AN-1747 3A LM20k Reference Designs

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1 Introduction

The LM20123, LM20133, and LM20143 are a full-featured family of high performance 3A synchronous buck converters. These devices are tailored to operate over an input voltage range of 2.95 V to 5.5 V and each can be optimized to meet many different performance requirements. The LM20123 operates at a fixed frequency and only requires 11 components to generate a solution. The LM20143 is similar to the LM20123 except the frequency of the device can be varied from 460 kHz to 1.5 MHz with an external resistor. This gives the power supply designer the flexibility to trade-off inductor size and efficiency. The LM20133 features a synchronization input pin that synchronizes the internal oscillator to an external signal to keep the switching regulators operating with the same phase, which is critical in many noise sensitive designs.

The reference designs discussed show how the 3A devices can be optimized for size, efficiency and transient response. The trade-offs made for each design discuss the various 3A devices. Test results for including efficiency, output voltage ripple, and transient response are shown for each design.

2 Solution Optimized for Efficiency

The LM20143 was selected for a high-efficiency design because the operating frequency can be adjusted to minimize switching losses. A low switching frequency minimizes the switching losses; however, this also requires a solution with a higher value inductance with a higher DC series resistance (DCR). Since the LM20k family of devices feature very low switching losses, a switching frequency of 620 kHz was selected. This choice of operating frequency balances the inductance DCR losses with the switching frequency losses to give a small, highly efficient solution. This design can also work with the LM20133 synchronizing to 620 kHz.

2.1 Inductor Selection

As per the data sheet recommendations, the inductor value should initially be chosen to give a peak-to-peak ripple current equal to roughly 30% of the maximum output current. The peak-to-peak inductor ripple current can be calculated by Equation 1:

$$\Delta I_{P\text{-}P} = \frac{(V_{IN} - V_{OUT}) \times D}{L \times f_{SW}} \quad (1)$$

Rearranging Equation 1 and solving for the inductance reveals that for this application (V_{IN} = 5 V, V_{OUT} = 3.3 V, D = V_{IN}/V_{OUT} = .66, f_{SW} = 620 kHz, and I_{OUT} = 3A) the nominal inductance value is roughly 2 µH. Once an inductance value is calculated, an actual inductor needs to be selected based on a trade-off between physical size, efficiency, and current carrying capability. The purpose of this design is to maximize the efficiency therefore, the choice of small value inductors with lower series resistance (DCR) can be examined provided the output current plus one-half the peak-to-peak ripple current does not exceed the device current limit. Examining several inductor vendors a TDK SPM6530T-1R5M100 inductor was selected. This 1.5 µH inductor results in a peak-to-peak ripple current of 1.2A when the converter is operating from 5 V and 3.3 V. For the a design targeting high efficiency the TDK SPM6530T-1R5M100 inductor offers a good balance between efficiency (9.7 mΩ DCR), size, and saturation current rating (10A I_{SAT} rating).

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2.2 Output Capacitor Selection

The value of the output capacitor in a buck regulator influences the voltage ripple that is present on the output voltage, as well as the large signal output voltage response to a load transient. Given the peak-to-peak inductor current ripple (that can be calculated using Equation 1) the output voltage ripple can be approximated by Equation 2:

$$\Delta V_{OUT} = \Delta I_{P\text{-}P} \times \left[R_{ESR} + \frac{1}{8 \times f_{SW} \times C_{OUT}} \right] \quad (2)$$

The variable R_{ESR} above refers to the ESR of the output capacitor. As can be seen in Equation 2, the ripple voltage on the output can be divided into two parts, one of which is attributed to the AC ripple current flowing through the ESR of the output capacitor and another due to the AC ripple current actually charging and discharging the output capacitor. The output capacitor also has an effect on the amount of droop that is seen on the output voltage in response to a load transient event.

