Application Note

Inverting Buck-Boost Application for the LM63615-Q1

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ABSTRACT

The LM63615-Q1 is a synchronous buck converter with a wide input voltage range from 3.5 V to 36 V and maximum output current of 1.5 A. The LM63615-Q1 can be configured as an inverting buck-boost (IBB) converter with a negative output voltage. This application note demonstrates how the LM63615-Q1 can be used as an inverting buck-boost converter, along with optional design considerations for inverting buck-boost converters such as a PGOOD or EN level-shifter. If higher output current is required, the LM63615-Q1 is pin-to-pin compatible with the 2.5-A rated LM63625-Q1 and the 3.25-A rated LM63635-Q1. The LM63615-Q1 is also pin-to-pin compatible with 1-A rated LM63610-Q1.

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1 Inverting Buck-Boost Topology

1.1 Concept

For the standard buck converter, the inductor is connected to V_{OUT} and the switch pin (SW) of the LM63615-Q1. To change to an inverting buck-boost topology, the V_{OUT} and ground nodes of the circuit must be reversed. With the nodes reversed, the LM63615-Q1 can now invert the output voltage from the input voltage.

To change an LM63615-Q1 buck converter to an inverting buck-boost, reassign the buck converter V_{OUT} to system ground, and the old buck system ground to $-V_{OUT}$. The input capacitor will need to be reconnected to the new system ground, and a new bypass capacitor, C_{IO}, is needed between V_{IN} and $-V_{OUT}$. The positive input and the feedback resistors will remain the same as in the buck converter. To adjust the output of the inverting buck-boost, calculate the feedback resistor values as if it was a buck converter. For further reading on the inverting buck-boost topology, refer to the *Working with Inverting Buck-Boost Converters* application note. The schematics in Figure 1-1 show the changes that have to be made when configuring the LM63615-Q1 buck converter as an inverting buck-boost converter.

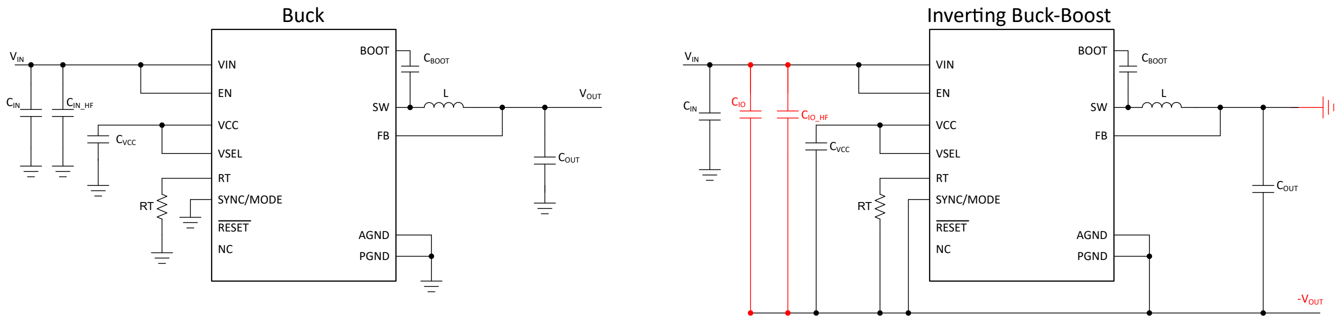


Figure 1-1. Converting From Buck to Inverting Buck-Boost Topology

1.2 Output Current Calculations

Changing to an inverting buck-boost topology will have an impact on the maximum possible output current. For an inverting buck-boost converter, the inductor current will always be larger than the output current. As a result, the maximum possible output current is calculated by:

$$I_{OUT}(IBB) = I_{OUT\_Buck} \times (1 - D) \tag{1}$$

where:

- I_{OUT_Buck} is the maximum buck converter DC output current
- D is the duty cycle

The duty cycle can be calculated as:

$$D = \frac{Vout}{Vout - Vin \times \eta} \tag{2}$$

V_{OUT} is represented as the negative output voltage of the inverting buck-boost converter. The efficiency term in the duty cycle equation helps account for power losses to provide a more accurate calculation of the output current. For example, if the output voltage is -5 V, the input voltage is 24 V, and the efficiency is assumed to be 85%, then the duty cycle is:

$$D = \frac{-5}{-5 - 24 \times 0.85} = 0.197 \tag{3}$$

In the case of the LM63615-Q1, which has a maximum current of 1.5 A, the resulting maximum output current of the inverting buck-boost converter would be:

