Application Note

SOT236 IBB Application Design with LMR51610

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ABSTRACT

The Invert Buck-Boost (IBB) circuits structure are widely used in systems which require a negative voltage power supply. The SOT package is a cost-effective, and well-established package. This application note provides a detailed design procedure for the LMR51610/06 in an IBB configuration. The newly released SOT23-6 package product LMR51610/06 is a buck convertor in 65 V 1 A/0.6 A with internal loop compensation, which is a good start to verify the typical -5 V and -12 V output for operational amplifiers circuit. LMR51610 maximum input voltage is high up to 65V, this can provide a wider range and more safe power rail for 12 V /24 V system. TI also provide a demo hardware for LMR51610, this will make it convenient to develop an IBB application on SOT236 device with same pinout.

The LMR51610 is introduced in Section 1. The input voltage and output current ranges when a buck converter IC is configured as buck-boost topology in detailed in Section 2. Section 3 provides the method to choose external components. In Section 4, bench performance test result are provided.

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1 Introduction

The LMR51610 regulator is an easy to use synchronous step-down DC-DC converter operating from 4.5-V to 65-V supply voltage. The regulator is capable of delivering up to 1-A DC load current in a very small design size. The family has different versions applicable for different applications, 400-KHz and 1.1-MHz switching frequency, PFM and FPWM, adjustable and fixed output voltage. The LMR51610 employs peak-current mode control with internal loop compensation, which reduces design time, and requires few external components. The family includes the LMR51606 with lower maximum output current.

To convert a buck to an IBB, use the LMR51610EVM as an example. Change Vout to GND and GND to -Vout, notice the device GND is the negative output, but input side system GND in does not change, and needs to be connected to the inductor output side as shown in Figure 1-1.

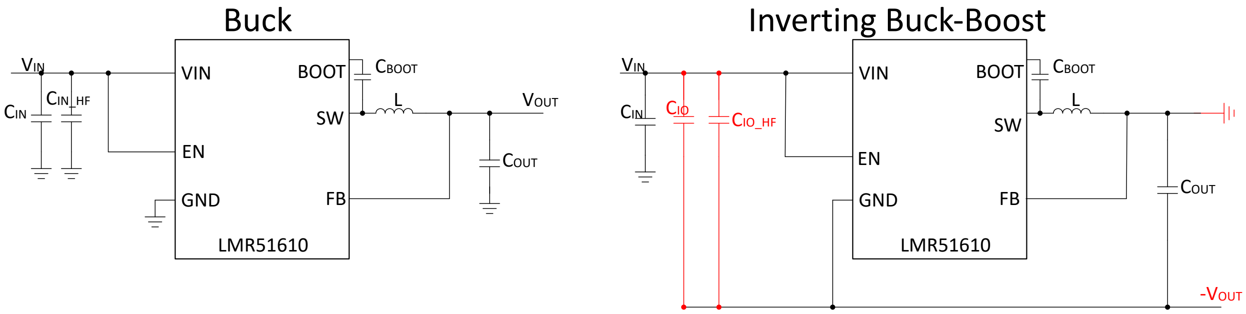


Figure 1-1. Comparison of a Buck Converter and Inverting Buck-Boost Topology With Same IC

2 Specifications

When a buck converter IC is configured as inverting buck-boost topology, the maximum input voltage and output current decreases. The buck IC needs to be chosen to satisfy the application requirement. Take LMR51610 1A device as example in this document.

2.1 Input Voltage Range

The LMR51610 IC can tolerate 65v Vin max voltage, however in the IBB circuit the input voltage ability is not only limited by the device, but also related with the -Vout, use Equation 1 to calculate the input voltage.

$$V_{IN\_max} \le V_{IC\_max} + V_O \tag{1}$$

The minimum operating input voltage of the inverting power supply is the minimum device operating voltage, see Equation 2. For LMR51610 the minimum input voltage is 4 V, so the inverting power supply input voltage must be higher than 4 V.

$$V_{IN\_min} \ge V_{IC\_min} \tag{2}$$

2.2 Output Current Range

The output current capability in the IBB topology is less than the buck configuration. This is because the inductor average current is different from Buck technology, that in buck circuit inductor current is the same as Iout current. As a result, refer to the following equations to choose the device to cover inductor max current in IBB use.

In Equation 4, where I_{OUT} is the maximum output current of the device (I_{OUT} = 1A). The inverting power supply output current limit is calculated as shown in Figure 2-1.Where D is duty cycle of IBB , and take consider the η= 80% for efficiency in Equation 3.