For this design, a TDK 100 µF ceramic capacitor is selected for the output capacitor to provide good transient and DC performance in a relatively small package. From the technical specifications of this capacitor, the ESR at the 1.5 MHz switching frequency is roughly 2 mΩ, and the effective in-circuit capacitance is approximately 45 µF (reduced from 100 µF due to the 3.3 V DC bias). With these values, the peak-to-peak voltage ripple on the output when operating from a 5 V input can be calculated to be 8 mV.

2.3 Compensation Selection

The compensation network was selected using the excel calculator to give a crossover frequency of 50 kHz. For this target crossover frequency, operating conditions, and filter components the excel design tool (available online) suggests a value of C_{C1} of 2.7 nF and a value of R_{C1} of 9.31 kΩ.

The final schematic for a 5 V or 3.3 V conversion optimized for efficiency is shown in Figure 1.

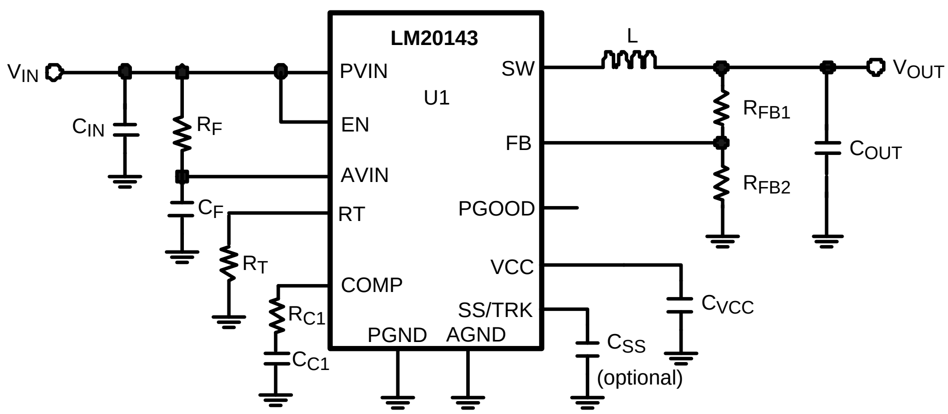

Figure 1. 3.3 V Output Solution Optimized for Efficiency

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Table 1. High Efficiency Bill of Materials (BOM) (V_{IN} = 5 V, V_{OUT} = 3.3 V, $I_{OUT(MAX)}$ = 3A)

Qty	Designator	Description	Part Number	Manufacturer
1	U1	Synchronous Buck Regulator	LM20143	Texas Instruments
1	C_{IN}	47 µF, 1206, X5R, 6.3 V	C3216JB0J476M	TDK
1	C_{OUT}	100 µF, 1210, X5R, 6.3 V	C3225X5R0J107M	TDK
1	L	1.5 µH, 9.7 mΩ	SPM6530T-1R5M100	TDK
1	R_F	1 Ω, 0603	CRCW06031R0J-e3	Vishay-Dale
1	C_F	1 µF, 0603, X7R, 10 V	GRM188R71A105KA01	Murata
1	C_{VCC}	1 µF, 0603, X7R, 10 V	GRM188R71A105KA01	Murata
1	R_{C1}	9.31 kΩ,0603	CRCW06039312F	Vishay-Dale
1	C_{C1}	2.7 nF,0603,X7R,25 V	VJ0603Y272KXA	Vishay-Vitramon
1	C_{SS}	33 nF,0603,X7R,25 V	VJ0603Y333KXXA	Vishay-Vitramon
1	R_{FB1}	30.9 kΩ,0603	CRCW06033092F	Vishay-Dale
1	R_{FB2}	10 kΩ, 0603	CRCW06031002F-e3	Vishay-Dale
1	R_T	196 kΩ, 0603	CRCW06031963F	Vishay-Dale

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The calculated component PCB area for this design is 104 mm². The efficiency vs. I_{OUT}, output voltage ripple and transient response are shown in Figure 2 through Figure 4.