$$I_{OUT}(IBB) = 1.5\ A \times (1 - 0.197) = 1.205\ A \tag{4}$$

Table 1-1. Maximum Output Current Calculations for the LM63615-Q1

V_{OUT} (V)	V_{IN} (V)	IOUT_Buck (A)	η	D	I_{OUT} (A)
–3.3	24	1.5	0.85	0.139	1.291
–5	24	1.5	0.85	0.197	1.205

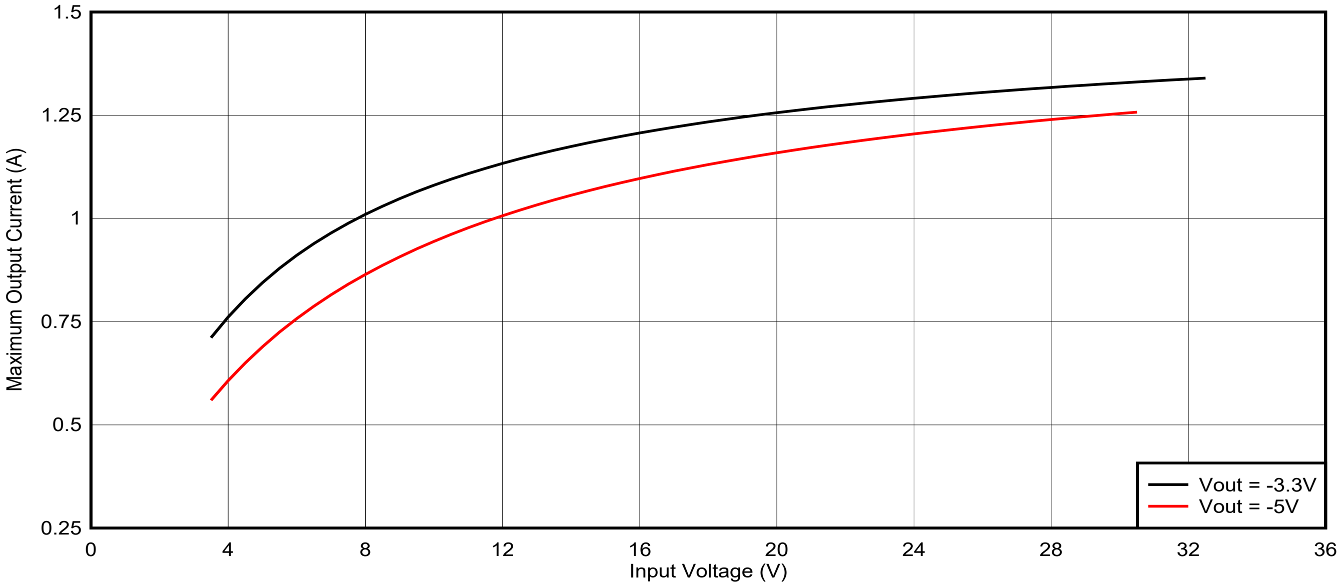


Figure 1-2. Maximum Output Current Calculations for the LM63615-Q1 with Assumed 85% Efficiency

1.3 Voltage Range of Inverting Buck-Boost Configuration

When using a buck converter as an inverting buck-boost, the connection changes limit the voltage range from input to output that the part can safely operate at. The ground (GND) pin of the IC is no longer referenced to 0 V, and it is now the output of the converter. As a result, the maximum voltage over the IC can be calculated as V_{IN} minus -V_{OUT}. For example, if the input voltage is 24 V and the output is -24 V, then the voltage over the IC is 48 V. In the case of the LM63615-Q1, this configuration would exceed the maximum input voltage of 36 V across the part listed in the data sheet. It is important to keep the input and output voltage difference within the maximum voltage rating of the IC.

2 Design Considerations

2.1 Bypass Capacitor and Optional Schottky Diode

A new bypass capacitance, from V_{IN} to $-V_{OUT}$ is used to help with load transients. The values for the bypass capacitance, C_{IO} and C_{IO_HF}, can be chosen using input capacitance recommendations from the buck data sheet, but it is important to note that the voltage across the capacitors will be V_{IN} + $|-V_{OUT}|$. The capacitors used must be appropriately sized for the voltage difference between V_{IN} and $-V_{OUT}$. When the input supply is turned on, the bypass capacitance can cause the output to shortly swing positive before becoming negative. If the desired load is sensitive to a positive swing, then an optional Schottky diode can be placed across the output to clamp the voltage.

