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AND8138/D

DC-DC Converter for Driving High-Intensity Light-Emitting Diodes with the SEPIC Circuit

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APPLICATION NOTE

INTRODUCTION

The new 350 mA light−emitting diodes (LEDs) present some new challenges in the area of the power converters that drive them. They must be driven from a “current source” rather than a voltage source because, as with previous LEDs, their forward voltage varies from part to part, and with temperature. It makes sense that in the interest of stable operation the source should remain a constant current. A second consideration is that the original source of power may have a voltage that varies above and below the voltage of the LEDs that are to be driven. For example, the input voltage may be between 10 Vdc and 15 Vdc, while a series string of LEDs may have a voltage of nominally 12 Vdc, such as would occur with four 3−V LEDs. Given that no galvanic isolation is required between the input and output, what’s needed is a nonisolated dc−dc converter that can handle an input that is below or above the output. The single−ended primary inductor converter (SEPIC) meets this requirement. It has an inductor input, providing smooth input current, requires only one switching transistor, and can operate over a wide range of input, both above and below the output voltage. Figure 1 shows the schematic diagram of an example SEPIC, designed for 5.0 V output and 10 V input.

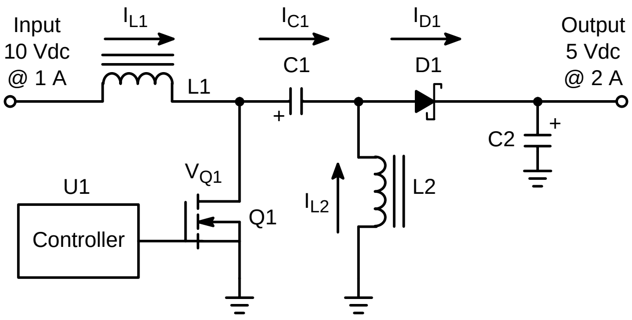

Figure 1. Example of a SEPIC

The function of the SEPIC is as follows. A controller, U1, produces constant−frequency, pulse−width modulated drive to the switching transistor, Q1. When Q1 is on, current flows from the input through L1 and Q1 to ground. During the conduction pulse, this current increases, and energy is stored in L1. When Q1 turns off, the current in L1 flows into capacitor C1 and through diode D1 to the output. Inductor L2 also contributes to the current in D1, discharging energy that was stored in it earlier. When Q1 turns on again, the cycle repeats. Some of the energy that was stored in C1 is delivered to L2, while diode D1 is reverse−biased. To understand the operation of the circuit it is helpful to realize that 1) The average voltage across an inductor is always zero (the winding is a dc short−circuit). Thus, the average voltage across capacitor C1 is simply the input voltage, since L1 is connected to the input and L2 is connected to ground, and 2) The current in an inductor cannot change instantaneously (the current in either inductor will be the same before and after Q1 turns on or off). Figure 2 shows the key waveforms of the circuit.