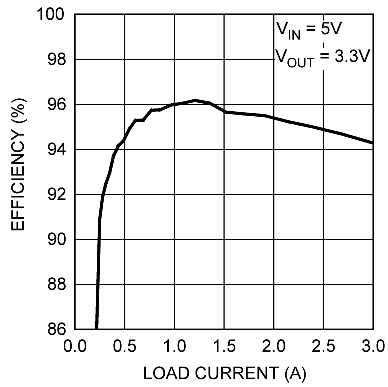

Figure 2. Efficiency vs I_{OUT}

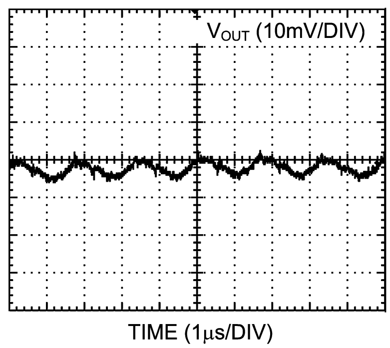

Figure 3. Output Voltage Ripple

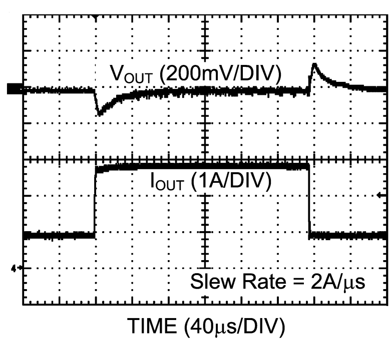

Figure 4. Transient Response

3 Optimizing a Solution for Size

For the smallest possible solution size, the fixed frequency LM20123 device was selected since the 1.5 MHz free running oscillator minimizes both the component count and inductor size. To minimize the solution size, careful attention needs to be paid to the selection of the external components such as the inductor, input, and output capacitors.

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3.1 Inductor Selection

The inductor should be sized for approximately 30% ripple current. For V_{IN} = 5 V, V_{OUT} = 1.2 V, f_{SW} = 1.5 MHz, and I_{OUT} = 3A, the ideal inductance value can be calculated from Equation 1 to be 0.68 µH. Once an inductance value is calculated, an actual inductor needs to be selected based on a tradeoff between physical size, efficiency, and current carrying capability. Since the purpose of this design is minimize the size, it is possible to select inductor values smaller than 0.68 µH, as long as the output current plus one-half the peak-to-peak ripple current does not exceed the device current limit. After examining several inductor vendors, a Coilcraft LPS4018-561 inductor was selected. This 0.56 µH inductor results in a peak-to-peak ripple current of 1.09A and 909 mA when the converter is operating from 5 V and 3.3 V, respectively. For a design where size is critical, the Coilcraft LPS4018-561 inductor offers an extremely small size (3.9 mm x 3.9 mm) with relatively low DC losses (30 mΩ DCR), and saturation current rating (5.2A I_{SAT} rating) that exceeds the device current limit.

3.2 Output Capacitor Selection

A TDK 47 µF ceramic capacitor is selected for the output capacitor to provide good transient and DC performance in a relatively small package. From the technical specifications of this capacitor, the ESR at the 1.5 MHz switching frequency is roughly 3 mΩ and the effective in-circuit capacitance is approximately 28 µF (reduced from 47 µF due to the 1.2 V DC bias). With these values, the peak-to-peak voltage ripple on the output when operating from a 5 V input can be calculated to be 6 mV.

3.3 Compensation Selection

The compensation network was selected using the excel calculator to give a crossover frequency of 119 kHz. For this target crossover frequency, operating conditions, and filter components selected above, the excel calculator suggested a value of C_{C1} of 2.2 nF and a value of R_{C1} of 3.65 kΩ.

The final schematic for a 5 V to 1.2 V or 3.3 V to 1.2 V solution is shown in Figure 1.