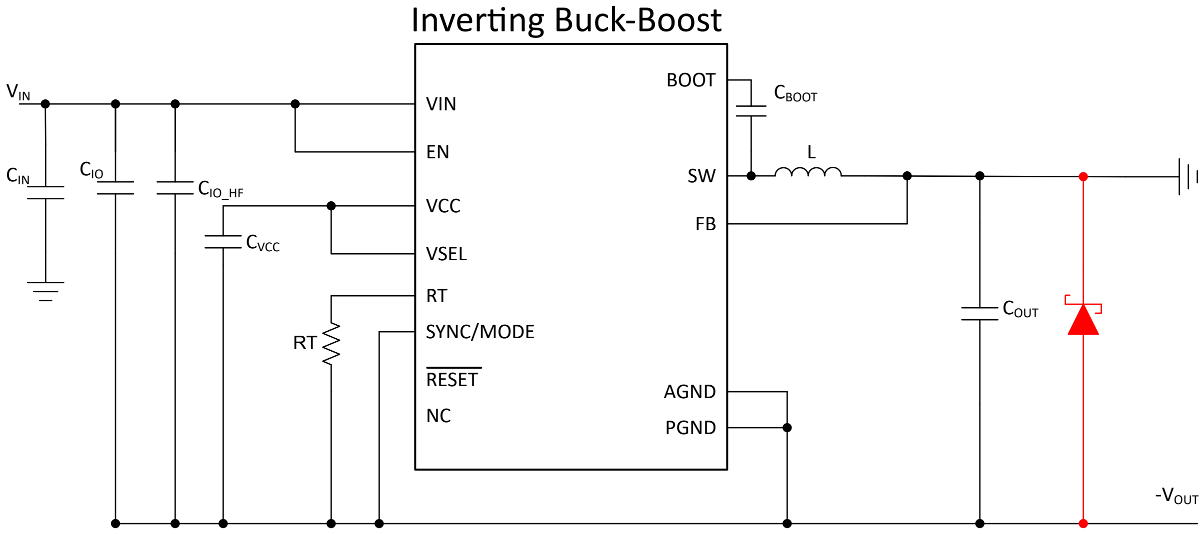


Figure 2-1. LM63615-Q1 Inverting Buck-Boost with Optional Schottky Diode

3 External Components

The LM63615-Q1 has integrated power MOSFETs and requires an inductor, input capacitance, and output capacitance. Feedback resistors might or might not need to be used depending on the application. In this application, the output voltage select pin (VSEL) is tied to either VCC or AGND depending on the desired output voltage. If an adjustable output voltage is required, the feedback pin (FB) can be connected with feedback resistors to choose a specific output voltage. The adjustable output can be used to improve the system loop response by placing a feed-forward capacitor, C_{FF}, across the top feedback resistor. Refer to the data sheet for proper sizing of C_{FF}.

3.1 Capacitor Selection

The capacitance values for C_{IO} and the high frequency capacitor C_{IO_HF} can follow the data sheet recommendations for input capacitance when using the LM63615-Q1 as a buck converter. When using the LM63615-Q1, it is important to include a 220-nF high frequency ceramic capacitor, per data sheet recommendations, as part of the bypass capacitance that is connected as closely to the input of the regulator as possible. An additional C_{IN} capacitance can be added to the inverting buck-boost as necessary. If needed, C_{IO} and C_{IN} can be increased. The output capacitance can also follow buck converter data sheet recommendations, but might need to be increased to improve performance.

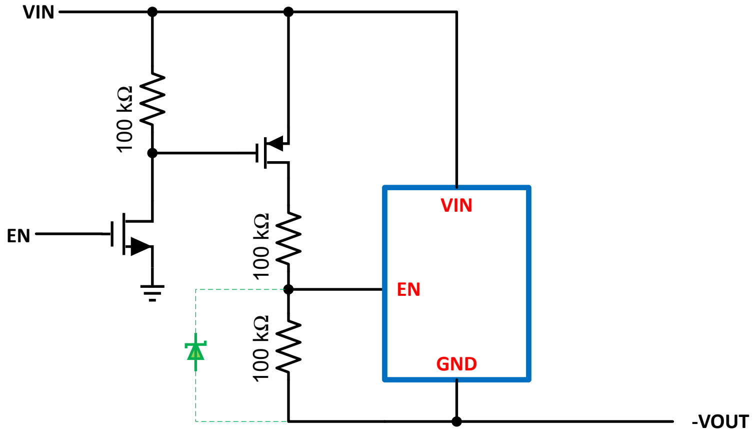
4 Digital Pin Configurations

4.1 Optional Enable (EN) Level Shifter

Since the ground of the buck converter IC is now referenced to the negative output voltage, a level shifter is required if a control signal is to be used on the enable pin. An example circuit is shown in Figure 4-1 that can be used to level shift an incoming enable signal. While the circuit requires two transistors, it has no hysteresis and requires no current from the control signal. If the enable pin is not rated for the full input voltage range, then a Zener diode must be used to clamp the enable pin below its maximum voltage. The enable pin needs to be configured properly even without a control signal, and the buck converter data sheet can be referenced for the proper connection of the EN pin.

When the enable signal is pulled low, then the NMOS switch is turned off, pulling the gate of the PMOS to V_{IN}. The PMOS then turns off, pulling the enable pin below the high-level threshold.

When the enable signal is pulled high, the NMOS switch is turned on, pulling the gate of the PMOS low. The PMOS then turns on, pulling the enable pin above the high level threshold from V_{IN}.



-VOUT is the negative output voltage of the inverting buck-boost converter

Figure 4-1. EN Pin Level Shifter

4.2 Power-Good (PG) Pin

Similar to EN, the power good flag needs to be level shifted if it is used for an inverting buck-boost application. The circuit shown in Figure 4-2 can be used to level shift the PGOOD logic as a signal that swings to zero volts. When using the circuit, the PGOOD pin needs to be rated for $|V_{OUT}|$.

When the internal PGOOD switch turns off, the gate of the first external MOSFET is pulled to ground, causing the MOSFET to turn on. With the first MOSFET on, the gate of the second MOSFET is pulled to $-V_{OUT}$, turning the second MOSFET off. With the second switch off, the PGOOD node is pulled to the logic voltage.

When the internal PGOOD switch turns on, the gate of the first external MOSFET is pulled to $-V_{OUT}$, turning off the MOSFET. With the first external MOSFET off, the gate of the second external MOSFET is pulled to the logic voltage of the controller. This causes the second external MOSFET to turn on and pull the PGOOD node to ground. When selecting the external MOSFETs, they must have a V_{GS} rating of at least $|V_{OUT}|$.