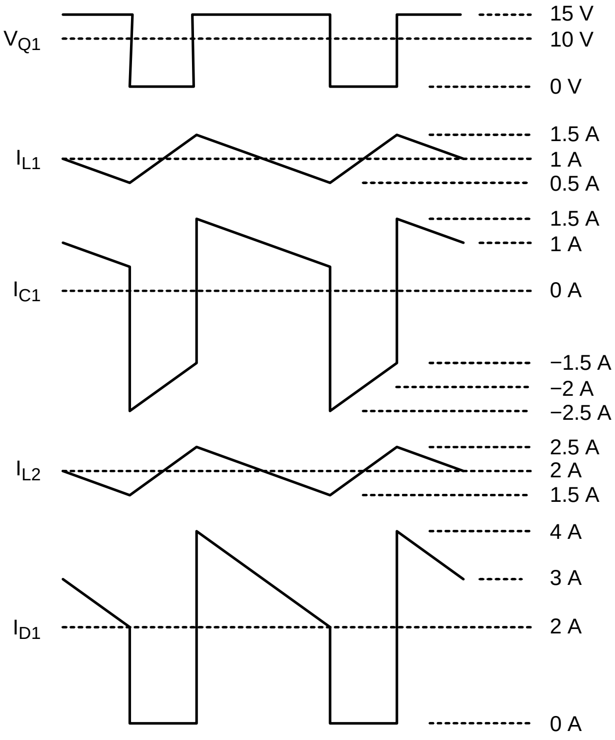

Figure 2. Waveforms of the Example SEPIC

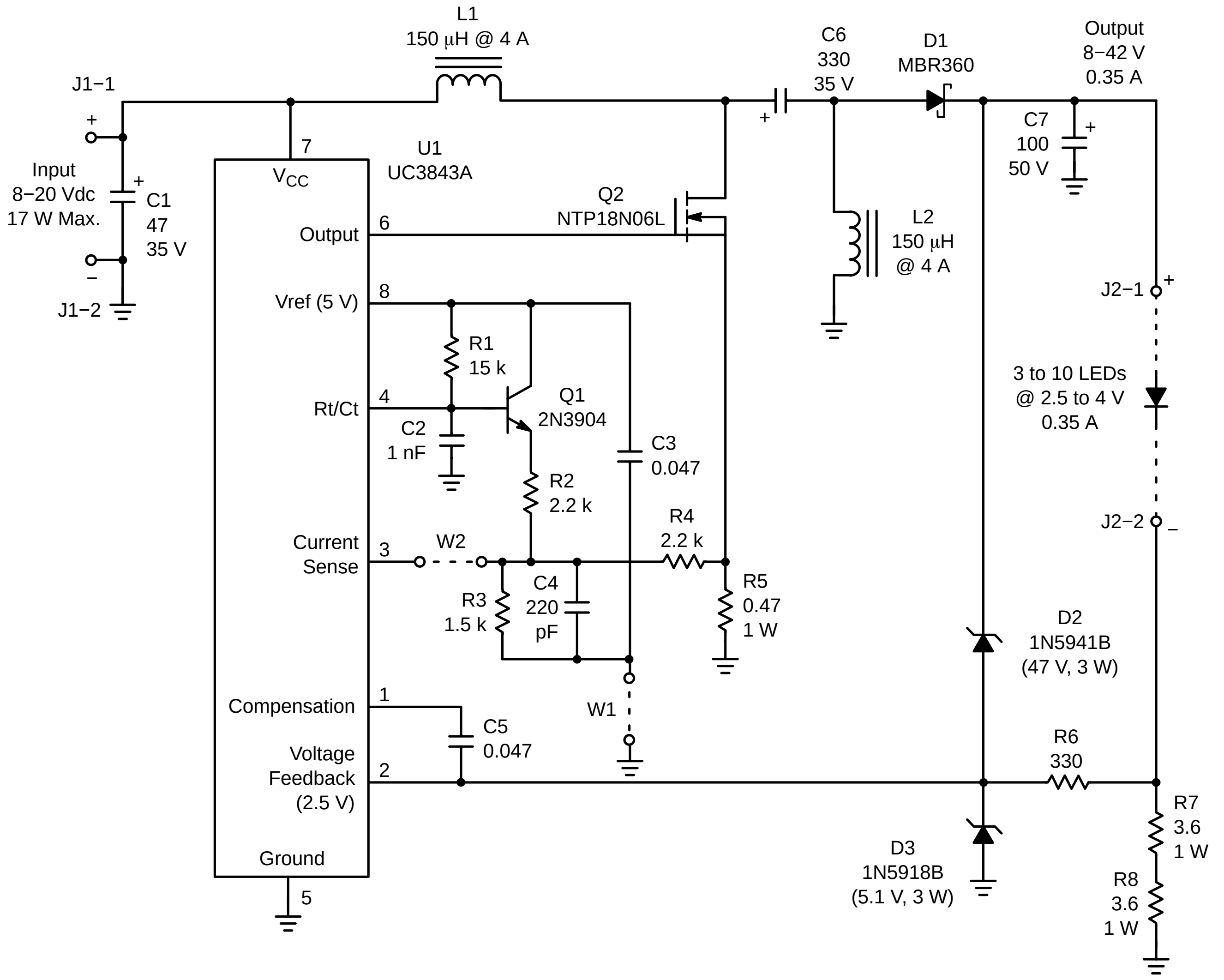

Figure 3. DC−DC Converter for Driving 3 to 10 High−Intensity LEDs

Regulating the Output

Figure 3 shows the complete circuit for driving up to 10 high−intensity LEDs at 0.35 A, from a wide−range input such as the rectified output of a low−voltage transformer. The controller is the popular UC3843 current−mode PWM device, running at 100 kHz. Current−mode control is achieved via the current−sensing resistor, R5, that senses the current in switching transistor Q2. For stable operation when the input voltage is less than the output, ramp compensation is required, as the duty ratio is greater than 50%. This is accomplished by feeding some of the ramp signal into the current sense input via Q1 and R2. The oscillator frequency is set by the timing resistor and timing capacitor, R1 and C2, respectively. Resistor R4 and capacitor C4 provide filtering to reduce the usual spike at the leading edge of the pulse across R5 due to capacitance of the FET, Q2. Resistor R3 provides level shifting to compensate for the voltage offset of the ramp signal injected by resistor R2. Capacitor C5 provides dominant−pole compensation of the main feedback loop. The LED current is regulated by sensing the voltage across resistors R7 and R8, which are in series with the load. The output current is regulated to 2.5 V (the reference input voltage of U1) divided by the resistance of R7 and R8, which sum to 7.2 Ω. This produces an output current of 0.35 A. Resistor R6 provides the input impedance for the loop compensation pole formed with capacitor C5.

Fault Protection

The circuit is inherently short−circuit proof, since the output is current regulated. There is no input protection, however, so a production design should have an input fuse and perhaps a series diode to protect against input lead reversal.

