Dual Output Boost Converter

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ABSTRACT

The boost converter is modified to provide bipolar 12-V outputs from 5-V supply. Using the UCC3803 to control the basic boost converter building block, the –12-V outputs are generated using a coupled inductor and a flying capacitor. Output voltage regulation and efficiencies are compared and presented.

CONTENTS

1 Introduction

Various low power applications require bipolar 12-V supplies derived from a single +5-V input. Modifying a simple boost converter to produce not only the 12-V output but also the –12-V output can be accomplished using two different techniques: derived from a coupled inductor or derived from a flying capacitor. Each technique has its advantages, but because cost, efficiency, and regulation are always priorities, one design appears to out-perform the other. For consistency, the two techniques are compared using the same 5-V to 12-V boost converter for the front end, controlled by the UCC3803 low power BiCMOS current–mode pulse width modulator (PWM).

2 The Boost

The basic building block of both designs is a boost converter, shown in Figure 1. The boost power stage converts a lower input voltage to a higher output voltage and doesn't traditionally have more than one output. The boost converter operates by linearly increasing the current through the inductor when the switch is on. During this portion of the cycle, the voltage across the inductor is equal to the input voltage and energy is loaded into the inductor. The load current is supplied entirely by the output capacitor while the switch is on. When the switch is turned off, the inductor current flows through the diode and charges the output capacitor, completing the energy transfer. Because current through an inductor cannot change instantaneously, during the switch off time the inductor current linearly decreases, causing the voltage across the inductor to reverse polarity, forward biasing the diode. One side of the inductor is fixed at the input rail, the other side is equal to the output voltage plus the forward drop across the diode and any voltage drop from the series resistance of the inductor itself. During the off time, the inductor and the input voltage source deliver energy to the output capacitor and the load.