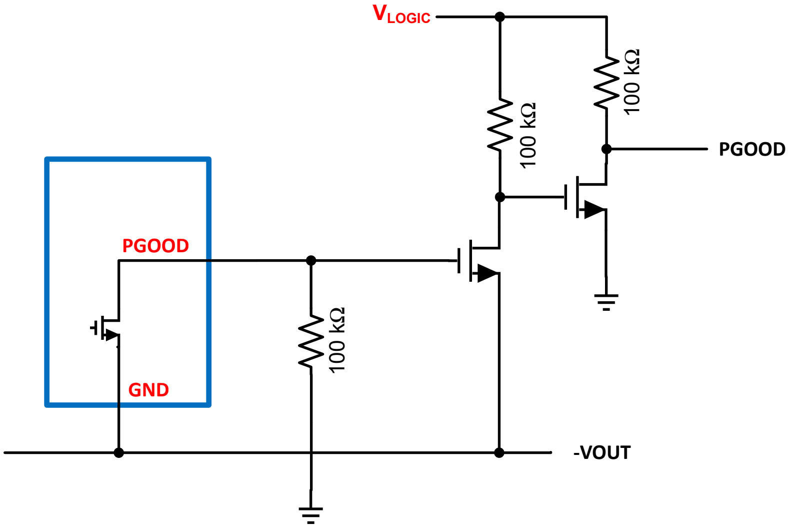


Figure 4-2. PG Pin Level Shifter

5 Typical Performance

5.1 V_{OUT} = -3.3 V, 2.1 MHz Typical Performance

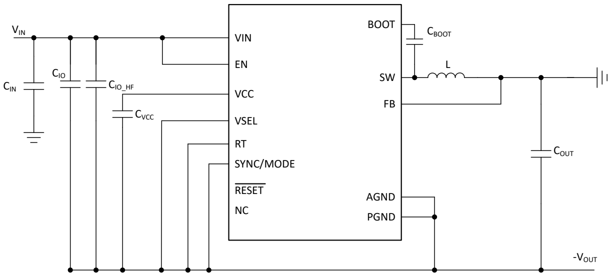
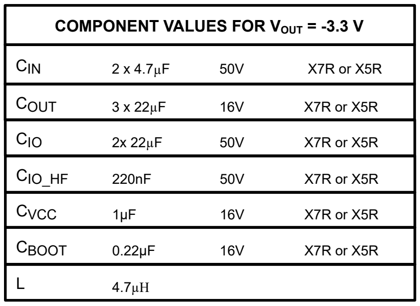
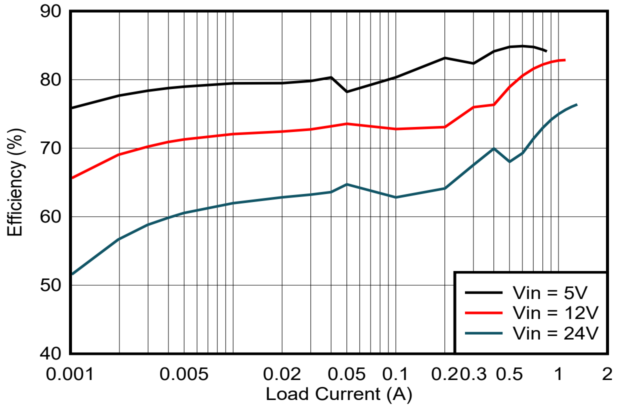


Figure 5-1. Schematic



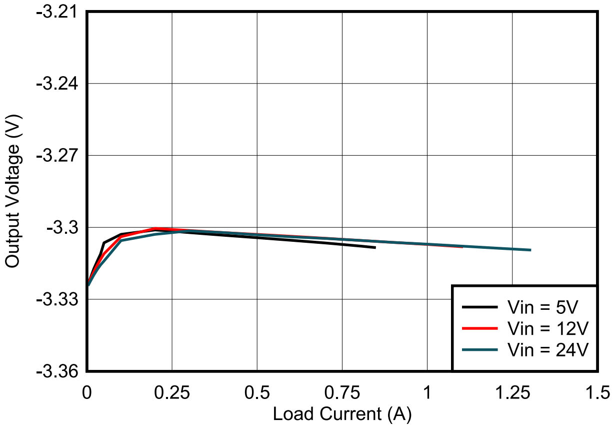
COMPONENT VALUES FOR V_{OUT} = -3.3 V			
C_{IN}	2 x 4.7µF	50V	X7R or X5R
C_{OUT}	3 x 22µF	16V	X7R or X5R
C_{IO}	2x 22µF	50V	X7R or X5R
C_{IO_HF}	220nF	50V	X7R or X5R
C_{VCC}	1µF	16V	X7R or X5R
C_{BOOT}	0.22µF	16V	X7R or X5R
L	4.7µH		

Figure 5-2. Bill of Materials



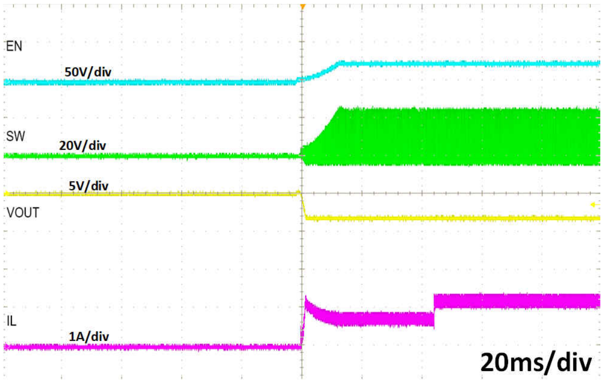
V_{OUT} = -3.3 V F_{SW} = 2.1 MHz (AUTO)