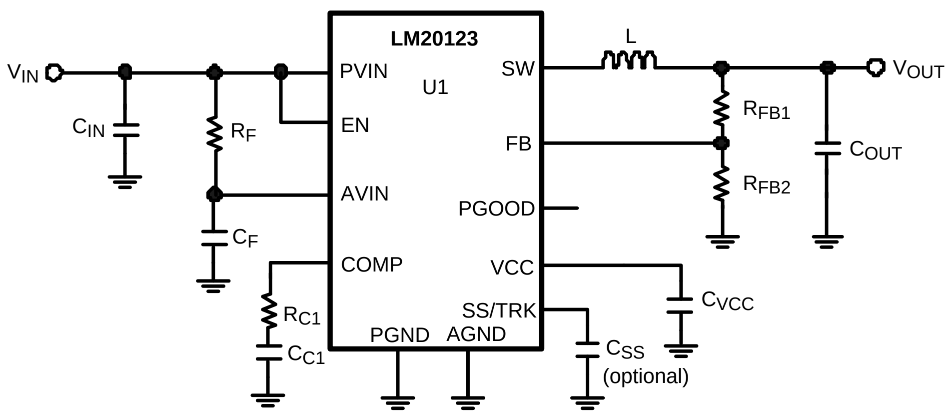

Figure 5. 1.2 V Output Solution Optimized for Size

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Table 2. Bill of Materials (BOM) (Small solution size, V_{IN} = 5 V, V_{OUT} = 1.2 V, $I_{OUT(MAX)}$ = 3A)

Qty	Designator	Description	Part Number	Manufacturer
1	U1	Synchronous Buck Regulator	LM20123	Texas Instruments
1	C_{IN}	47 µF, 1206, X5R, 6.3 V	C3216JB0J476M	TDK
1	C_{OUT}	47 µF, 1206, X5R, 6.3 V	C3216JB0J476M	TDK
1	L	.56 µH, 30 mΩ	LPS4018-561MLC	Coilcraft
1	R_F	1 Ω, 0402	CRCW04021R0J-e3	Vishay-Dale
1	C_F	1 µF, 0402, X5R, 10 V	GRM155R61A105KE15	Murata
1	C_{VCC}	1 µF, 0402, X5R, 10 V	GRM155R61A105KE15	Murata
1	R_{C1}	3.65 kΩ, 0402	CRCW04023652F-e3	Vishay-Dale
1	C_{C1}	2.2 nF,0402,X7R, 25 V	VJ0402Y222KXXA	Vishay-Vitramon
1	C_{SS}	33 nF,0402,X5R, 25 V	VJ0402G333KXJA	Vishay-Vitramon
1	R_{FB1}	4.99 kΩ,0402	CRCW04024992F-e3	Vishay-Dale
1	R_{FB2}	10 kΩ, 0402	CRCW04021002F-e3	Vishay-Dale

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The calculated component PCB area for this design is 64 mm². The efficiency vs. I_{OUT}, output voltage ripple, and transient response are shown in Figure 6 through Figure 8.