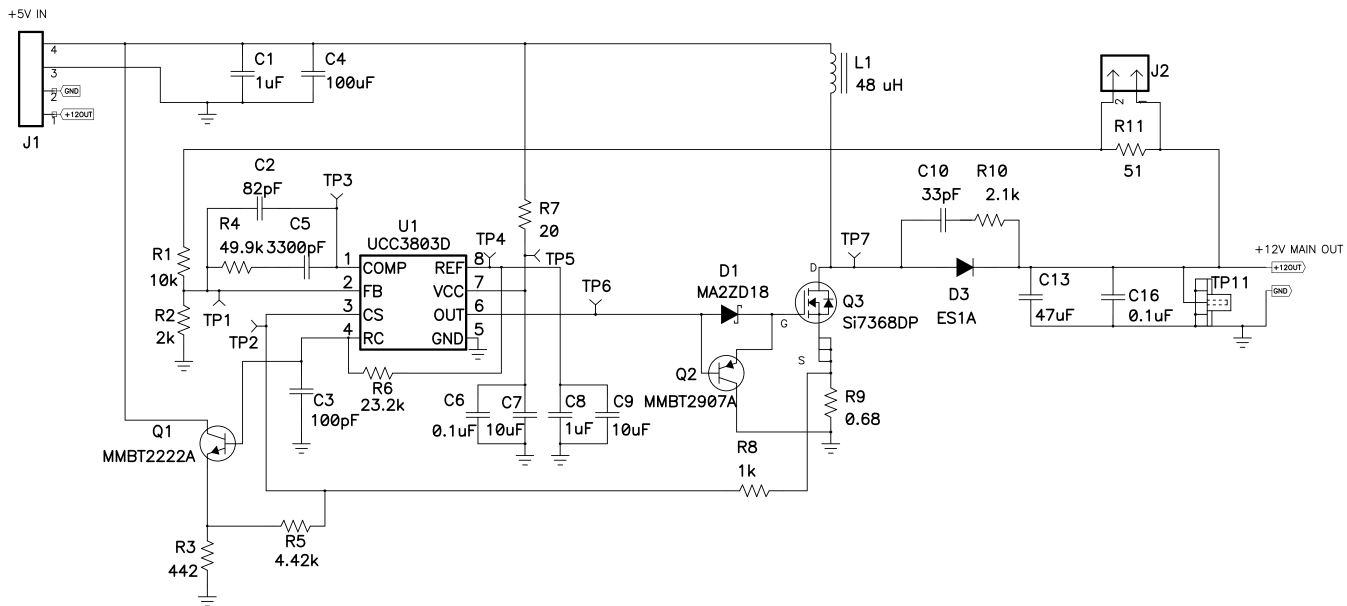


Figure 1. 5-V to 12-V Boost Converter

The UCC3803 uses current mode control to turn the main switch on and off by a pulse width modulated control voltage. This low power BiCMOS current mode PWM controller is ideal for this application because it has a turn on threshold of 4.1 V and therefore can be biased from the 5-V input voltage rail with a biasing resistor that is sized large enough to supply the UCC3803 quiescent current and the average gate drive current, eliminating the need for a separate bootstrap circuit. In addition, the controller requires very few external parts because of its internal leading edge blanking and internal soft start. Also, the high current output stage provides a low impedance to overshoot and undershoot so this design did not require external clamp diodes on the output stage. The controller is set up for a switching frequency of 300 kHz.

Although the ideal transfer function of the continuous current mode controlled boost power stage is solely dependent upon the duty cycle:

$$\frac{V_{OUT}}{V_{IN}} = \frac{1}{1 - D}\ , \tag{1}$$

the actual maximum duty cycle, D_{MAX}, is equal to:

$$D_{MAX} = \frac{V_{OUT} + V_F - V_{IN(min)}}{V_{OUT} + V_F - V_{SAT}}\ , \tag{2}$$

where V_{OUT} is the regulated output voltage of the converter, V_F is the forward voltage drop across the output diode, V_{SAT} is the saturation voltage of the MOSFET switch, and $V_{IN(min)}$ is the minimum input voltage of the converter. Based upon the design requirements, this converter will run at approximately 62% to 70% duty cycle. Using peak current mode control necessitates adding slope compensation, derived from the oscillator ramp. The power stage was designed to supply two outputs, each at 100-mA load currents.

Continuous inductor current mode occurs when current flows through the inductor during the entire switching cycle during steady state operation. The smallest possible physical size for the continuous current mode inductor will result when the inductor ripple current is equal to twice the average input current at the minimum input voltage. Unfortunately, using an inductor of this size results in the highest possible transistor switching losses. Opting for a larger inductor, so as to decrease the ripple current, results in a physically larger core. This design uses an inductor value that results in a ripple current equal to 40% of the average input current, compromising between core size, switching losses, and current ripple. The average input current is the same as the average inductor current, $I_{L(avg)}$, which is equal to:

$$I_{L(avg)} = \frac{I_{OUT}}{1 - D_{MAX}} \tag{3}$$

I_{OUT}, in this case is the sum of the main output current with the additional auxiliary output current. The inductor is sized such that its ripple current, ΔI_L, is equal to 40% of $I_{L(avg)}$

$$L = \frac{1}{f_{SW}}\left(V_{OUT} + V_F - V_{IN(min)}\right)\left(\frac{V_{IN(min)}}{V_{OUT} + V_F}\right)\left(\frac{1}{\Delta I_L}\right) \tag{4}$$

Due to the relatively low load current, switching losses will dominate over conduction losses, so the switching device is selected to minimize switching losses. Selecting an N–channel MOSFET with low gate to drain charge, low output capacitance, and fast rise and fall times will have a much greater effect on efficiency than simply selecting a device based upon its drain to source on-state resistance. Adding a small PNP transistor in parallel with a schottkey diode enhances efficiency by quickly turning the switch off at the end of the on time. An ultra-fast diode was used as the main output rectifier, instead of a lower loss schottkey to cancel the drop across the two output schottkey diodes on each of the auxiliary output schemes, improving regulation.

A type II compensator was used for the control loop, placing a pole at 40 kHz and a zero at 1 kHz resulting in a crossover frequency of 5 kHz.

3 The Auxiliary Outputs

Because many analog circuits require bipolar supply rails to drive devices such as precision op amps, the basic boost circuit can be modified to provide an additional output. There are two ways of producing this extra output. Figure 2 shows the auxiliary output derived from a discrete charge pump driven by capacitively coupling the inductor-switch-diode switching node. The energy is transferred to the output by way of the switching voltage waveform. Although not isolated, this scheme requires simple low cost components, maintains regulation to within 3.5% over the entire load range, and was consistently more efficient.