Figure 5-3. Efficiency vs. Load Current



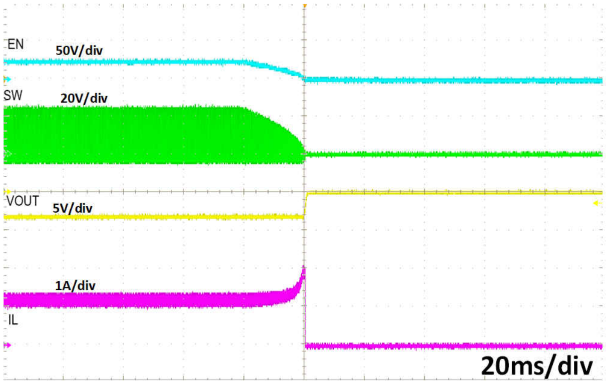
V_{OUT} = -3.3 V F_{SW} = 2.1 MHz (AUTO)

Figure 5-4. Load Regulation vs. Load Current



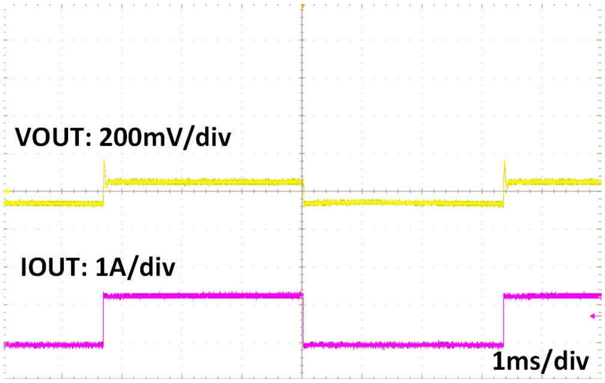
V_{OUT} = -3.3 V I_{LOAD} = 1 A

Figure 5-5. Startup at V_{IN} = 24 V



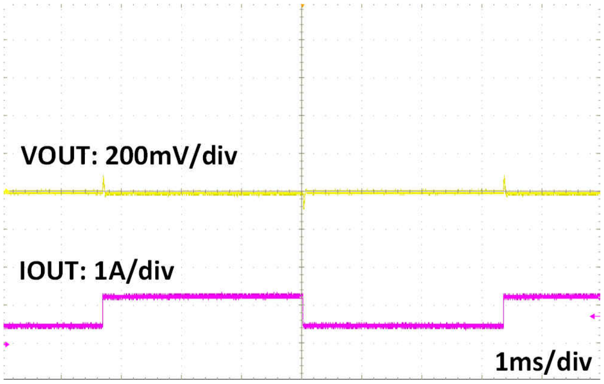
V_{OUT} = -3.3 V I_{LOAD} = 1 A

Figure 5-6. Shutdown at V_{IN} = 24 V



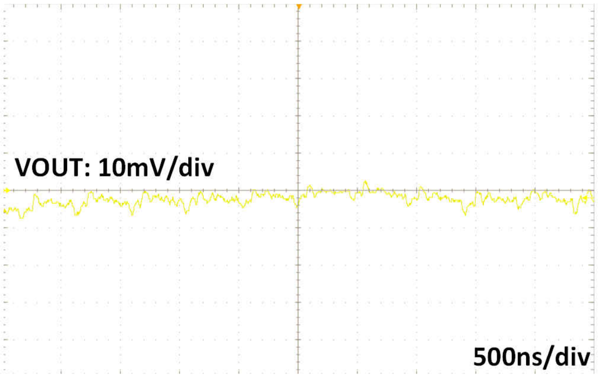
V_{OUT} = -3.3 V I_{LOAD} = 0 A to 1.3 A

Figure 5-7. Full Load Transient at V_{IN} = 24 V



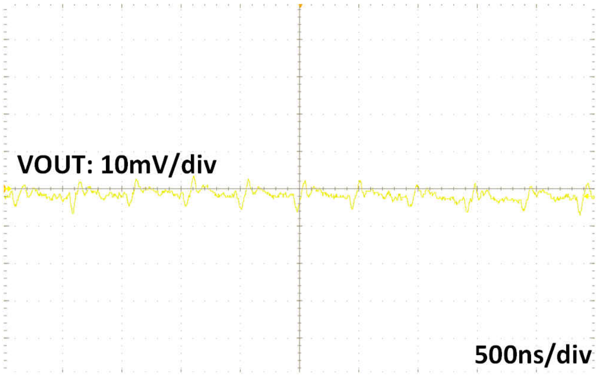
V_{OUT} = -3.3 V I_{LOAD} = 500 mA to 1.3 A