$$D = \frac{Vout}{Vout - Vin*\eta} \tag{3}$$

$$I_{OUT}(IBB) = I_{OUT\_Buck} \times (1 - D) \tag{4}$$

Table 2-1. Maximum Output Current Calculations for LMR51610

V_O (V)	V_{IN} (V)	η	D	I_{OUT} (A)
-12	24	0.8	0.38	0.61
-5	24	0.8	0.20	0.79
-15	24	0.8	0.43	0.56

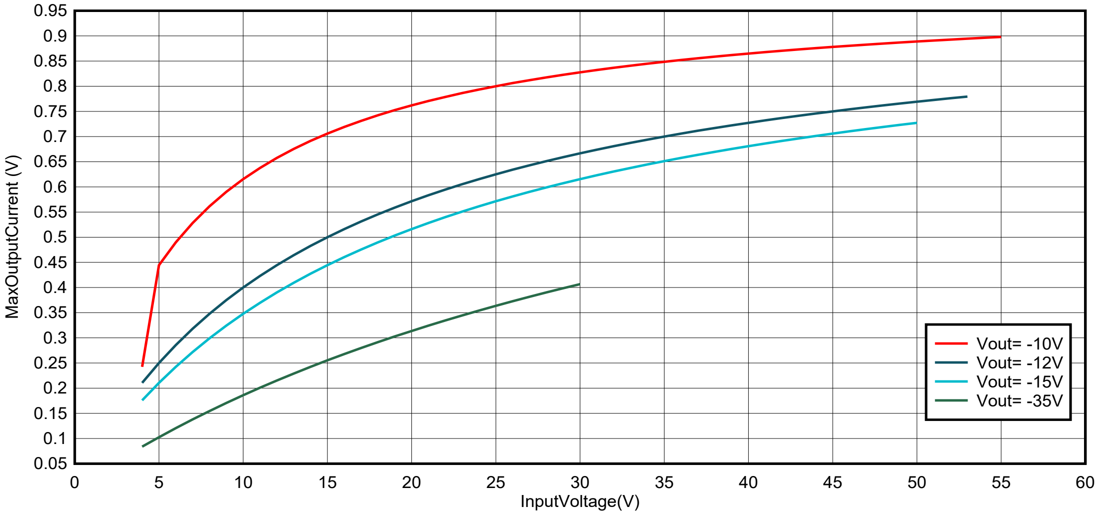


Figure 2-1. Maximum Output Current of the Inverting Power Supply

3 External Component Selection

In this section, the inductor and output capacitor is designed in a practical application. The loop response is considered during the process. Note that V_O is negative in all the equations.

Detailed design procedure is described based on a design example. For this design example, 400 kHz operating frequency LMR51610X is used with design specs as shown in Table 3-1. Figure 3-1 shows the reference design circuit.

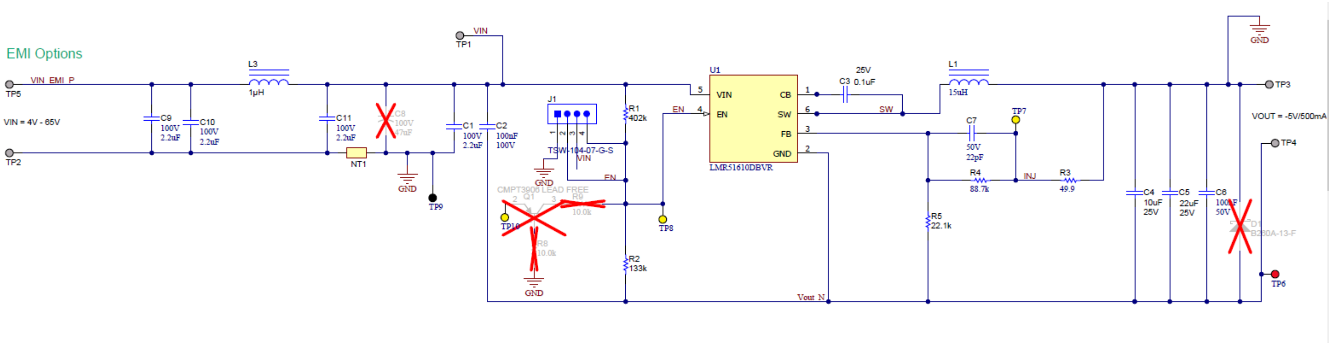


Figure 3-1. Design Example Circuit

Table 3-1. Design Example Specification

V_O (V)	V_{IN} (V)			I_O (A)	f_{SW} (kHz)	Output Voltage Ripple ΔV_O
	V_{IN_min}	V_{IN_norm}	V_{IN_max}			
-12	12	24	48	0.4	400	0.5%*|V_O| = 60 mV

3.1 Duty Cycle Calculation

Duty cycle is calculated using Equation 5. The maximum duty cycle is needed at the minimum input voltage. For example, V_O=-12V, D_{max} = 0.55 at V_{IN_min} = 12V, D_{min} = 0. 23 at V_{IN_max} = 48V, D_{norm} = 0.38 at V_{IN_norm} = 24V.

$$D = \frac{-V_O}{V_{IN} - V_O} \tag{5}$$

3.2 Output Voltage Calculation

The output voltage of the LMR51610 device is same as buck design, Equation 6 is used to determine the output voltage of the converter. Choose the value of RFBB to be 22.1 kΩ. With the desired output voltage set to -12V and the VREF = 0.8 V, the RFBT value can then be calculated using Equation Equation 6. The formula yields to a value 309kΩ .

$$R_{FBT} = \frac{V_{OUT} - V_{REF}}{V_{REF}} \times R_{FBB} \tag{6}$$

Table 3-2. Output Voltage Set Table

V_O (V)	RFBT (kΩ)	RFBT (kΩ)
-3.3	69.8	22.1
-5	118	22.1
-12	309	22.1
-15	392	22.1

3.3 Inductor Selection

Focused on light loading application the designed inductor current ripple is 20% to 40% the inductor average current ,and the total loading with 100mA as example, show SCH in the following.

