UCC38C42 30-W Synchronous Buck Converter Reference Design (PR112B)

Lisa Dinwoodie — *System Power*

ABSTRACT

This reference design presents a synchronous buck converter using the UCC38C43 BiCMOS low-power current-mode PWM controller, the TPS2838 synchronous buck MOSFET driver with drive regulator, and the INA138 high-side measurement current shunt monitor. The input voltage for this converter is from a 3.3-Vdc rail which draws the bias voltage for the devices from an available 12-Vdc bus. The converter is designed to operate at a switching frequency of 400 kHz and supports a non-isolated 1.8-Vdc, 17-A output. The complete schematic, board layout, circuit description, list of materials, and circuit performance curves are included.

Contents

1 Introduction

Synchronous buck converters have significantly better efficiency than conventional buck converters because the commutation diode is replaced by a power MOSFET, reducing the typical diode forward voltage drop to less than 0.1 V thanks to the low $R_{DS(on)}$ of the FET. Buck converters are relatively simple to design due to the absence of a transformer. The controller used is the UCC38C43. Its low start-up and operating currents, high-frequency operation, and industry standard familiarity make this general-purpose controller easy to use. The TPS2838 driver enhances the converter's performance because of its high sink and source peak currents and shoot through protection with its adaptive/adjustable dead-time control. The INA138 current shunt monitor, combined with an LM311 comparator, provides over current protection for this voltage-mode converter. A single resistor provides the gain to the differential voltage across a current sense resistor, which is then compared to a threshold voltage corresponding to an overcurrent load condition. The UCC38C43 controller is then forced into a hiccup mode until the fault is removed.

2 Features

- Fixed input range: 3.3 V_{DC}
- 1.8 V_{DC} output voltage
- 17-A maximum output load, 30-W maximum continuous output power
- High-efficiency 400-kHz switching frequency
- Synchronous buck topology
- Voltage mode control
- Overcurrent hiccup mode
- Soft start
- Synchronization input

3 Schematic

Figure 1 shows the schematic of the design.

