# AN-1752 5A LM20k Reference Designs


## ABSTRACT

This application note discusses the design options using the high performance 5A synchronous buck converters LM20125 and LM20145.


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# 1 Introduction

The LM20125 and LM20145 are a full-featured family of high performance 5A synchronous buck converters. These devices are tailored to operate over an input voltage range of 2.95V to 5.5V and each can be optimized to meet many different performance requirements. The LM20125 operates at a fixed frequency and only requires 11 components to generate a solution. The LM20145 is similar to the LM20125 except the frequency of the device can be varied from 250 kHz to 750 kHz with an external resistor. This gives the power supply designer the flexibility to trade-off inductor size, efficiency, as well as AC performance.

The reference designs discussed will show how the 5A devices can be optimized for size, efficiency and transient response. The trade-offs made for each design will be discussed as well as possible tweaks to interchange the various 5A devices. Test results for including efficiency, output voltage ripple, and transient response will be shown for each design

# 2 Solution Optimized for Size and Efficiency

To minimize the switching losses and reduce the solution size the LM20125 device was selected. This device operates at a fixed frequency of 500kHz keeping the switching losses down; while also allowing use of a relatively small inductor. Therefore, this solution can offer both small size, as well as, high efficiency.

## 2.1 Inductor Selection

As per the datasheet 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 the equation:

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

Rearranging the above equation and solving for the inductance reveals that for this application ($V_{IN}$ = 5V, $V_{OUT}$ = 3.3V, $f_{SW}$ = 500 kHz, and $I_{OUT}$ = 5A) the nominal inductance value is roughly 1.5 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. Since the purpose of this design is to maximize the efficiency and keep the solution size small the inductor values smaller than 1.5 µH 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 1.5A when doing a 5V to 3.3V conversion. For the LM20125 demo board, a TDK SPM6530T-1R5M100 inductor offers a good balance between efficiency (9.7 mΩ DCR), size, and saturation current rating (10A $I_{SAT}$ rating).

## 2.2 Output Capacitor Selection

The value of the output capacitor in a buck regulator influences the voltage ripple that will be 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 (which can be calculated using equation 1) the output voltage ripple can be approximated by the equation:

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

The variable $R_{ESR}$ above refers to the ESR of the output capacitor. As can be seen in the above equation, 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 500 kHz switching frequency is roughly 2 mΩ, and the effective in-circuit capacitance is approximately 45 µF (reduced from 100 µF due to the 3.3V DC bias). With these values, the peak-to-peak voltage ripple on the output when operating from a 5V input can be calculated to be 8 mV.

## 2.3 Compensation Selection

The compensation network was selected using the excel design tool (available online) to give a crossover frequency of 59 kHz. For this target crossover frequency, operating conditions, and filter components the excel design tool suggested a value of $C_{C1}$ of 1.2 nF and a value of $R_{C1}$ of 19.6 kΩ.