The output is protected in two ways, by Zener diodes D2 and D3. Zener diode D2 protects the circuitry in the event of an open−circuit output or LED open−circuit failure. In this case, the feedback loop is closed via D2 and the output will regulate at the Zener voltage (47 V) plus the internal feedback reference (2.5 V). Zener diode D3 protects the circuitry from the positive voltage surge that will occur when the output circuit opens and the energy stored in the inductors L1 and L2 is discharged into the output.

Performance of the Converter

The efficiency of the converter is dependent on many factors, of course. The main contributors are the switching FET, Q2, and the output boost diode, D1. There are also losses in the switch−current−sensing resistor, R5, and the output current sampling resistors, R7 and R8. It is also a characteristic of the SEPIC that there is a reasonable amount of energy stored within the converter. This adds to the losses. For example, unless the inductors are quite large in value, there is considerable change in current during each portion of the switching cycle. This causes additional losses in the inductors, as well as the switching elements. There is also loss in the main internal capacitor, C6, as it must pass all of the energy from the input to the output of the converter. The output capacitor is also subjected to a reasonable amount of ripple current. These must all be taken into account during the design.

Figure 4 shows the measured performance of the converter, with the equivalent of 10 LEDs as a load. The actual load is a 100 Ω resistor, causing an output voltage of 35 V at 0.35 A − the same as would be obtained from 10 LEDs with a forward voltage drop of 3.5 V each.