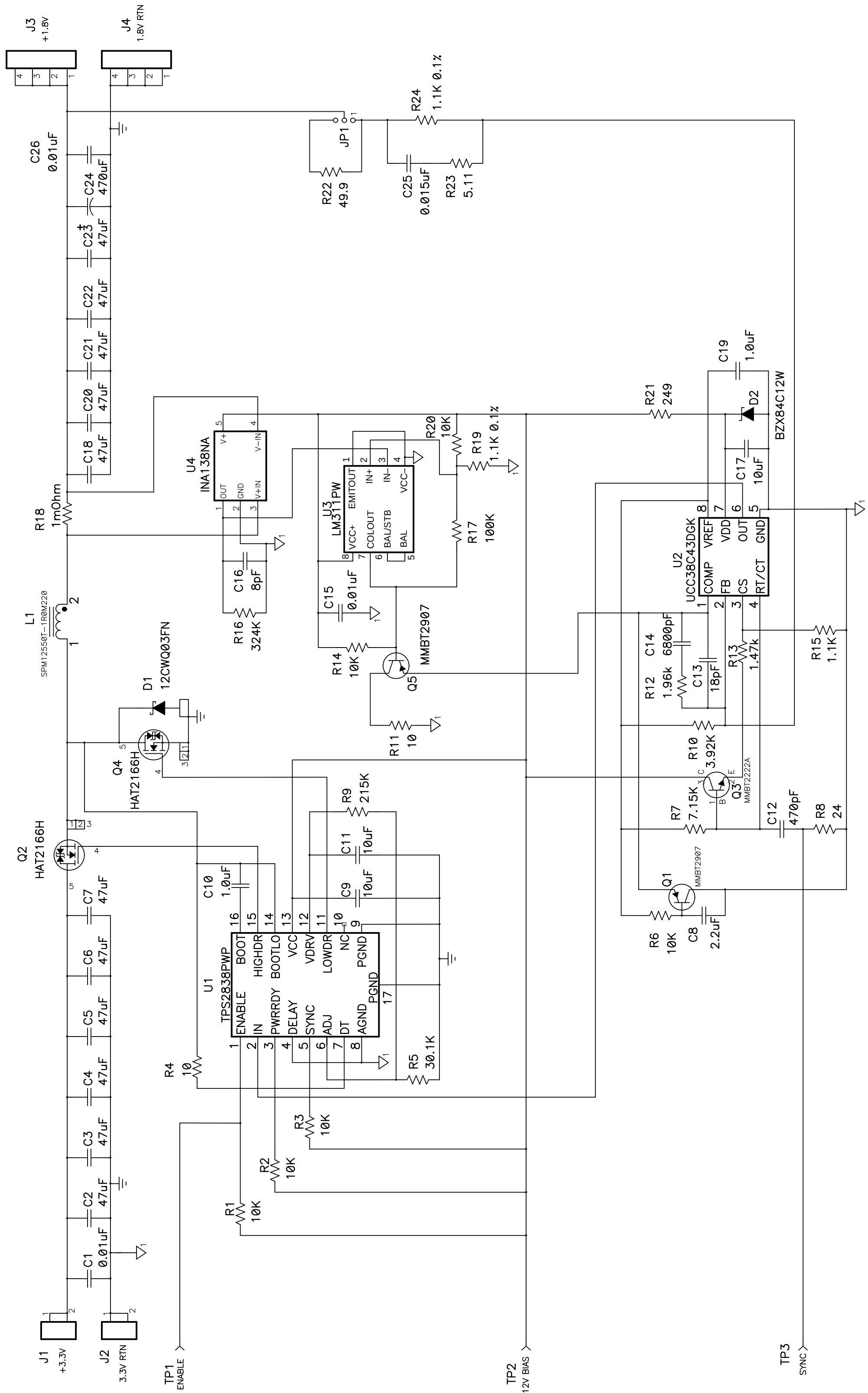


Figure 1. Synchronous Buck Converter Featuring the UCC38C43

4 Reference Design Layout

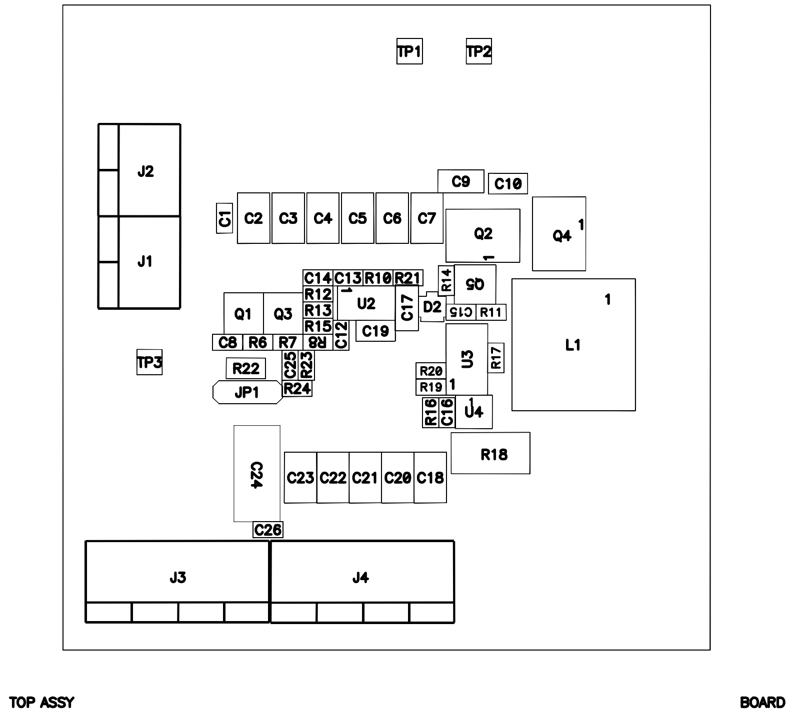