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

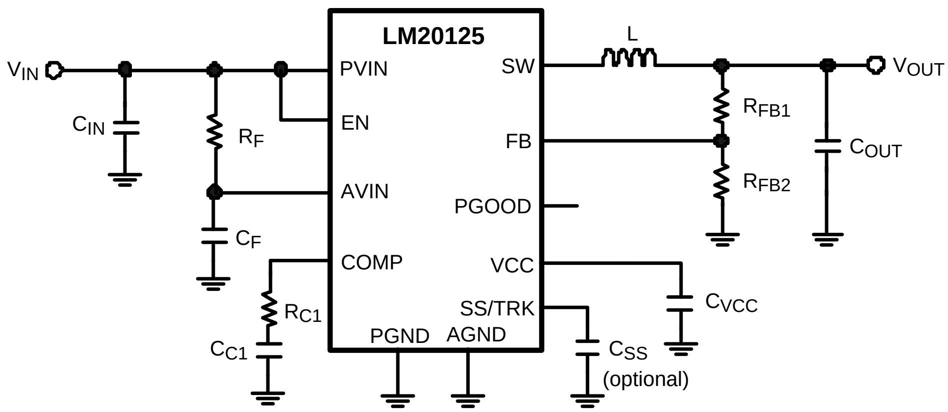


**Figure 1. 3.3V Output Solution Optimized for Size and Efficiency**

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

| Designator | Description | Part Number | Manufacturer | Qty |
|---|---|---|---|---|
| U1 | Synchronous Buck Regulator | LM20125 | Texas Instruments | 1 |
| $C_{IN}$ | 47µF, 1206, X5R, 6.3V | C3216JB0J476M | TDK | 1 |
| $C_{OUT}$ | 100µF, 1206, X5R, 6.3V | C3225X5R0J107M | TDK | 1 |
| L | 1.5µH, 9.7mΩ | SPM6530T-1R5M100 | TDK | 1 |
| $R_F$ | 1Ω, 0402 | CRCW04021R0J-e3 | Vishay-Dale | 1 |
| $C_F$ | 1µF, 0402, X7R, 10V | GRM155R61A105KE15 | Murata | 1 |
| $C_{VCC}$ | 1µF, 0402, X7R, 10V | GRM155R61A105KE15 | Murata | 1 |
| $R_{C1}$ | 19.6kΩ,0402 | CRCW06031962F | Vishay-Dale | 1 |
| $C_{C1}$ | 1.2nF,0402,X7R,25V | VJ0603Y122KXA | Vishay-Vitramon | 1 |
| $C_{SS}$ | 33nF,0402,X7R,25V | VJ0402G333KXJA | Vishay-Vitramon | 1 |
| $R_{FB1}$ | 30.9kΩ,0402 | CRCW04023092F-e3 | Vishay-Dale | 1 |
| $R_{FB2}$ | 10kΩ, 0402 | CRCW04021002F-e3 | Vishay-Dale | 1 |