Notice the current limit is 1.6A for LMR51610. And the max Iout can support for IBB use Equation 7. K_{IND} is a coefficient that represents the amount of inductor ripple current relative to the maximum output current of the device, usually K=0.2 – 0.4. I_{OUT_IC} = 1A for LMR51610. D_{norm} = 0.38 at V_{IN_norm} = 24V, K=0.4, f_{sw} = 400khz, result L=56uH.

$$L_{min} = \frac{V_{IN\_max} \times D_{min}}{f_{SW} \times I_{O\_IC\_max} \times K_{IND}} \tag{7}$$

The LMR51610 is protected from over-current conditions by cycle-by-cycle current limit. To prevent inductor saturation in case of short circuit conditions, the inductor saturation current needs to be greater than the device maximum peak current limit.

3.4 Input and Output Capacitor

The input side is the same as a buck circuit stage, the input cap design can reuse the positive application. In order to perform a low output voltage ripple,2.2-uf ceramic capacitors with low ESR are preferred, and it's better to have X7R act as input and output side, consider the temperature characteristics and DC biases of capacitor. Also a high frequency capacitor 0.1-uf is recommend together with 2.2-uf 100-V input cap put very close to the pin.

High frequency bypass capacitor from Vin to Buck Vout, example as 0.1uf, this can improve the stability and reduce Vout ripple. Because the device GND is the power supply output voltage, the voltage rating of the capacitor must be greater than the differences in the maximum input and output voltage of the power supply, a 0.1-μF, 100-V ceramic capacitor is chosen here for high-frequency filtering and also place it as close as possible to the device pins.

The output capacitance can also follow buck converter data sheet recommendations, but might need to be increased to improve performance. Refer to different output voltage in Table 3-3 give out a min value, start from 22-μF, 25-V as a example.

Table 3-3. LC Table

V_O (V)	Input Cap(uF)	C_{IO} (uF)	Inductor (uH)	Output Cap(uF)
-12	2.2+0.1 uF/100 V	0.1 uF/100 V	68uH	22×2+0.1 uF/25 V
-15	2.2+0.1 uF/100 V	0.1 uF/100 V	100uH	22×3+0.1 uF/25 V

3.5 Enable Level Shift

The LMR51610 has an EN pin to turn the output on and off. The typical threshold voltage of the EN pin specify in LMR51610 data sheet high about 1.27 V and low about 1 V. However, in the inverting buck-boost configuration, EN referenced point is change from device GND to –VOUT voltage. Therefore, the threshold for the EN pin is change to rise is 1.27 V + –VOUT, and the threshold for the EN pin to be considered low is 1 V + -VOUT. For example, if –VOUT = –12 V, EN will be considered high for voltages above –12 V-1.27 V=-10.73V and low for voltages below –12 V+1 V=-11 V. So, in the negative application it is require a voltage of at least 1 V + –VOUT to shutdown the device.

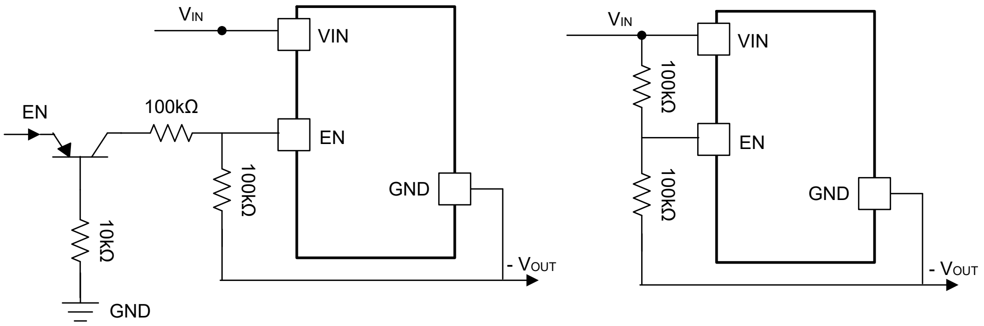


Figure 3-2. EN External Control and EN Control by Vin

3.6 Output Clamp Diode

To prevent the negative output from becoming too positive, a diode across the negative output supply needs to be used. Because there is a cap from Vin to negative output, if large line transients, the current can go through from input cap to LS and inductor return to GND, hence larger spike on negative side show up, adding a diode can help to protect LS from damaged by positive voltage on output. Increase the output cap can also help to solve this problem. See Figure 3-3.