Figure 5-8. Load Transient at V_{IN} = 24 V



V_{OUT} = -3.3 V I_{LOAD} = 1.13 A

Figure 5-9. Full Load Output Ripple at V_{IN} = 12 V



V_{OUT} = -3.3 V I_{LOAD} = 1.3 A

Figure 5-10. Full Load Output Ripple at V_{IN} = 24 V

5.2 V_{OUT} = -3.3 V, 400 kHz Typical Performance

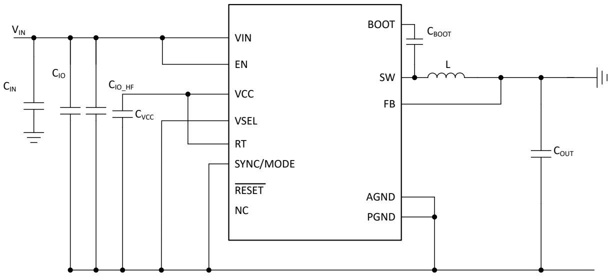
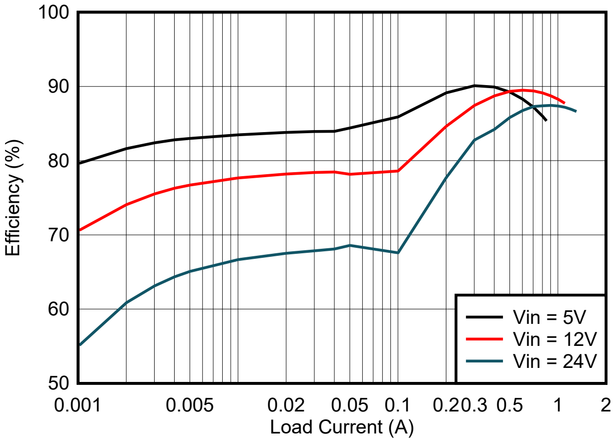


Figure 5-11. Schematic

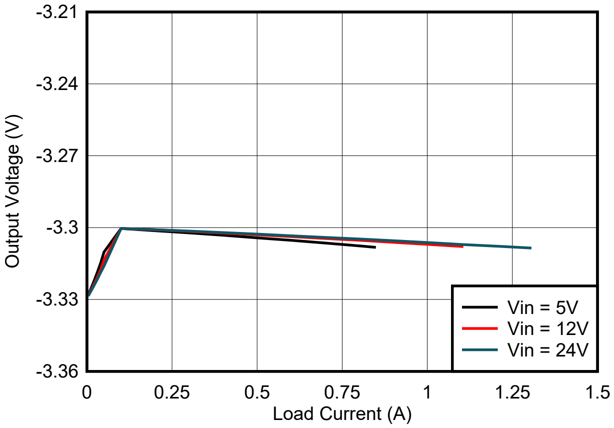
COMPONENT VALUES FOR V_{OUT} = -3.3 V			
C_{IN}	2 x 4.7µF	50V	X7R or X5R
C_{OUT}	3 x 22µF	16V	X7R or X5R
C_{IO}	2x 22µF	50V	X7R or X5R
C_{IO_HF}	220nF	50V	X7R or X5R
C_{VCC}	1µF	16V	X7R or X5R
C_{BOOT}	0.22µF	16V	X7R or X5R
L	10µH		

Figure 5-12. Bill of Materials



V_{OUT} = -3.3 V F_{SW} = 400 kHz (AUTO)

Figure 5-13. Efficiency vs. Load Current



V_{OUT} = -3.3 V F_{SW} = 400 kHz (AUTO)

Figure 5-14. Load Regulation vs. Load Current

5.3 V_{OUT} = -5 V, 2.1 MHz Typical Performance

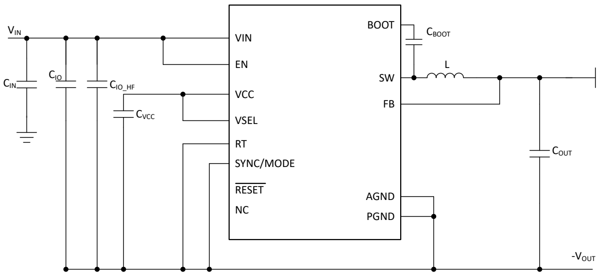
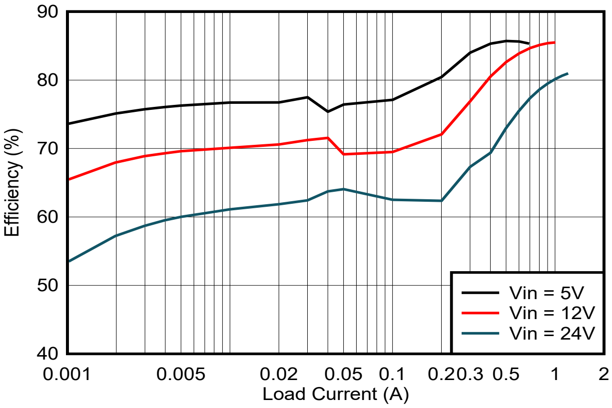


Figure 5-15. Schematic

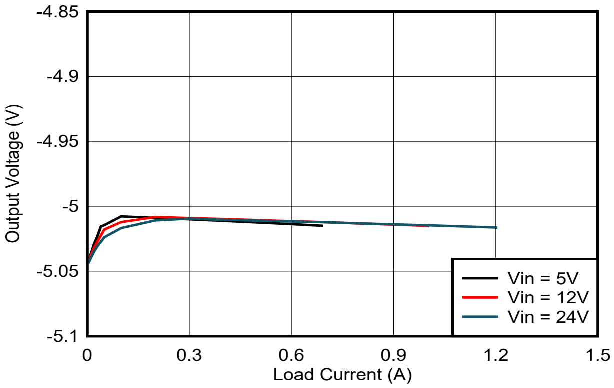
COMPONENT VALUES FOR V_{OUT} = -5 V			
C_{IN}	2 x 4.7µF	50V	X7R or X5R
C_{OUT}	3 x 22µF	16V	X7R or X5R
C_{IO}	2x 22µF	50V	X7R or X5R
C_{IO_HF}	220nF	50V	X7R or X5R
C_{VCC}	1µF	16V	X7R or X5R
C_{BOOT}	0.22µF	16V	X7R or X5R
L	4.7µH		