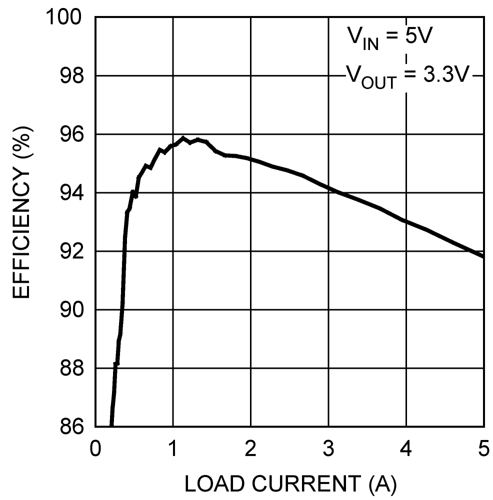


**Figure 2. Efficiency vs $I_{OUT}$**

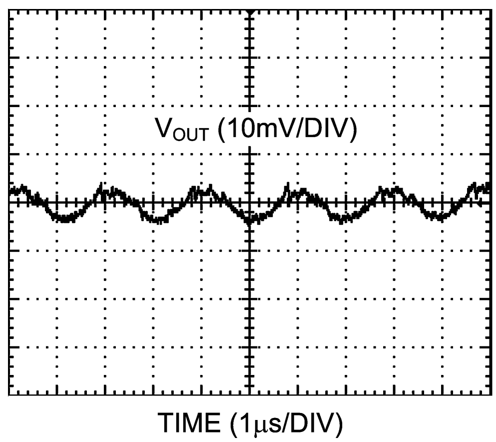


**Figure 3. Output Voltage Ripple**

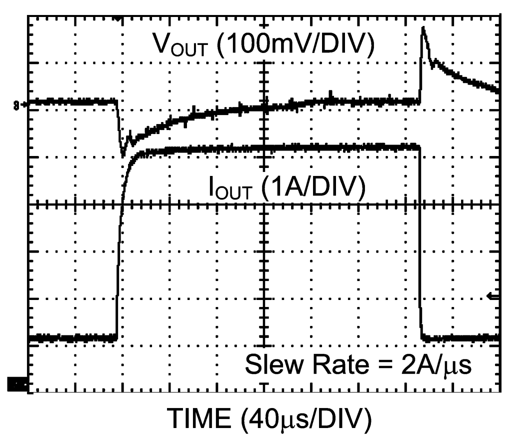


**Figure 4. Transient Response**

## 3 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.

### 3.1 Inductor Selection

The inductor should be sized for approximately 30% ripple current. For $V_{IN}$ = 5V, $V_{OUT}$ = 1.2V, $f_{SW}$ = 750 kHz, and $I_{OUT}$ = 5A, the ideal inductance value can be calculated from equation 1 to be of 0.81 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. Since the purpose of this design is to select the smallest value inductor, values smaller than 0.81 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-1R0M120 inductor was selected. This 1 µH inductor results in a peak-to-peak ripple current of 1.22 A when the converter is operating from 5V and 3.3V. For the this design, the TDK SPM6530T-1R0M120 inductor offers a good balance between efficiency (7.1 mΩ DCR), size, and saturation current rating (12A $I_{SAT}$ rating).

### 3.2 Output Capacitor Selection

A Sanyo 680 µF POSCAP capacitor with 18 mΩ of series resistance (ESR) is selected for the output capacitor to provide good transient and DC performance in a relatively small package. To further reduce the output voltage ripple, a 47 µF ceramic capacitor is placed in parallel with the Sanyo POSCAP.

### 3.3 Compensation Selection

The compensation network was selected using the excel design tool (available online) to give a crossover frequency of 91 kHz. For this target crossover frequency, operating conditions, and filter components a value for $C_{C1}$ of 0.68 nF and a value for $R_{C1}$ of 82.5 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 27pF.

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

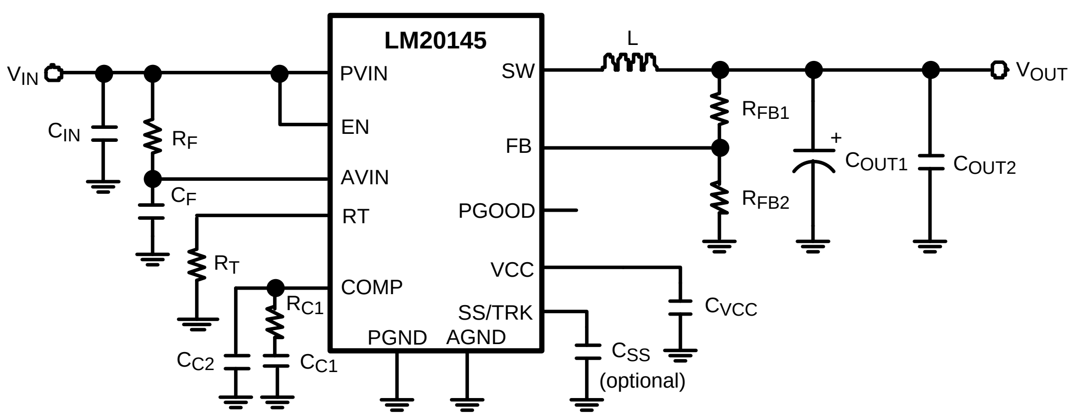


**Figure 5. 1.2V Output Solution Optimized for Load Transients**

**Table 2. Transient Response Bill of Materials ($V_{IN}$ = 5V, $V_{OUT}$ = 1.2V, $I_{OUT(MAX)}$ = 5A, $f_{SW}$ = 750 kHz)**

| Designator | Description | Part Number | Manufacturer | Qty |
|---|---|---|---|---|
| U1 | Synchronous Buck Regulator | LM20145 | Texas Instruments | 1 |
| $C_{IN}$ | 47µF, 1206, X5R, 6.3V | C3216JB0J476M | TDK | 1 |
| $C_{OUT1}$ | 680µF, D4D,POSCAP, 6.3V | 6TPE680MIL | Sanyo | 1 |
| $C_{OUT2}$ | 47µF, 1206, X5R, 6.3V | C3216JB0J476M | TDK | 1 |
| L | 1.0µH, 7.1mΩ | SPM6530T-1R0M120 | TDK | 1 |
| $R_F$ | 1Ω, 0603 | CRCW06031R0J-e3 | Vishay-Dale | 1 |