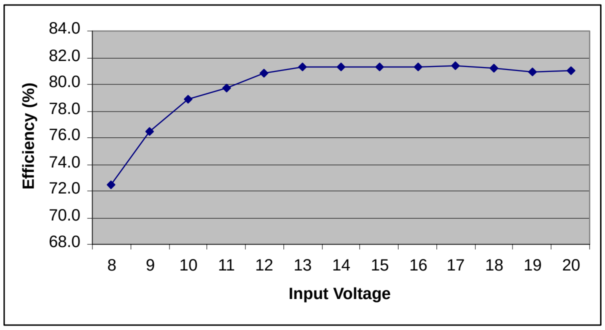

Figure 4. Efficiency of the SEPIC at 11 W Output

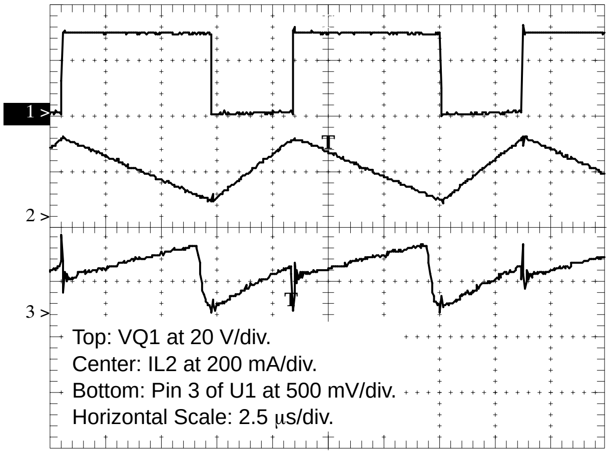

Figure 5. Waveforms − 18 V In, 7.0 V @ 0.35 A Out

Figure 5 shows typical waveforms in the final circuit with an input of 18 Vdc and the output driving a 100 Ω load at 0.35 A (the equivalent of 10 high−intensity LEDs in series). Note the presence of the ramp compensation (increased slope) at the beginning of each current ramp.

Printed Wiring Board Design

Figures 6 and 7 show the component side silk screen artwork and the solder side copper traces, respectively.

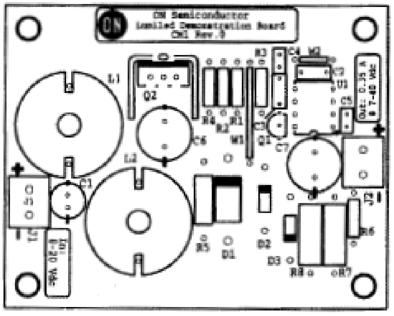

Figure 6. Component Side, Silk Screen Art

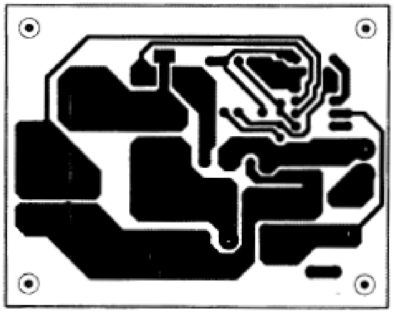

Figure 7. Circuit Artwork (Board is 3″ x 2.38″)

The demonstration board has been designed for easy modification. The two inductors are intentionally overdesigned (rated at 4.0 A) and the switching transistor is an 18 A device with a heat sink attached, allowing additional power−handling capability. When making significant changes, the designer is cautioned to observe the ripple current ratings on capacitors C1, C6 and C7. Figure 2 gives the designer a good picture of this situation. The waveform of I_{C1} in Figure 2 corresponds to the current in series capacitor C6 in the final circuit. The waveform of I_{D1} is identical to the ac current in the output capacitor, C7, and the rms value is nearly identical to the current in C6, as can be seen in Figure 2. The ripple current in C1 is identical to the input inductor current, I_{L1}, which is fairly trivial as shown in Figure 2.