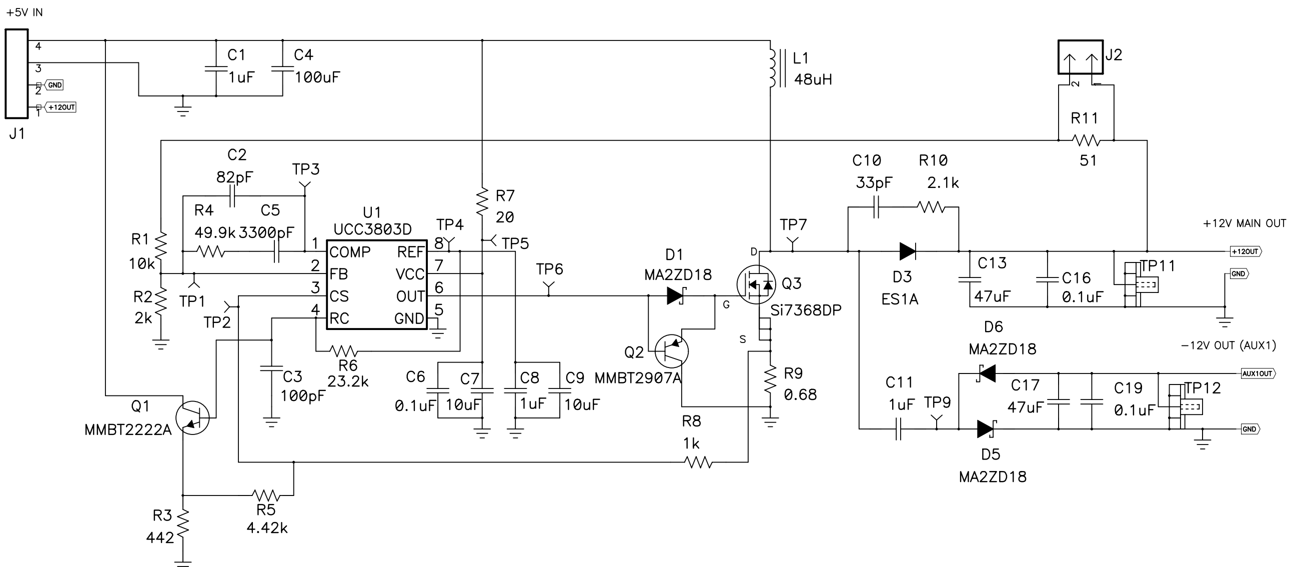


Figure 2. Boost converter with capacitively coupled auxiliary output.

The alternative approach for generating a –12-V output from the basic boost converter is to use a coupled inductor, as shown in Figure 3. Although isolated from the main output, this option requires a more elaborate magnetic design. This output was not as well regulated as the previous, capacitively coupled output most likely due to the fact that the energy transfer for the inductively coupled output is based upon the current ramp signal. Output voltage regulation would benefit from a less limited load range and a more custom inductor design.