Figure 5-16. Bill of Materials



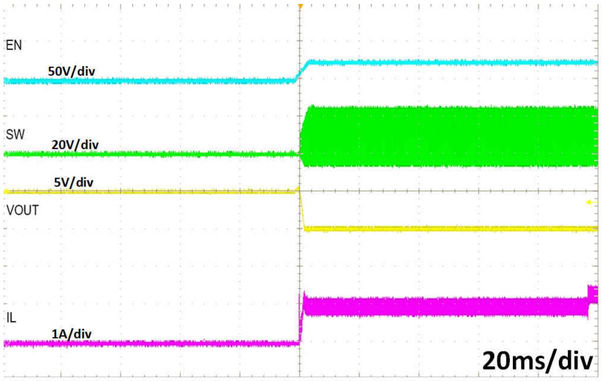
V_{OUT} = -5 V F_{SW} = 2.1 MHz (AUTO)

Figure 5-17. Efficiency vs. Load Current



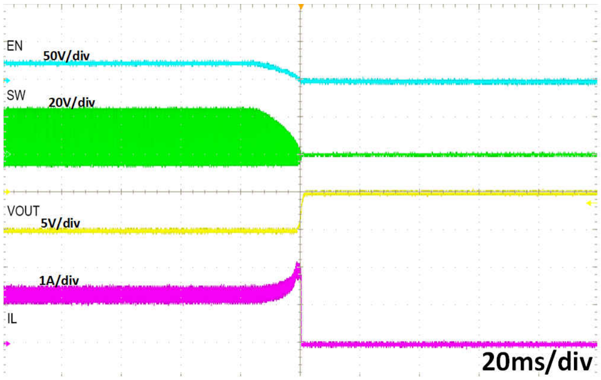
V_{OUT} = -5 V F_{SW} = 2.1 MHz (AUTO)

Figure 5-18. Load Regulation vs. Load Current



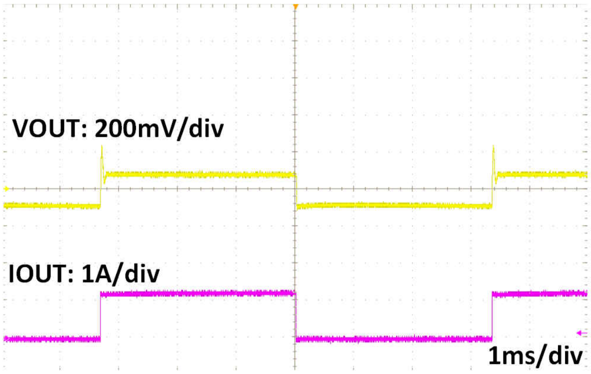
V_{OUT} = -5 V I_{LOAD} = 1 A

Figure 5-19. Startup at V_{IN} = 24 V



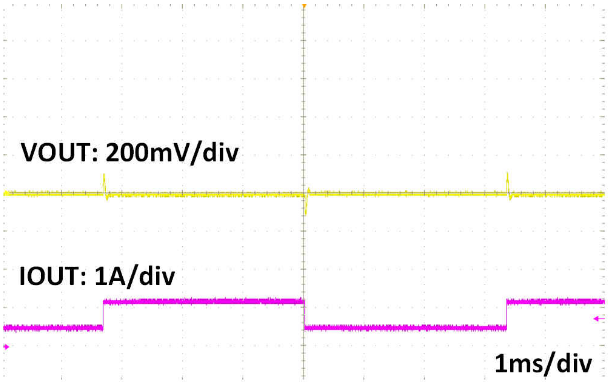
V_{OUT} = -5 V I_{LOAD} = 1 A

Figure 5-20. Shutdown at V_{IN} = 24 V



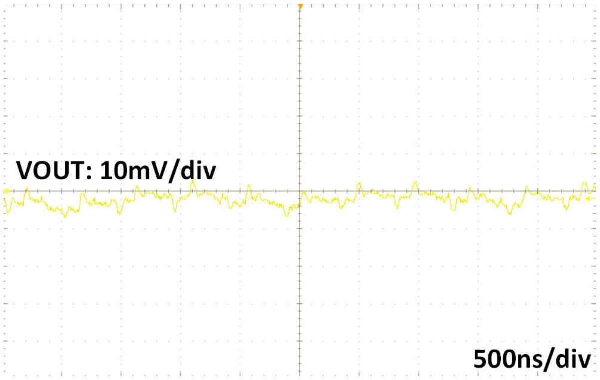
V_{OUT} = -5 V I_{LOAD} = 0 A to 1.2 A

Figure 5-21. Full Load Transient at V_{IN} = 24 V



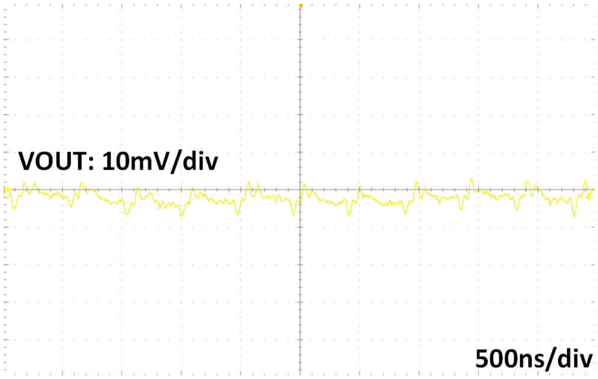
V_{OUT} = -5 V I_{LOAD} = 500 mA to 1.2 A