Figure 2. Top Layer Assembly

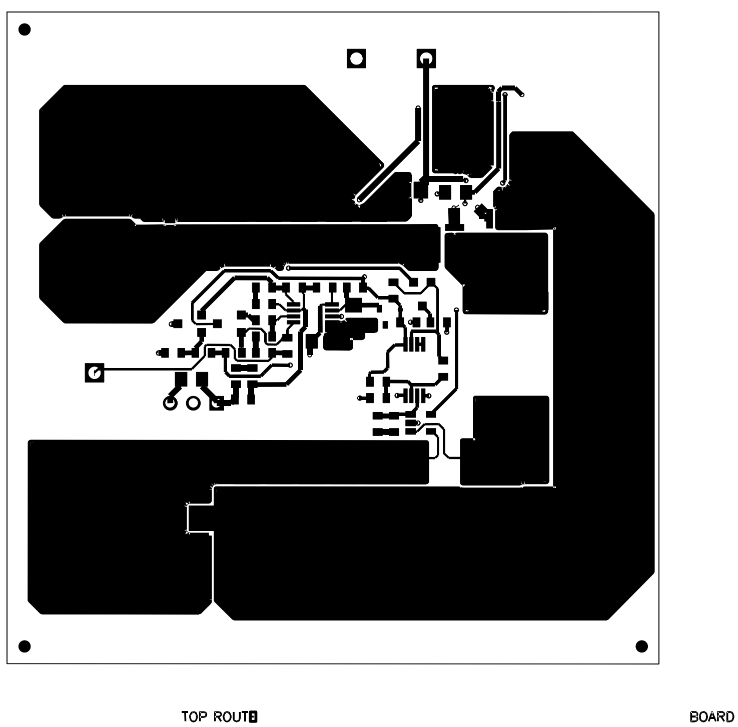
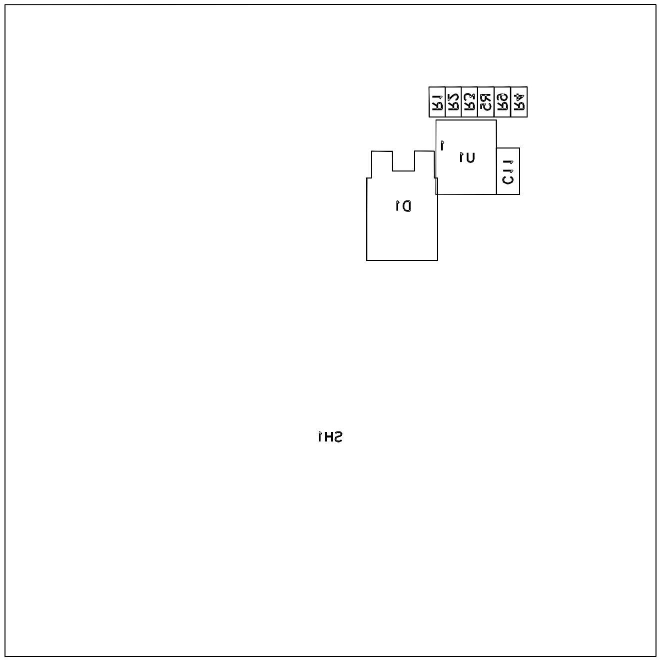
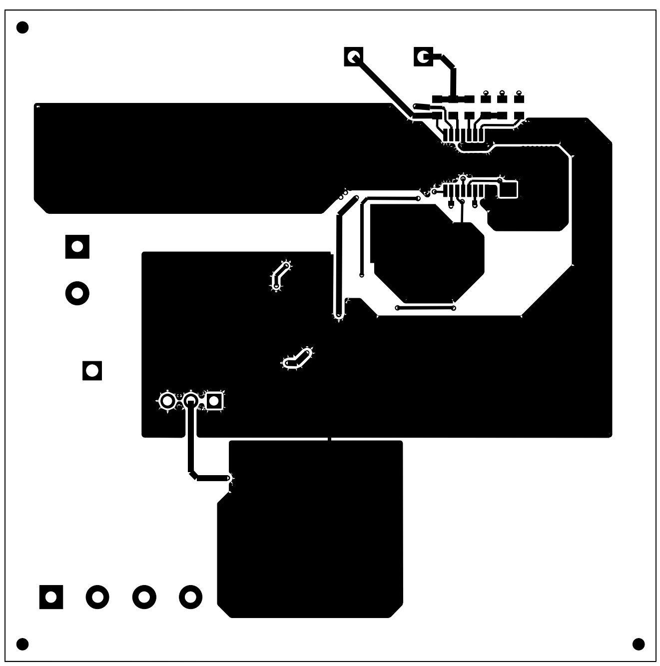