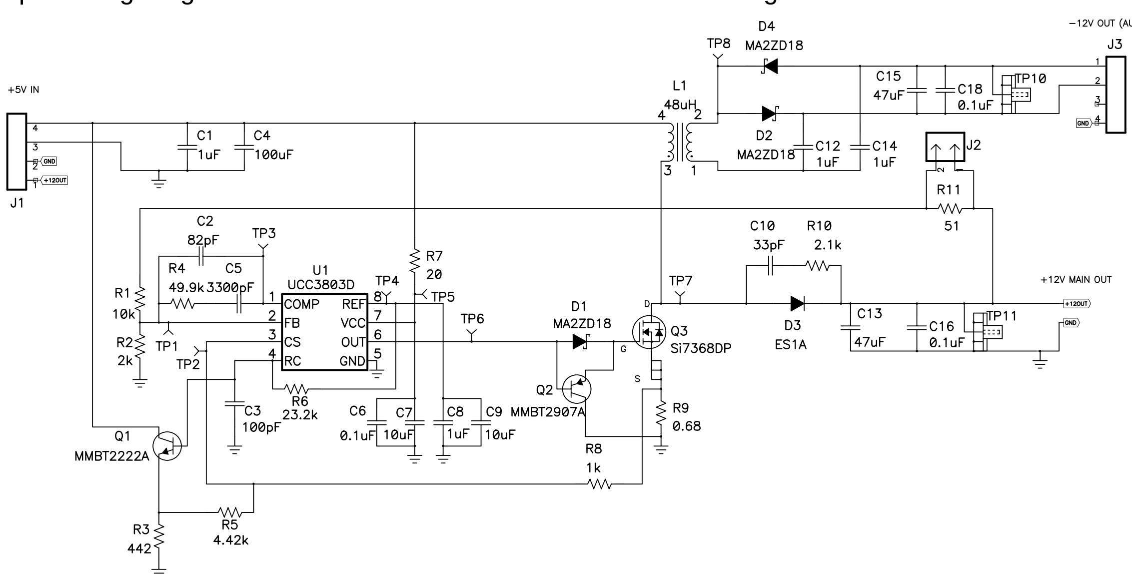


Figure 3. Boost Converter With Inductively Coupled Auxiliary Output

4 Experimental Results

In the following figures, Aux 1 refers to the capacitively coupled auxiliary output, as shown in Figure 2, and Aux 2 refers to the coupled inductor auxiliary output, as shown in Figure 3. Figure 4 is the actual schematic used in the laboratory evaluation. Note that only one auxiliary output was powered at a time.

