0805
R21	1	Resistor 330Ω 5% 1210Panasonic (ERJ14YJ331V)
R3, R9, R15, R16	4	Resistor 511Ω 1% 0805
R7, R17	2	Resistor 1.2kΩ 5% 1206
R10, R18	2	Resistor 7.5kΩ 1% 0805
R12, R20	2	Resistor 1.0kΩ 1% 0805
R11, R19	2	Resistor 10.0kΩ 1% 0805
R4	1	Resistor 100kΩ 5% 0805
R1	1	Resistor 130kΩ 1% 0805
T1	1	Transformer, 11.3uH 1:1:1:1:1:1 Coiltronics (VP4-0140)
U1	1	IC x DSL/cable-modem triple-output power supplies 16 QSOP, Maxim (MAX1864TEEE)

Application Note 3654: www.maxim-ic.com/an3654

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AN3654, AN 3654, APP3654, Appnote3654, Appnote 3654