Figure 3. Top Layer Route



BOTTOM ASSY BOARD

Figure 4. Bottom Layer Assembly



BOTTOM ROUTE BOARD

Figure 5. Bottom Layer Route

5 Circuit Description

A brief description of the circuit elements follows:

- Input capacitors C1 through C7, MOSFETs Q2 and Q4, inductor L1, and output capacitors C18, C20 through C24, and C26 form the power stage of the converter. Transistor Q2 is the power switch while Q4 is the synchronous switch. Diode D1, in parallel with Q4, allows inductor current to flow during the dead time when Q2 turns off and Q4 has not yet turned on, improving converter efficiency by decreasing the body diode conduction time of the synchronous switch.
- Resistor R21 provides biasing to the PWM controller, U2, from the 12V bus. Zener diode D2 protects the IC by clamping the bias voltage.
- PNP transistor Q1, resistor R6, and capacitor C8 provide soft start.
- NPN transistor Q3, resistors R13 and R15 convert the current mode controller into voltage mode operation by dividing down the oscillator timing capacitor waveform and feeding this signal into the current sense pin.
- Resistor R7 and capacitor C12 provide a charge and discharge path for the internal oscillator, setting the switching frequency of the controller. Resistor R8 provides a means of inserting an external synchronization pulse into the circuit.
- The voltage sense feedback loop uses the internal error amplifier in the UCC38C43. Resistors R24 and R10 bias up the 1.8-V output to the 2.5-V feedback threshold level. Resistors R12 and R23, capacitors C13, C14, and C25, along with R24, set up a Type-III compensator and provide the necessary gain, poles, and zeros to stabilize the control loop. Resistor R22 provides an impedance port for loop measurement with a gain phase analyzer.
- Decoupling to the PWM is performed by capacitors C17 and C19 while C9 and C11 decouple the MOSFET driver, U1.
- Resistors R1, R2, and R3 provide pull-up to the 12-V rail to the digital control signals ENABLE, PWRRDY, and SYNC of the driver device.
- Capacitor C10 is needed to configure the floating bootstrap voltage for the high-side MOSFET.
- Resistors R9 and R5 adjust the driver regulator output to 2-V below VCC for optimum efficiency.
- The overcurrent detect circuit consists of the power resistor R18, which senses the inductor current while current shunt monitor U4 converts this current into a differential voltage. This voltage is then transformed into an output current, which is converted into a proportionally gained output voltage with the help of resistor R16 and small filter capacitor C16. This output voltage is used as the input to the inverting terminal of an LM311 comparitor. The non-inverting terminal input is a threshold voltage, which is derived from the R19/R20 divider from the 12-Vdc rail. Resistor R17 provides hysteretic feedback to the comparator. The output of the comparator is used to drive the base of the PNP transistor Q5. The emitter of this bipolar transistor is used to pull down the COMP pin of the controller, initiating a hiccup mode in the event of an inductor over current. A small impedance, R11, between the collector and ground, ensures the COMP pin does not get pulled below ground.

6 Performance Data

The following figures show the performance of a circuit built as described, using inductors from three different vendors; TDK, Panasonic, and Pulse Engineering.

Efficiencies greater than 89.4% are achieved with this reference design (see Figure 6). Load regulation is measured to be better than 0.2% (see Figure 7).