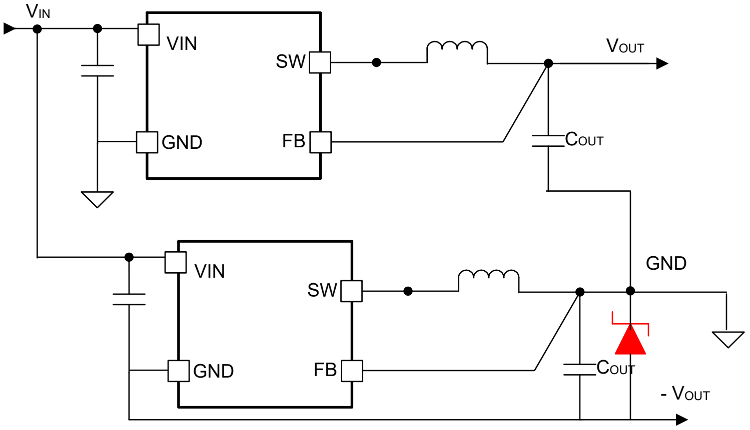
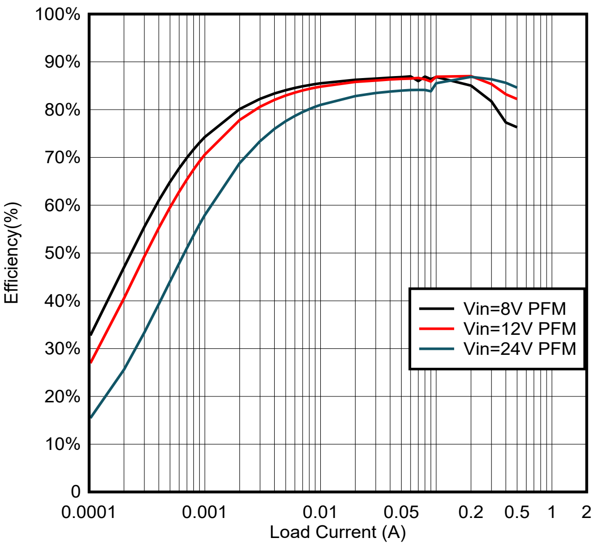


Figure 3-3. Design Negative and Positive Output in one System Circuit

4 Evaluation Results

4.1 Typical Performance

Figure 4-1 to Figure 4-13 show the experimental test results of the Figure 3-1 design. Unless otherwise specified, the following conditions apply: V_{IN} = 24 V, V_O = -12 V, I_O = 0.4 A, T_A = 25 °C.



EffIBB400k5Vout.grf

Figure 4-1. Efficiency vs Load Current Vout=-5 V

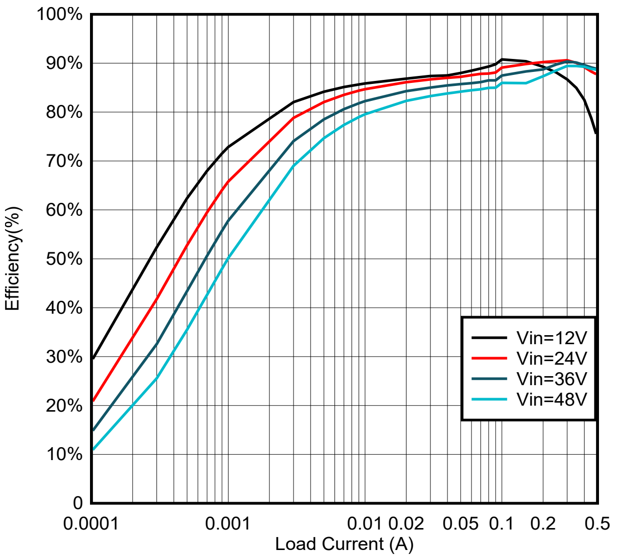
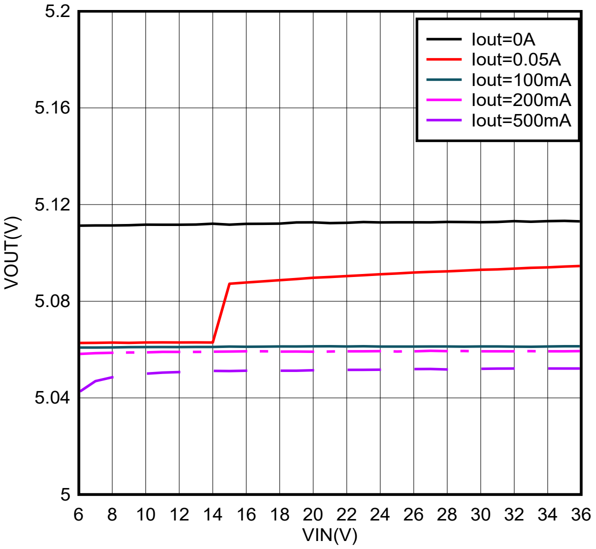