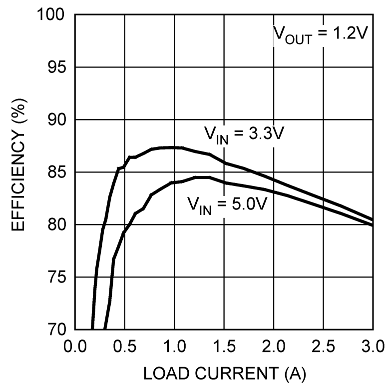

Figure 6. Efficiency vs I_{OUT}

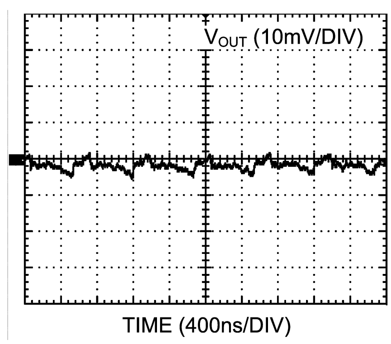

Figure 7. Output Voltage Ripple

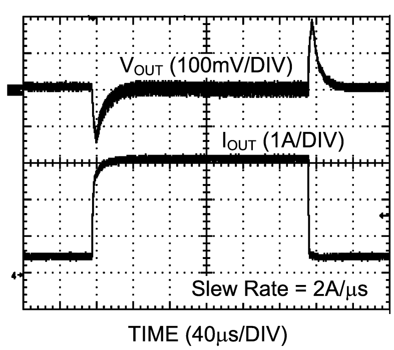

Figure 8. Transient Response

4 Solution Optimized for Transient Response

To optimize the transient response, the switching frequency should be as high as possible. A high switching frequency allows the crossover frequency to maximized and the inductor size to be minimized. A small inductor permits also permits the inductor current to quickly ramp during a load step change.

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4.1 Inductor Selection

Again selecting the inductor to be sized for approximately 30% ripple current for V_{IN} = 5 V, V_{OUT} = 1.2 V, f_{SW} = 1.5 MHz, and I_{OUT} = 3A, the ideal inductance value can be calculated from Equation 1 to be 0.68 µH. Once an inductance value is calculated, an actual inductor needs to be selected based on a tradeoff between physical size, efficiency, and current carrying capability. Since the purpose of this design is to select the smallest possible inductor values smaller than 0.68 µH can be examined as long as the output current plus one-half the peak-to-peak ripple current does not exceed the device current limit. Examining several inductor vendors a TDK SPM6530T-R47M170 inductor was selected. This 0.47 µH inductor results in a peak-to-peak ripple current of 1.29A and 1.08A when the converter is operating from 5 V and 3.3 V, respectively. For optimization of the transient response, the TDK SPM6530T-R47M170 inductor offers a good balance between efficiency (3.3 mΩ DCR), size, and saturation current rating (17A I_{SAT} rating).

4.2 Output Capacitor Selection

A Sanyo 470 µF POSCAP capacitor with 10 mΩ of series resistance (ESR) is selected for the output capacitor to provide good transient and DC performance in a relatively small package. If desired, the output voltage ripple can be further reduced by placing a 47 µF ceramic capacitor in parallel with the Sanyo POSCAP.

4.3 Compensation Selection

The compensation network was selected using the excel design tool (available online) to give a crossover frequency of 110 kHz. For this target crossover frequency, operating conditions, and filter components a value for C_{C1} of 0.47 nF and a value for R_{C1} of 57.6 kΩ were selected. Since the output capacitor value and ESR are large an additional capacitor C_{C2} is recommended. For this design, C_{C2} is 100 pF.

The final schematic for a 5 V to 1.2 V or 3.3 V to 1.2 V conversion is shown in Figure 1.