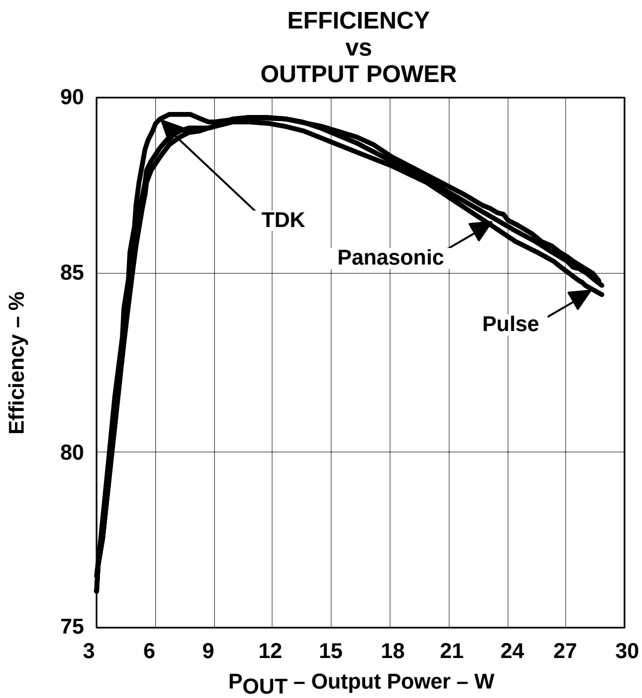


Figure 6.

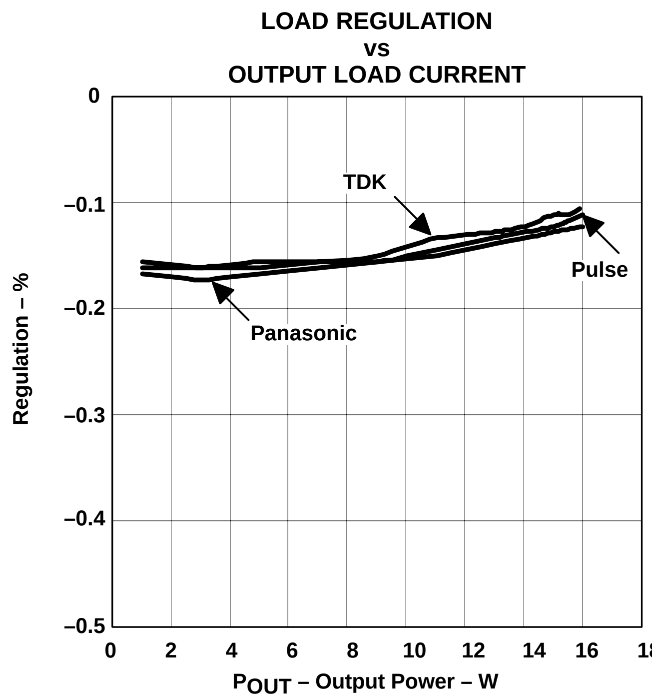


Figure 7.