Figure 5-22. Load Transient at V_{IN} = 24 V



V_{OUT} = -5 V I_{LOAD} = 1 A

Figure 5-23. Full Load Output Ripple at V_{IN} = 12 V



V_{OUT} = -5 V I_{LOAD} = 1.2 A

Figure 5-24. Full Load Output Ripple at V_{IN} = 24 V

5.4 V_{OUT} = -5 V, 400 kHz Typical Performance

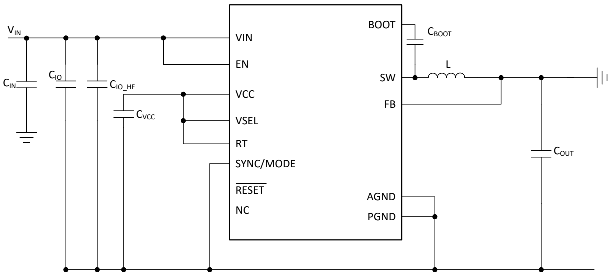
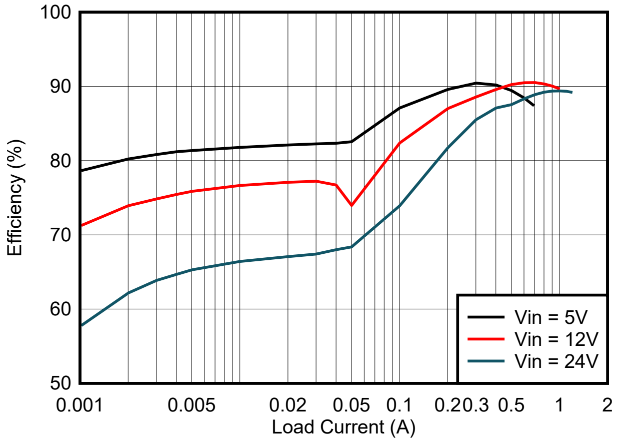


Figure 5-25. Schematic

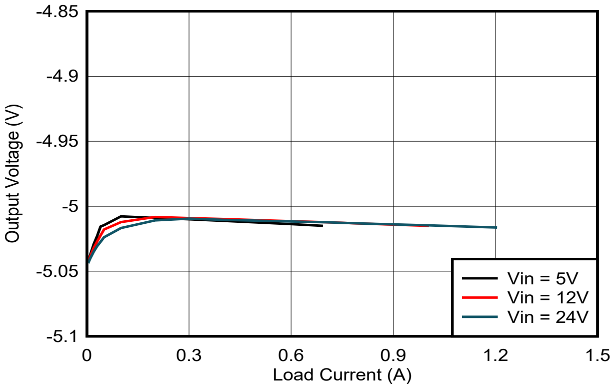
COMPONENT VALUES FOR V_{OUT} = -5 V			
C_{IN}	2 x 4.7µF	50V	X7R or X5R
C_{OUT}	3 x 22µF	16V	X7R or X5R
C_{IO}	2x 22µF	50V	X7R or X5R
C_{IO_HF}	220nF	50V	X7R or X5R
C_{VCC}	1µF	16V	X7R or X5R
C_{BOOT}	0.22µF	16V	X7R or X5R
L	10µH		

Figure 5-26. Bill of Materials



V_{OUT} = -5 V F_{SW} = 400 kHz (AUTO)

Figure 5-27. Efficiency vs. Load Current



V_{OUT} = -5 V F_{SW} = 400 kHz (AUTO)

Figure 5-28. Load Regulation vs. Load Current

6 Conclusion

The LM63615-Q1 is a buck converter that can be configured as an inverting buck-boost (IBB) topology by changing the output voltage and ground connections. Since the IBB is referenced to -V_{OUT} rather than ground, the input voltage range of the LM63615-Q1 is limited depending on the magnitude of -V_{OUT}. The maximum possible output current is also limited since the maximum inductor current is always larger than the maximum output current. This report explains the IBB topology and how to select the external components for a design. Data is provided from a test circuit. For further information on the inverting buck-boost topology, refer to the *Working with Inverting Buck-Boost Converters* application note.

7 References

1. Texas Instruments, *Working with Inverting Buck-Boost Converters* application note.
2. Texas Instruments, *LM636x5-Q1 3.5-V to 36-V, 1.5-A, and 2.5-A Automotive Step-down Voltage Converter* data sheet.
3. Texas Instruments, *LM63635-Q1 3.5-V to 36-V, 3.25-A, Automotive Step-down Voltage Converter* data sheet.
4. Texas Instruments, *LM63610-Q1 3.5-V to 36-V, 1-A, Automotive Step-down Voltage Converter* data sheet.
5. Texas Instruments, *Inverting Application for the LMZM23601 and LMZM23600* application note.
6. Texas Instruments, *Using the TPSM5601R5H-IBB-EVM* users guide.

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