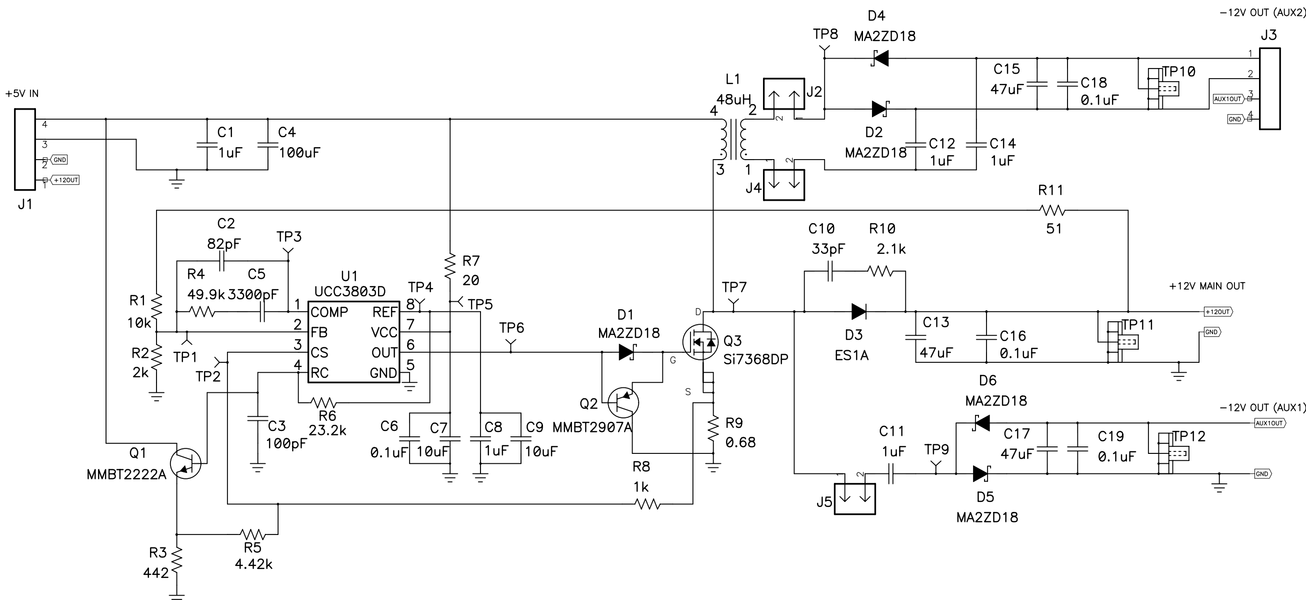


Figure 4. Boost Converter Evaluation Board Containing Both Auxiliary Outputs

5 Waveforms

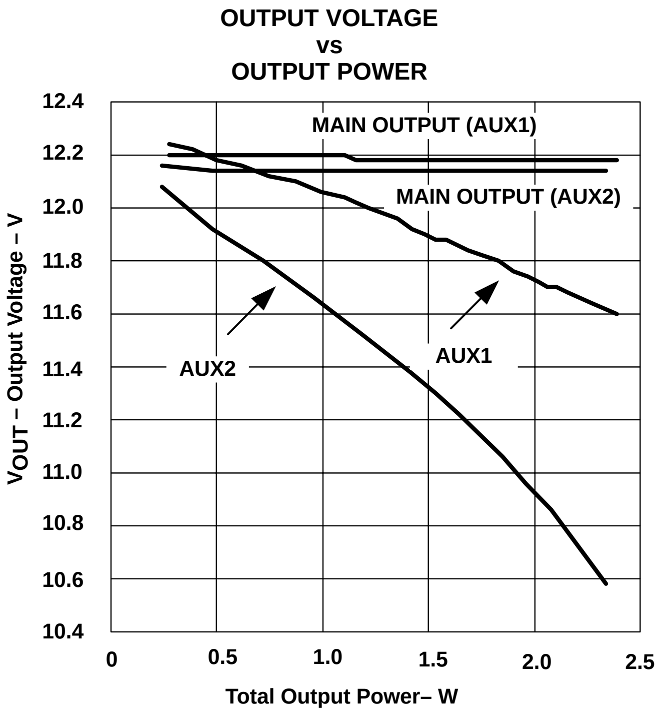


Figure 5

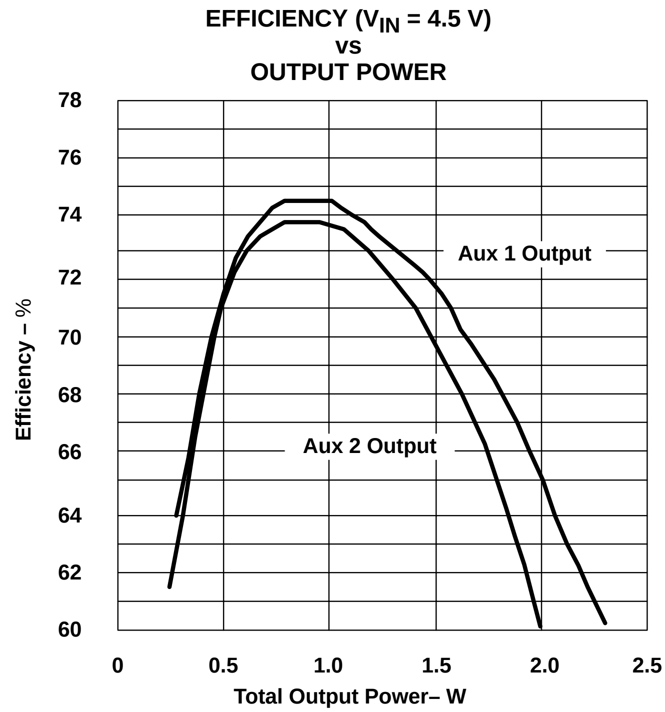


Figure 6