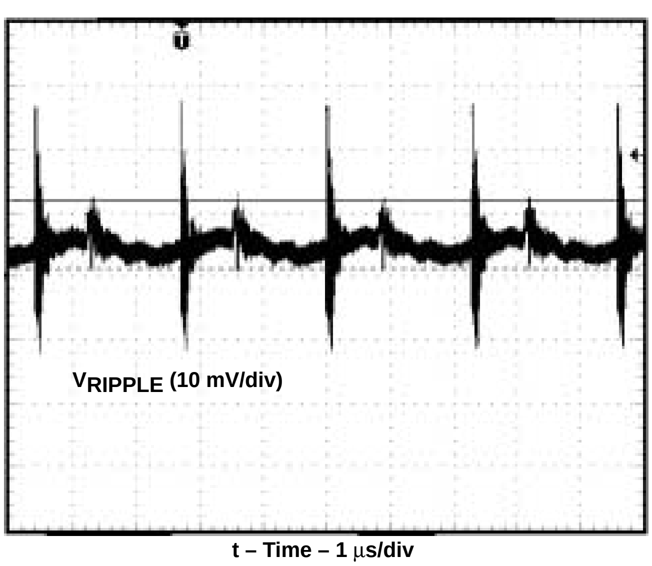


Figure 8.
Output Ripple and Noise at Minimum Load

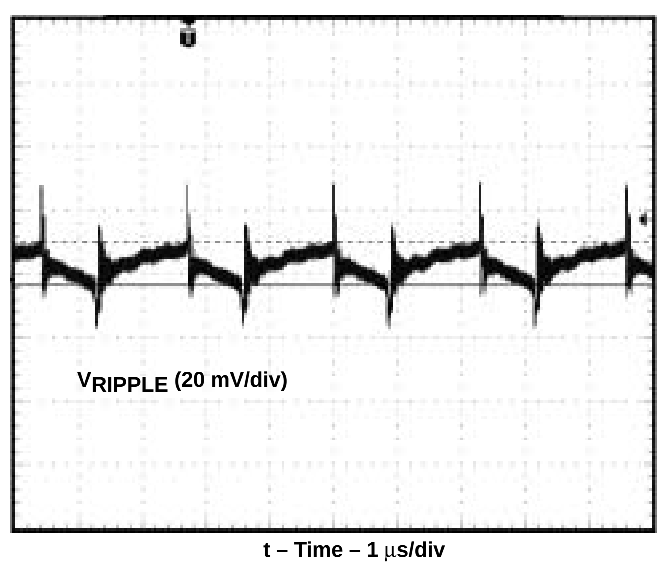


Figure 9.
Output Ripple and Noise at Maximum Load

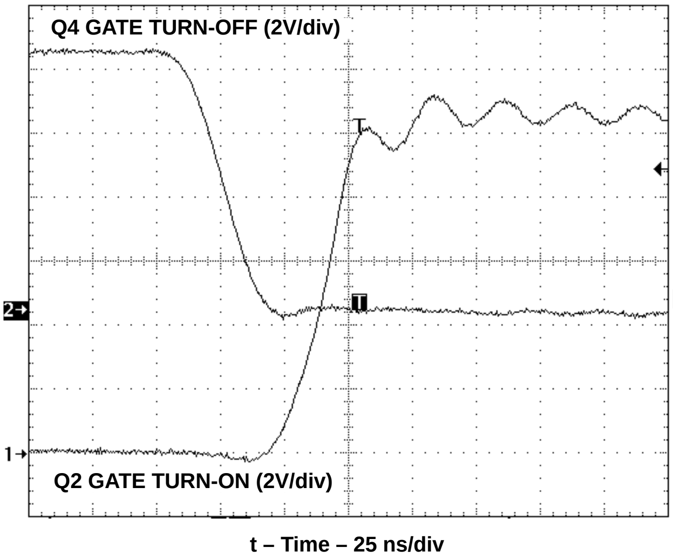


Figure 10.

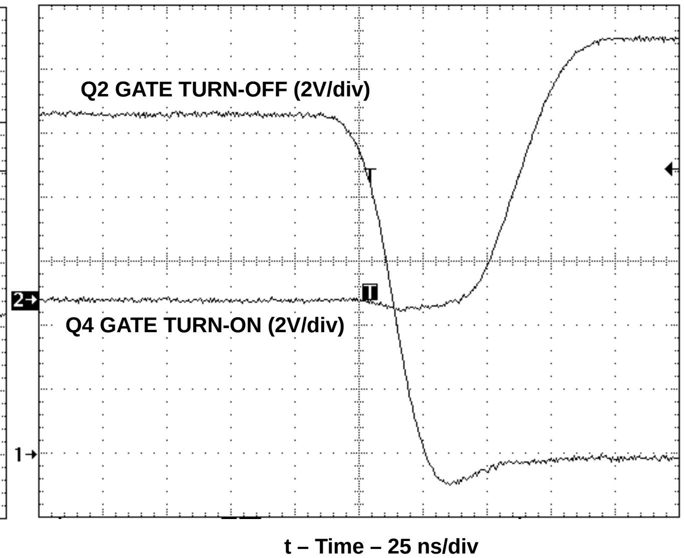


Figure 11.

Figure 12 shows a Bode plot with a crossover frequency of 40 kHz and a phase margin of approximately 60 degrees.