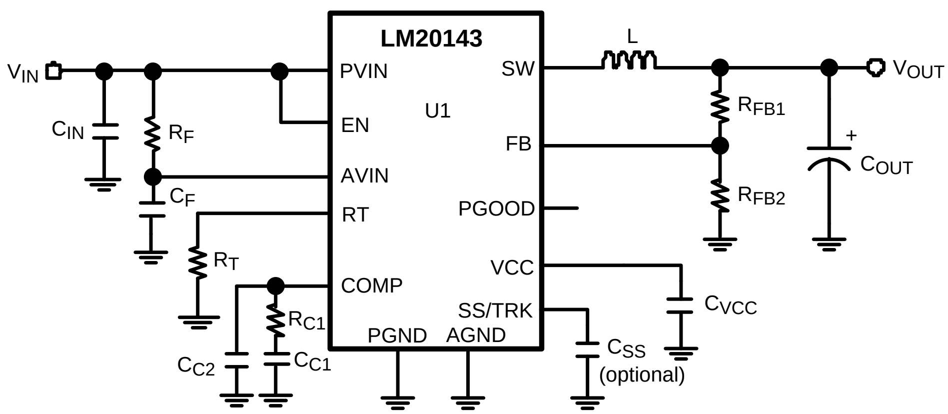

Figure 9. 1.2 V Output Solution Optimized for Load Transients

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Table 3. Transient Response Bill of Materials (BOM) (V_{IN} = 5 V, V_{OUT} = 3.3 V, $I_{OUT(MAX)}$ = 3A, f_{SW} = 500 kHz)

Qty	Designator	Description	Part Number	Manufacturer
1	U1	Synchronous Buck Regulator	LM20143	Texas Instruments
1	C_{IN}	47 µF, 1206, X5R, 6.3 V	C3216JB0J476M	TDK
1	C_{OUT}	470 µF, D4D, 6.3 V	4TPD470M	Sanyo
1	L	0.47 µH,3.3 mΩ	SPM6530T-R47M170	TDK
1	R_F	1 Ω, 0603	CRCW06031R0J-e3	Vishay-Dale
1	C_F	1 µF, 0603, X7R, 10 V	GRM188R71A105KA01	Murata
1	C_{VCC}	1 µF, 0603, X7R, 10 V	GRM188R71A105KA01	Murata
1	R_{C1}	57.6 kΩ, 0603	CRCW06035762F-e3	Vishay-Dale
1	C_{C1}	.47 nF,0603,X7R, 25 V	VJ0603Y471KXXA	Vishay-Vitramon
1	C_{C2}	100 pF,0603, 50 V,COG	GRM1885C1H101JA01	Murata
1	C_{SS}	33 nF,0603,X7R, 25 V	VJ0603Y333KXXA	Vishay-Vitramon
1	R_{FB1}	4.99 kΩ,0603	CRCW06034992F-e3	Vishay-Dale
1	R_{FB2}	10 kΩ, 0603	CRCW06031002F-e3	Vishay-Dale
1	R_T	48.7 kΩ, 0603	CRCW06034872F-e3	Vishay-Dale

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The calculated component PCB area for this design is 126 mm[2]. The efficiency vs. I_{OUT}, output voltage ripple, and transient response are shown in Figure 10 through Figure 12.

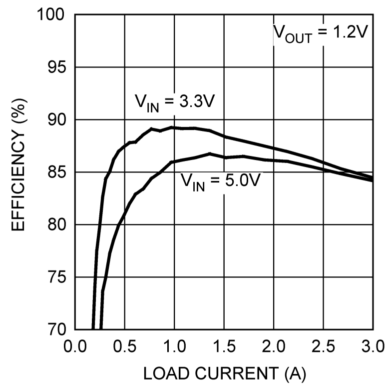

Figure 10. Efficiency vs I_{OUT}

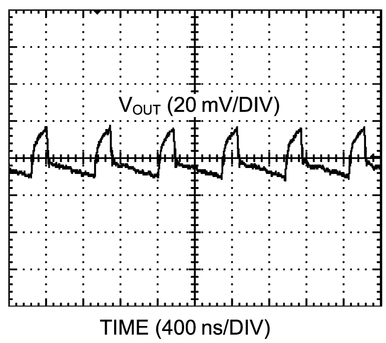

Figure 11. Output Voltage Ripple

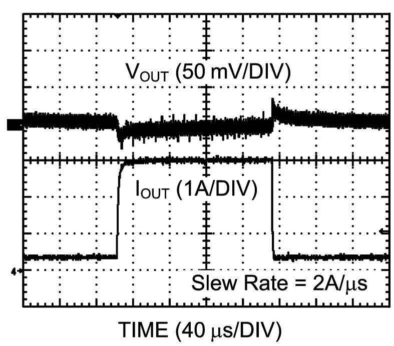

Figure 12. Transient Response

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