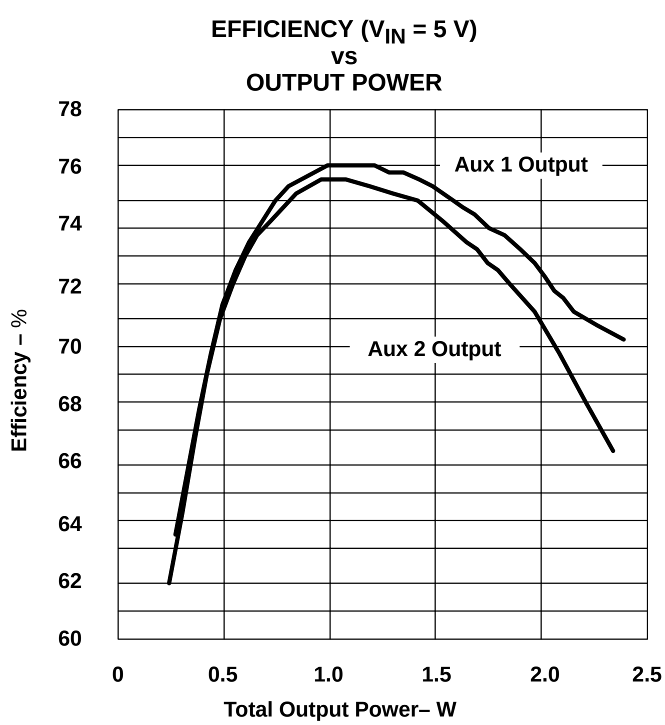


Figure 7

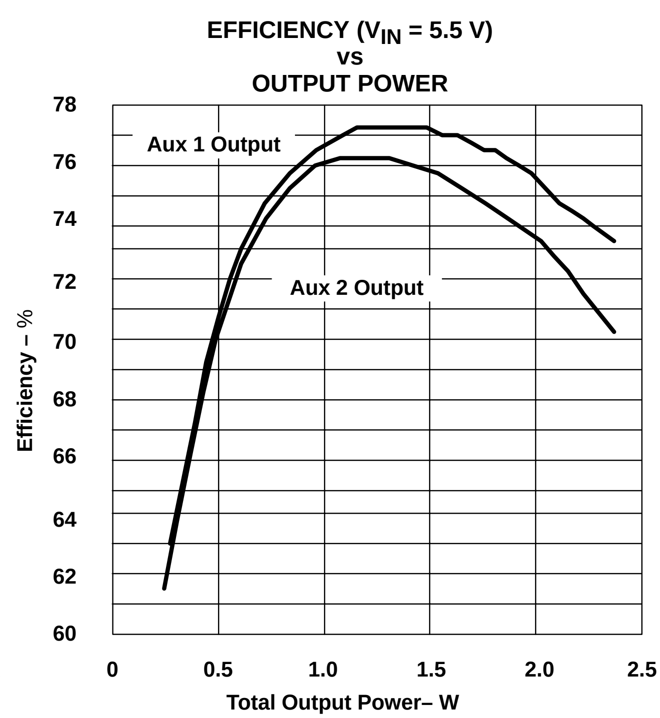


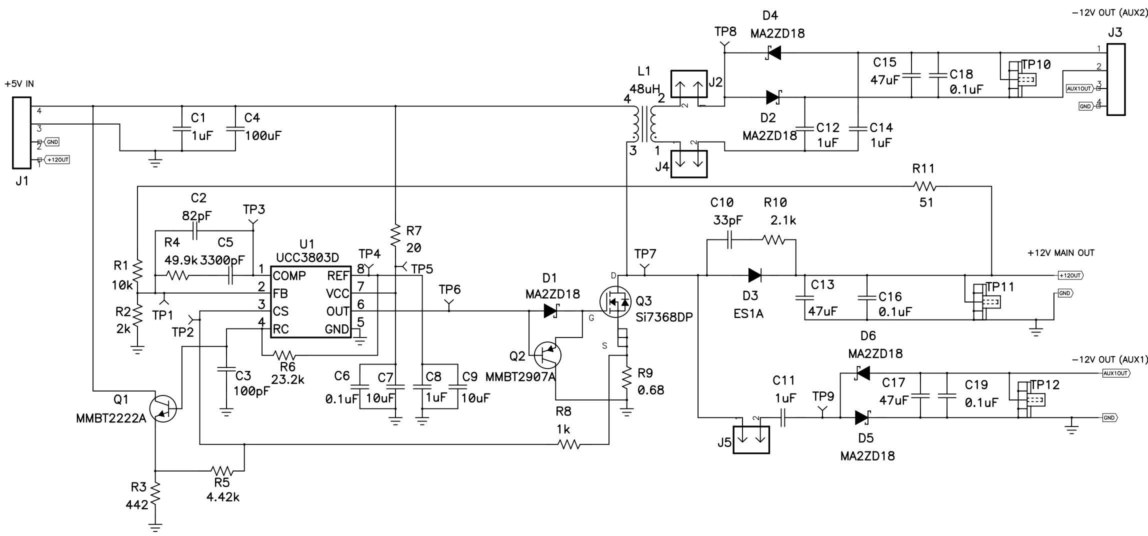
Figure 8

6 List of Materials

Table 1 lists the board components and their values, which can be modified to meet the application requirements.