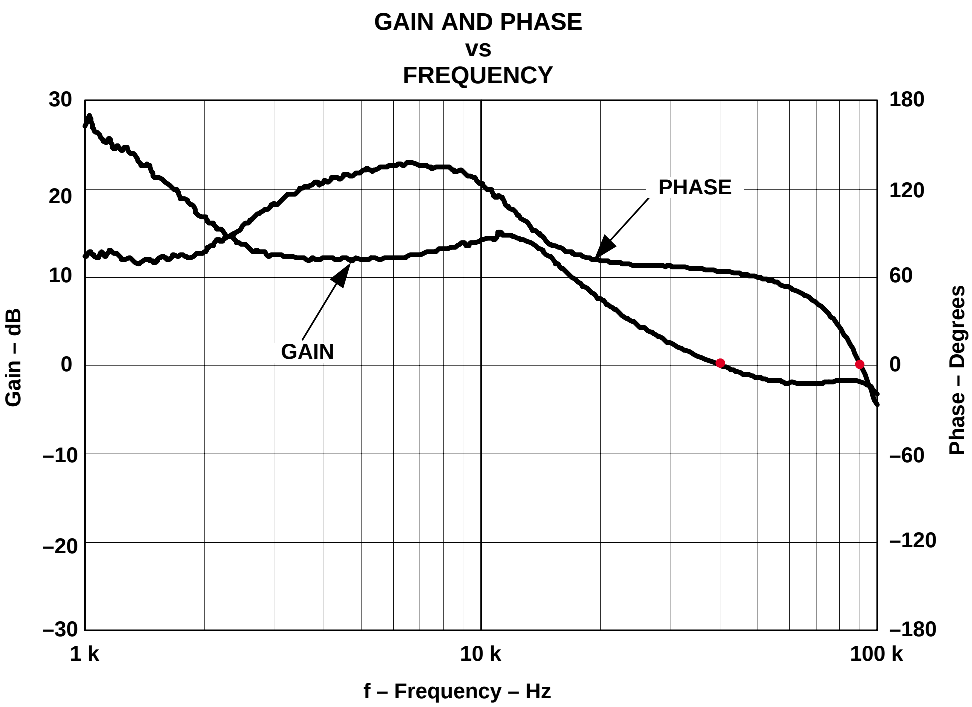


Figure 12.

7 References

1. *BiCMOS Low-Power Current-Mode PWM Controller*, Texas Instruments Literature No. SLUS458.
2. Andreycak, Bill, *The UCC38C42 Family of High-Speed, BiCMOS Current-Mode PWM Controllers*, Texas Instruments Literature No. SLUA257.