Figure 4-2. Efficiency vs Load Current Vout=-12 V



LineReg5V400khz.grf

Figure 4-3. Line Regulation Vout=-5 V

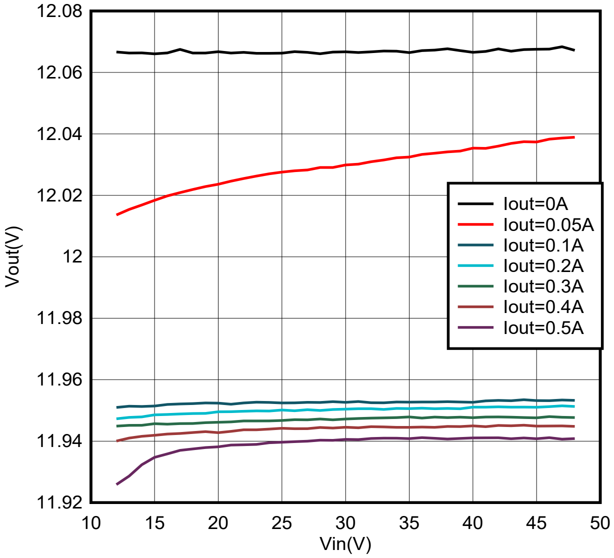


Figure 4-4. Line Regulation Vout=-12 V

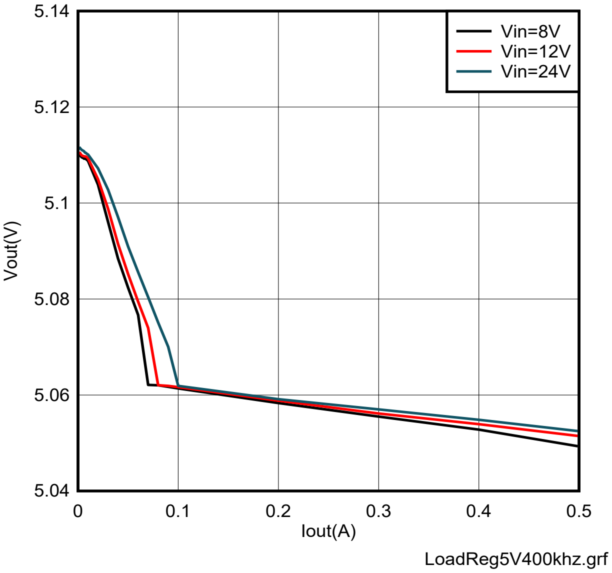


Figure 4-5. Load Regulation Vout=-5 V

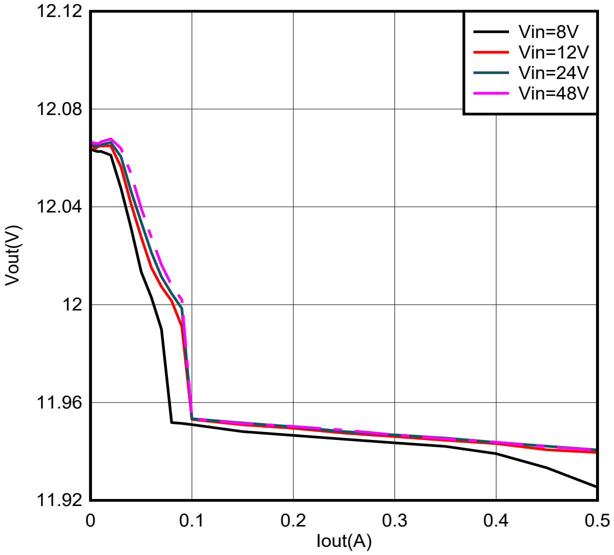


Figure 4-6. Load Regulation Vout=-12 V

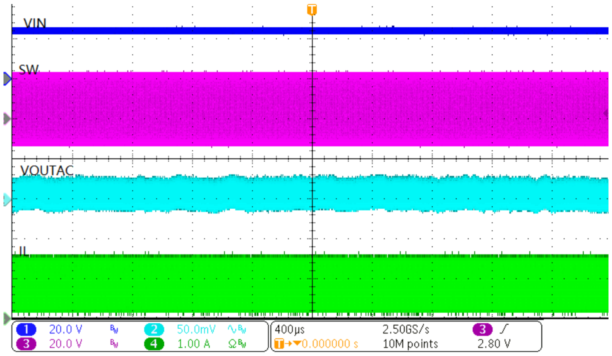


Figure 4-7. Output Voltage Ripple at no Load

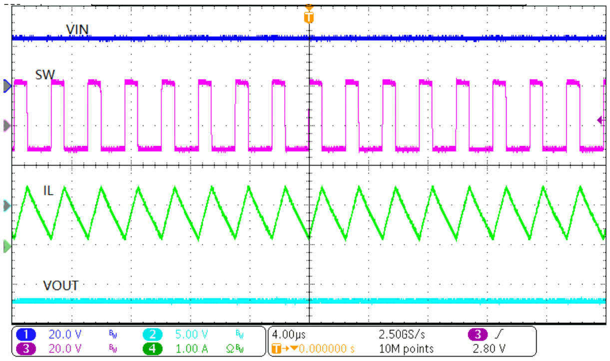