Table 1. List of Materials

REFERENCE	QTY	DESCRIPTION	MANUFACTURER	PART NUMBER
C1, C8	2	Capacitor, ceramic, 1 μF, 16 V, X5R, ±10%, 0805	Std	Std
C2	1	Capacitor, ceramic, 82 pF, 50 V, NPO, ±5%, 0805	BC Components	0805N820J500NT
C3	1	Capacitor, ceramic, 330 pF, 50 V, NPO, ±5%, 0603	BC Components	0805N331J500NT
C4	1	Capacitor, ceramic, 100 μF, 6.3 V, ±20%, 18x12	TDK	C4532X5R0J107M
C5	1	Capacitor, ceramic, 3300 pF, 50 V, X7R, ±10%, 0805	BC Components	0805B332K500BT
C6, C16, C18, C19	4	Capacitor, ceramic, 0.1 μF, 50 V, ±10%, 0805	Std	Std
C7, C9	2	Capacitor, ceramic, 10 μF, 6.3 V, X5R, ±10%, 0805	Std	Std
C10	1	Capacitor, ceramic, 33 pF, 50 V, NPO, ±5%, 0805	Std	Std
C11, C12, C14	3	Capacitor, ceramic, 1 μF, 16 V, X7R, ±10%, 0805	Std	Std
C13	1	Capacitor, ceramic, 47 μF, 16 V, X5R, ±15%, 2220	TDK	C5750X5R1C476M
C15, C17	2	Capacitor, ceramic, 16 V, X5R, ±15%, 2220	TDK	C5750X5R1C476M
D1, D2, D4, D5, D6	5	Diode, schottky, 500 mA, 20 V, SMini2–F1	Panasonic	MA2ZD18
D3	1	Diode, super fast rectifier, 35 V, 1 A, SMA	Diodes Inc.	ES1A
J1, J3	2	Terminal block, 4 pin, 15 A, 5.1 mm, 0.80 x 0.35	OST	ED2227
J2	1	Header, 2 pin, 100-mil spacing, (36-pin strip), 0.100 x 2	Sullins	PTC36SAAN
L1	1	Inductor, dual 48 μH, 700 mΩ, 0.455 X 0.400	Pulse	PA0607
Q1	1	Bipolar, NPN, 40 V, 500 mA, SOT–23	Fairchild	MMBT2222A
Q2	1	Bipolar, PNP, 60 V, 150 mA, , SOT–23	Fairchild	MMBT2907A
Q3	1	MOSFET, N–channel, 20 V, 13 A, 8.0 mΩ , PWRPAK S0–8	Vishay–Siliconix	Si7368DP
R1	1	Resistor, chip, 10 kΩ, 1/10 W, ±1%, 0805	Std	Std
R2	1	Resistor, chip, 2.0 kΩ, 1/10 W, ±1%, 0805	Std	Std
R3	1	Resistor, chip, 442 Ω, 1/10 W, ±1%, 0805	Std	Std
R4	1	Resistor, chip, 49.9 kΩ, 1/10 W, ±1%, 0805	Std	Std
R5	1	Resistor, chip, 4.42 kΩ, 1/10 W, ±1%, 0805	Std	Std
R6	1	Resistor, chip, 10 kΩ, 1/10 W, ±1%, 0805	Std	Std
R7	1	Resistor, chip, 20 Ω, 1/10 W, ±1%, 0805	Std	Std
R8	1	Resistor, chip, 1 kΩ, 1/10 W, ±1%, 0805	Std	Std
R9	1	Resistor, chip, 0.68 Ω, 1/2 W, ±5%, 2010	Std	Std
R10	1	Resistor, chip, 2.1 kΩ, 1/10 W, ±1%, 0805	Std	Std
R11	1	Resistor, chip, 51 Ω, 1/10 W, ±1%, 0805	Std	Std
TP1, TP2, TP3, TP4, TP5, TP6, TP7, TP8, TP9	9	Test point, 0.050 hole		
TP10, TP11, TP12	3	Adaptor, 3.5-mm probe clip	Tektronix	131–4244–00 (or 131–5031–00)
U1	1	IC, Controller, Low-power BiCMOS Current-Mode PWM, SO8	TI	UCC3803D



+5V IN
J1
GND
+12OUT
C1
1uF
C4
100uF
L1
48uH
J2
J4
D4
MA2ZD18
D2
MA2ZD18
TP8
C12
1uF
C14
1uF
C15
47uF
C18
0.1uF
TP10
−12V OUT (AUX2)
J3
AUX1OUT
GND
R11
51
C2
82pF
TP3
R4
49.9k
C5
3300pF
U1
UCC3803D
COMP
FB
CS
RC
REF
VCC
OUT
GND
TP4
TP5
R7
20
R1
10k
R2
2k
TP1
TP2
C3
100pF
R6
23.2k
C6
0.1uF
C7
10uF
C8
1uF
C9
10uF
TP6
D1
MA2ZD18
Q2
MMBT2907A
TP7
Q3
Si7368DP
R9
0.68
R8
1k
C10
33pF
R10
2.1k
D3
ES1A
C13
47uF
C16
0.1uF
TP11
+12V MAIN OUT
+12OUT
GND
Q1
MMBT2222A
R3
442
R5
4.42k
C11
1uF
TP9
J5
D6
MA2ZD18
D5
MA2ZD18
C17
47uF
C19
0.1uF
TP12
−12V OUT (AUX1)
AUX1OUT
GND

IMPORTANT NOTICE

Mailing Address:

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