**Table 2. Transient Response Bill of Materials ($V_{IN}$ = 5V, $V_{OUT}$ = 1.2V, $I_{OUT(MAX)}$ = 5A, $f_{SW}$ = 750 kHz) (continued)**

| Designator | Description | Part Number | Manufacturer | Qty |
|---|---|---|---|---|
| $C_F$ | 1µF, 0603, X7R, 10V | GRM188R71A105KA01 | Murata | 1 |
| $C_{VCC}$ | 1µF, 0603, X7R, 10V | GRM188R71A105KA01 | Murata | 1 |
| $R_{C1}$ | 82.5kΩ,0603 | CRCW06038252F-e3 | Vishay-Dale | 1 |
| $C_{C1}$ | 0.68nF,0603,X7R,25V | VJ0603Y681KXXA | Vishay-Vitramon | 1 |
| $C_{C2}$ | 27pF, 0603,50V,COG | GRM18885C1H2701 | Murata | 1 |
| $C_{SS}$ | 33nF,0603,X7R,25V | VJ0603Y333KXXA | Vishay-Vitramon | 1 |
| $R_{FB1}$ | 4.99kΩ,0603 | CRCW06034992F-e3 | Vishay-Dale | 1 |
| $R_{FB2}$ | 10kΩ, 0603 | CRCW06031002F-e3 | Vishay-Dale | 1 |
| $R_T$ | 48.7kΩ, 0603 | CRCW06034872F-e3 | Vishay-Dale | 1 |

The calculated component PCB area for this design is 134 $mm^2$. The efficiency vs. $I_{OUT}$, output voltage ripple, and transient response are shown below for this solution.

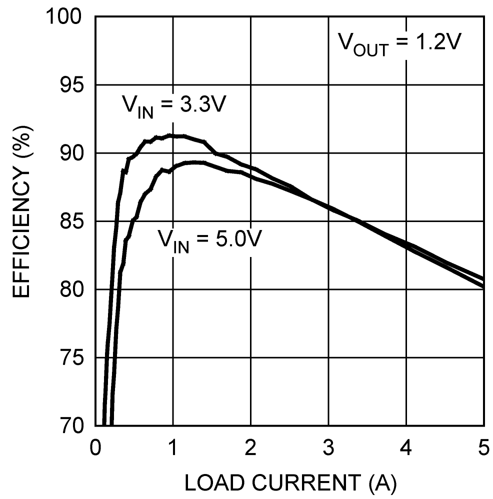


**Figure 6. Efficiency vs $I_{OUT}$**

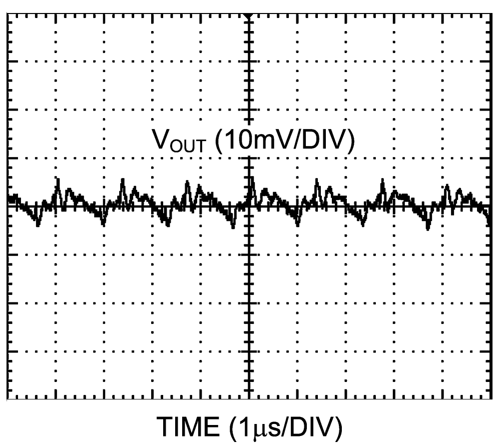


**Figure 7. Output Voltage Ripple**

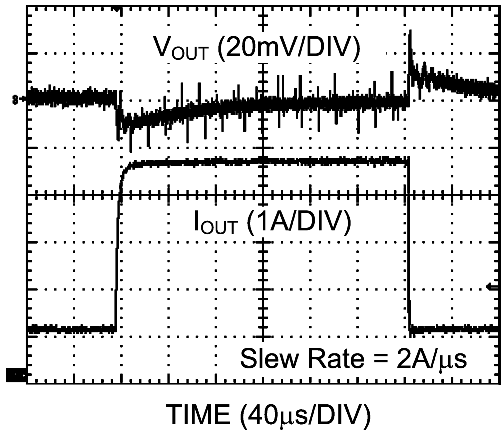


**Figure 8. Transient Response**

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