Figure 4-8. Steady States at Full Load 500mA

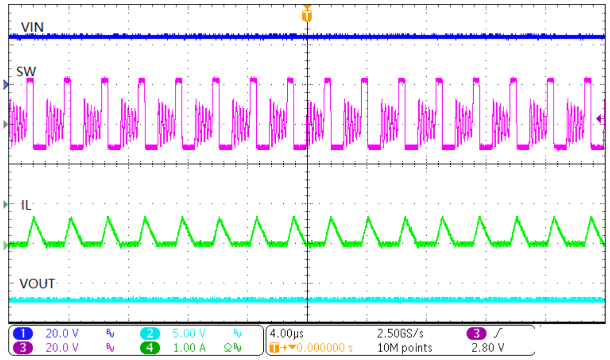


Figure 4-9. Steady States at Light Load 100 mA

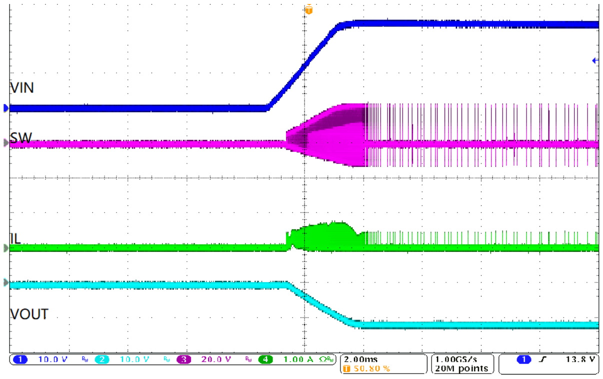


Figure 4-10. Start Up by Vin no Load

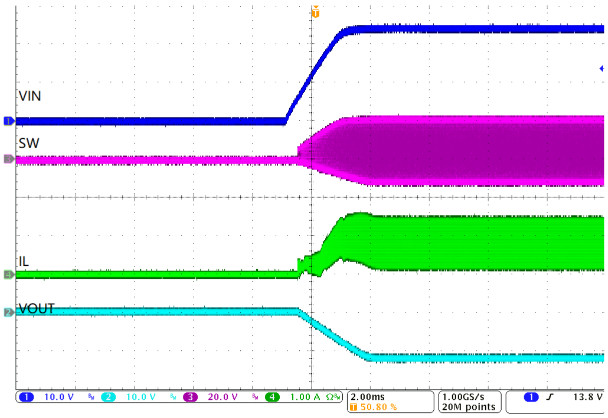


Figure 4-11. Start Up by Vin 500mA Load

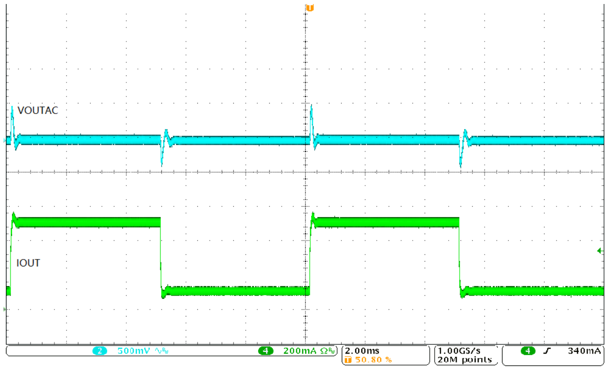


Figure 4-12. Load Transient 100mA to 500mA

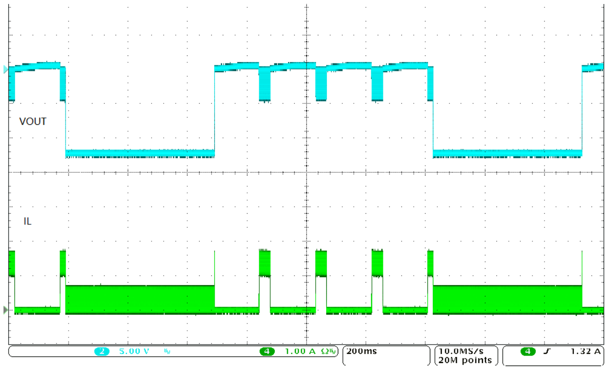
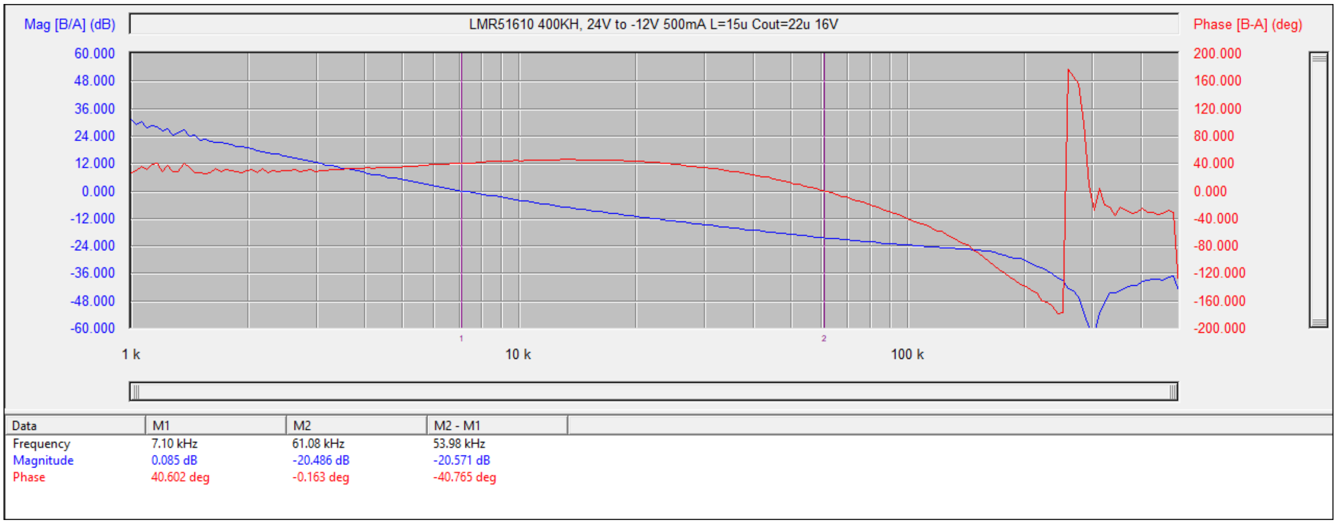