8 List of Materials

Table 1. UCC38C43EVM List of Materials

	QTY	REFERENCE DESIGNATOR	DESCRIPTION	SIZE	MANUF	PART NUMBER
Capacitor	1	C1	Ceramic, 0.01 μF, 50 V, X7R, ±10%	0603	TDK	C1608X7R1H103K
	11	C2, C3, C4, C5, C6, C7, C18, C20, C21, C22, C23	Ceramic, 47 μF, 6.3 V, X5R, ±20%	1210	TDK	C3225X5R0J476M
	1	C8	Ceramic, 2.2 μF, 6.3 V, X5R, ±20%	0603	TDK	C1608X5R0J225M
	3	C9, C11, C17	Ceramic, 10 μF, 16 V, X5R, ±20%	1206	TDK	C3216X5R1C106M
	2	C10, C19	Ceramic, 1 μF, 25 V, X7R, ±10%	0805	TDK	C2012X7R1E105K
	1	C12	Ceramic, 470-pF, 50 V, C0G, ±10%	0603	TDK	C1608C0G1H471J
	1	C13	Ceramic, 18 pF, 50 V, C0G, ±10%	0603	TDK	C1608C0G1H180J
	1	C14	Ceramic, 6800 pF, 50 V, X7R, ±10%	0603	TDK	C1608X7R1H682K
	2	C15, C26	Ceramic, 0.01 μF, 50 V, X7R, ±10%	0603	TDK	C1608X7R1H103K
	1	C16	Ceramic, 8 pF, 50 V, C0G, ±10%	0603	TDK	C1608C0G1H080D
	1	C24	Tantalum, 470 μF, 6.3 V, ±10%	E size	Vishay Sprague	293D477X96R3E2T
	1	C25	Ceramic, 15000 pF, 50 V, X7R, ±10%	0603	TDK	C1608X7R1H153K
Diode	1	D1	Schottky, 12 A, 30 V,	TO–252AA	International Rectifier	12CWQ03FN
	1	D2	Zener, 12 V, 200 mW	SOT–323	Diodes, Inc.	BZX84C12W–7
Inductor	1	L1	SMT, 1.0 μH, 22 A, 2.28 mΩ	0.524 × 0.492	TDK	SPM12550T1R0M220
Transistor	2	Q1, Q5	Bipolar, PNP, 60 V, 150 mA, 350 mΩ	SOT–23	Diodes, Inc.	MMBT2907A–7
	2	Q2, Q4	MOSFET, N-channel, 30 V, 45 A, 2.9 mΩ	LFPAK	HITACHI	HAT2166H
	1	Q3	Bipolar, NPN, 40 V, 500 mA, 350 mΩ	SOT–23	Diodes, Inc.	MMBT2222A–7
Resistor	6	R1, R2, R3, R6, R14, R20	Chip, 10 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF1002V
	1	R10	Chip, 3.92 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF3921V
	1	R12	Chip, 1.96 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF1961V
	1	R13	Chip, 1.47 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF1471V
	1	R15	Chip, 1.1 kΩ, 1/16W, ±0.1%	0603	Panasonic–ECG	ERA–3YEB112V
	1	R16	Chip, 324 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF3243V
	1	R17	Chip,100 kΩ, 1/16W, ±5%	0603	Panasonic–ECG	ERJ–3GEYJ104V
	1	R18	Metal strip, 1 mΩ, 1W, ±1%	2512	Vishay Dale	WSL–2512 0.001 ±1%
	2	R19, R24	Chip, 49.9 Ω, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF49R9V
	1	R21	Chip, 249 Ω, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF2490V
	1	R22	Chip, 49.9 Ω, 1/10W, ±1%	0805	Panasonic–ECG	ERJ–6ENF49R9V
	1	R23	Chip, 5.11 Ω, 1/16W, ±1%	0603	Yageo America	9C06031A5R11FKHFT
	2	R4, R11	Chip, 10 Ω, 1/16W, ±5%	0603	Panasonic–ECG	ERJ–3GEYJ100V
	1	R5	Chip, 30.1 kΩ, 1/16W, ±5%	0603	Panasonic–ECG	ERJ–3EKF3012V
	1	R7	Chip, 7.15 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF7151V
	1	R8	Chip, 24 Ω, 1/16W, ±5%	0603	Panasonic–ECG	ERJ–3GEYJ240V
	1	R9	Chip, 215 kΩ, 1/16W, ±1%	0603	Panasonic–ECG	ERJ–3EKF2153V

	QTY	REFERENCE DESIGNATOR	DESCRIPTION	SIZE	MANUF	PART NUMBER
Integrated Circuit	1	U1	Synchronous-buck MOSFET driver	PWP–16	Texas Instruments	TPS2838PWP
	1	U2	BiCMOS, low-power current-mode PWM controller	MSOP–8		UCC38C43DGK
	1	U3	Differential comparators with strobes	PS–8		LM311PW
	1	U4	High–sdide measurement current shunt monitor	SOT23–5		INA138NA
Connector	2	J1, J2	Terminal block, 2–pin, 15 A, 5.1mm	0.40×0.35	On Shore Technology Inc.	ED 120/2DS
	2	J3, J4	Terminal block, 4–pin, 15 A, 5.1mm	0.80×0.35		ED2227
	1	JP1	Header, 3–pin, 100-mil spacing, (36–pin strip)	0.100 × 3”	Sullins Electronics Corp.	PTC36SAAN
	1	JP1 Mate	Shorting jumper, single, 2 position			STC02SYAN
Terminal	3	TP1, TP2, TP3	Test Point, O.050 Hole”		Mill Max	3156-2-00-01-00-00-08-0
	1	SH1	This part is designed to be used for keeping GNDs separate when laying out PCB’s.			

IMPORTANT NOTICE

Mailing Address:

Texas Instruments
Post Office Box 655303
Dallas, Texas 75265