Table 1. Lumiled Demonstration Board CM1, Bill of Material

Ref.	Qty.	Same As	Description	Value	Package	Vendor	Vendor PN	Digikey #	Dia./ W mm	L mm	H mm	Lead Sp. mm	Lead Dia. mm
C1	1		Cap., Electrolytic	47 μF, 35 V	Radial	Illinois Capacitor	476RZS035M						
			Alternate for the Above	68 μF, 35 V	Radial	Panasonic	EEU−FC1V680	P10292−ND	6.3		11.2	2.5	0.5
C2	1		Cap., Ceramic	1.0 nF, 50 V	Disk	AVX							
			Alternate for the Above	1.0 nF, 50 V	Disk	Panasonic	ECU−S1H102JCB	P4937−ND	5.0	3.1	6.5	5.0	0.55
C3	2		Cap., Ceramic	47 nF, 50 V	Disk								
			Alternate for the Above	47 nF, 50 V	Tab	Panasonic	ECU−S1H473KBB	P4955−ND	5.0	2.5	5.5	5.0	0.55
C4	1		Cap., Ceramic, C0G	220 pF, 50 V	Disk								
			Alternate for the Above	220 pF, 50 V	Disk	Panasonic	ECU−S1H221JCA	P4929−ND	5.0	2.5	5.0	2.5	0.55
C5		C3											
C6			Cap., Electrolytic	330 μF, 35 V	Radial	Nichicon	UPL1V331MPH						
			Alternate for the Above	330 μF, 35 V	Radial	Panasonic	EEU−FC1V331	P10299−ND	10		16	5.0	0.6
C7	1		Cap., Electrolytic	100 μF, 50 V	Radial	Nichicon							
			Alternate for the Above	220 μF, 50 V	Radial	Panasonic	EEU−FC1H221	P10325−ND	10		20	5.0	0.6
D1	1		Diode, Schottky	3.0 A, 60 V	DO−201AD	ON Semiconductor	MBR360		5.05	7.9		16.5	1.3
D2	1		Diode, Zener	47 V, 3.0 W	DO−41	ON Semiconductor	1N5941B		2.7	5.2		12.7	0.9
D3	1		Diode, Zener	5.1 V, 3.0 W	DO−41	ON Semiconductor	1N5918B		2.7	5.2		12.7	0.9
J1	2		Terminal Block	2−Position		Phoenix	MKDSN1.5/2−5.08	277−1247−ND	8.1	10.2	10	5.08	1.0
J2		J1											
L1	2		Inductor	150 μH, 4.0 A	Vert. TH	J.W. Miller	1120−151K	M6268−ND	21		16.3	16	0.76
L2		L1											
Q1	1		Transistor, NPN	40 V	TO−92	ON Semiconductor	2N3904						
Q2	1		MOSFET, N Channel	60 V, 18 A	TO−220	ON Semiconductor	NTP18N06L						
R1	1		Res., Carbon Film, 5%, 1/4 W	15 k	Axial	Yageo	CFR−25JB−15K	15KQBK−ND				10	0.6
R2	2		Res., Carbon Film, 5%, 1/4 W	2.2 k	Axial	Yageo	CFR−25JB−2.2K	2.2KQBK−ND				10	0.6
R3	1		Res., Carbon Film, 5%, 1/4 W	1.5 k	Axial	Yageo	CFR−25JB−1.5K	1.5KQBK−ND				10	0.6
R4		R2											
R5	1		Res., Metal Oxide, 5%, 1.0 W	0.47 Ω	Axial	Yageo		0.47W−1−ND				15	0.8
R6	1		Res., Carbon Film, 5%, 1/4 W	330 Ω	Axial	Yageo	CFR−25JB−330	330QBK−ND				10	0.6
R7	2		Res., Metal Oxide, 5%, 1.0 W	3.6 Ω	Axial	Yageo		3.6W−1−ND				20	0.8
R8		R7											
U1	1		IC, Current−Mode Controller		8−Pin DIP	ON Semiconductor	UC3843AN						
W1	1		Jumper, Insulated, Blk. #22	0.8″ Centers	Cut from item X3 to 1.2″ and strip 0.25″ from each end. Bend 90° and install into holes at 0.8″ centers.								
W2	1		Jumper, Insulated, Blk. #22	0.3″ Centers	Cut from item X3 to 0.7″ and strip 0.25″ from each end. Bend 90° and install into holes at 0.3″ centers.								
X1	1		Heat Sink, TO−220	18.8 C/W		Aavid	576802B04100	HS211−ND					
X2	4		Feet, Nylon			HHSmith	3929	See Web for Distr.		Note: Use 0.156″ hole			
X3	1		Wire, 22 AWG, Solid, Black Insul.		100 Ft. Roll	Alpha	305/1BK005	A3051B−100−ND					
X4	1		Printed Wiring Board	Lumiled Demonstration Board CM1, Rev. 0									

Notes

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