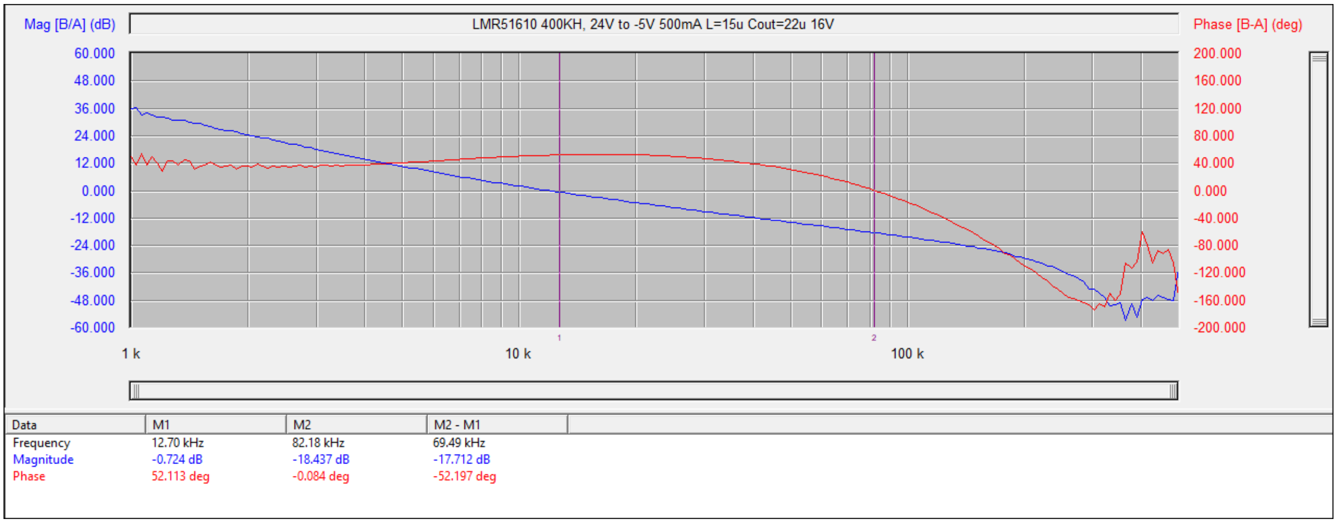
Figure 4-13. Over Current Protection

4.2 Loop Response Bench Verification



Data	M1	M2	M2 - M1
Frequency	7.10 kHz	61.08 kHz	53.98 kHz
Magnitude	0.085 dB	-20.486 dB	-20.571 dB
Phase	40.602 deg	-0.163 deg	-40.765 deg

Figure 4-14. Bode Plot Test Result at V_{IN} = 24V, V_O = -12V, I_O = 0.5 A



Data	M1	M2	M2 - M1
Frequency	12.70 kHz	82.18 kHz	69.49 kHz
Magnitude	-0.724 dB	-18.437 dB	-17.712 dB
Phase	52.113 deg	-0.084 deg	-52.197 deg

Figure 4-15. Bode Plot Test Result at V_{IN} = 24V, V_O = -5V, I_O = 0.5 A

Table 4-1. Loop Test Bench Measurement Results Summary

V_{IN} (V)	V_O (V)	I_O (A)	Measurement Result		
			f_c (kHz)	Gain Margin (dB)	Phase Margin (°)
24	-12	0.5	7.1	-20.4	40.9
48	12	0.5	8.44	-21.2	45
24	-5	0.5	12.7	-18.4	52.13
48	-5	0.5	12.7	-18	52.5

5 Conclusion

The LMR51610 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 -VOUT rather than ground, the input voltage range of the LMR51610 depending on the both input voltage and -VOUT. The maximum possible output current is also limited by input current and output current, because the maximum inductor current is always larger than the maximum output current. This report explains the IBB topology and design example of how to select the external components. Data is provided from a test circuit. For further information on the operation, refer to application note in reference next page.

6 References

1. Texas Instruments, *LMR51610 4-V to 65-V, 1A Synchronous Step-Down Converter,* data sheet.
2. Texas Instruments,*LMR50410 4-V to 36-V, 1A Synchronous Step-Down Converter,* data sheet.
3. Texas Instruments, *LMR51610EVM User's Guide*, user guide.
4. Texas Instruments, *LMR50410EVM User's Guide*, user guide.
5. Texas Instruments, *Working With Inverting Buck-Boost Converters*, application note.
6. Texas Instruments, *Create an Inverting Power Supply Using a Synchronous Step-Down Regulator*, application note.
7. Texas Instruments, *Inverting Buck-Boost Application for the LM63615-Q1*, application note.

7 LMR50410 Design Example

With the same pinout, LMR50410 can be used the same as IBB application in this design, notice the difference is switching frequency, we can design with the same calculation and get the result .

7.1 LMR50410 Output Current Range

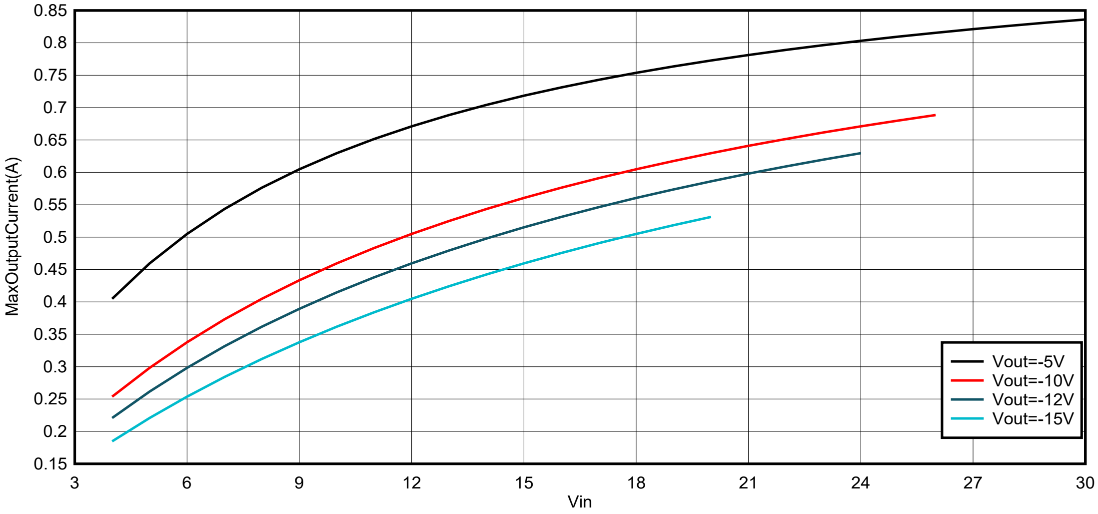


Figure 7-1. Maximum Output Current of the Inverting Power Supply

7.2 LMR50410 Efficiency

Figure 7-2 to Figure 7-4 show the experimental test results of the Figure 3-1 design. Unless otherwise specified, the following conditions apply: V_{IN} = 12V, I_O = 0.4 A, T_A = 25 °C.

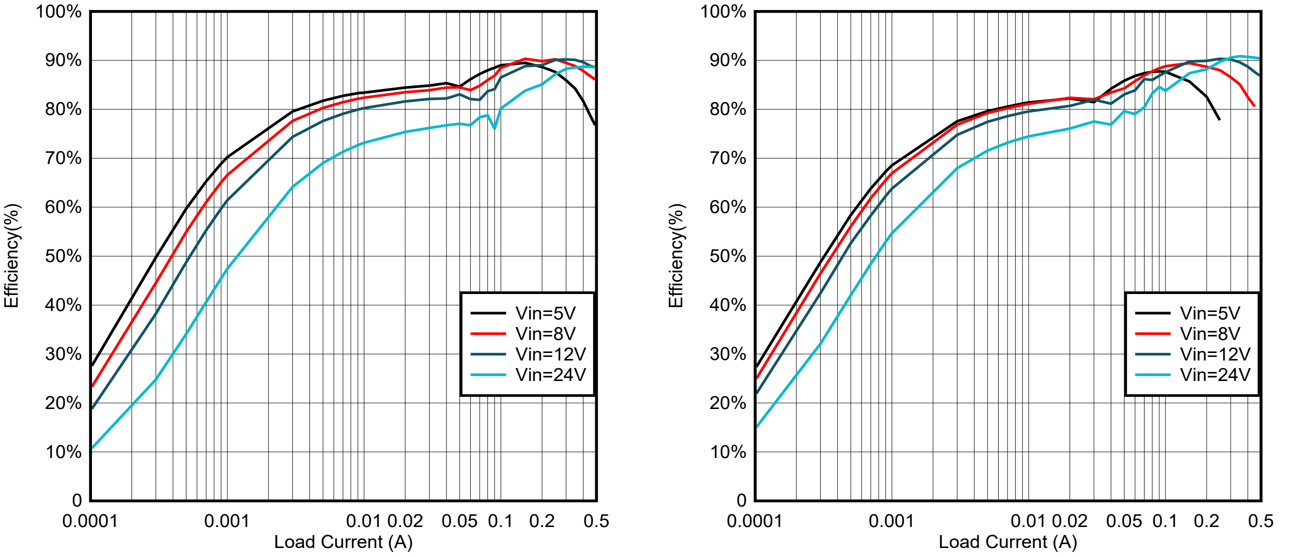


Figure 7-2. Efficiency vs Load Current Vout=-5 V **Figure 7-3. Efficiency vs Load Current Vout=-12 V**

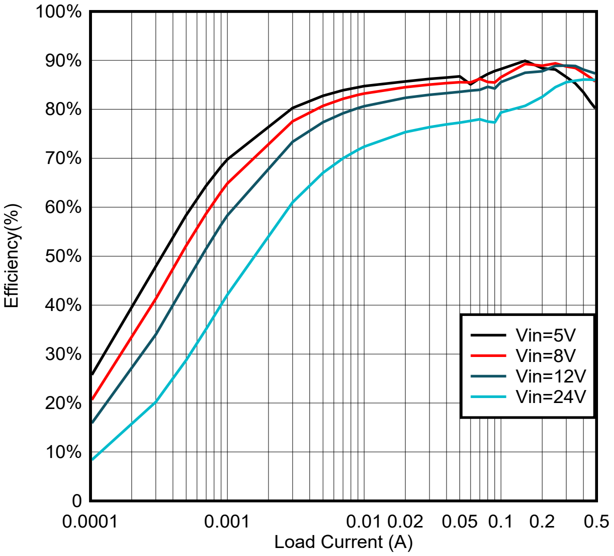


Figure 7-4. Efficiency vs Load Current Vout=-3.3 V

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