Design Example Using the NR111E:

V_{OUT} = 5 V, $I_{OUT(MAX)}$ = 4 A

DC/DC Converter

Contents

1. Introduction

This document describes the design example of a power supply using the NR111E intended for the DC/DC converter that supports a 5 V/4 A (max.) output. The NR111E is a buck converter IC with a built-in power MOSFET. By using the peak current control method, the IC stably operates with a low ESR capacitor such as a ceramic capacitor.

The IC has the protections including overcurrent protection (OCP), undervoltage lockout (UVLO), and thermal shutdown (TSD).

This document contains the following: the specifications of the design example, circuit diagrams, the bill of materials, the setting examples of component constants, a pattern layout example, and the evaluation results of the power supply characteristics. For more details on the parts listed in this document, refer to the corresponding data sheets.

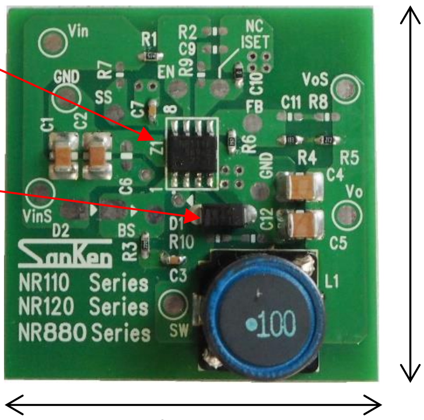
2. Power Supply Features

- Efficiency: 94% (V_{IN} = 9 V, V_O = 5 V, I_O = 1 A)
- Current Mode PWM Control
- Few Components and Small Mounting Area
  Built-in power MOSFET
  Ceramic Capacitor can be used for Output Capacitor
  Built-in Phase Compensation Circuit
- Soft Start Function
  Soft-start Period Adjustment by External Capacitor
- Enable Function
- Protections
  Overcurrent Protections (OCP): Drooping Type, Auto-restart
  Thermal Shutdown (TSD): Auto-restart
  Undervoltage Lockedout (UVLO)

3. Application

- Audio Visual Equipment
- White Goods
- Auxiliary Power Supply
- Other Switched Mode Power Supplies (SMPS)

4. Design Example: Appearance



5. Design Example

5.1 Power Supply Specifications

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Unit
Input						
Input Voltage	V_{IN}		8	—	31	V
Output						
Rated Voltage	V_{OUT}		—	5	—	V
Rated Current[(1)]	I_{OUT}		—	—	4	A
Output Ripple Voltage	V_{RIPPLE}	V_{OUT} = 5 V, I_{OUT} = 4 A, C4 = 22 μF, C5 = 22 μF[(2)]	—	20	—	mV_{P_P}
Efficiency	η	V_{IN} = 9 V, I_{OUT} = 0.5 A, T_A = 25 °C	—	94	—	%
Environment						
Conduction Noise	—	T_A = 25 °C	As per CISPR22B / EN55022B			—
Temperature						
Operating Ambient Temperature[(1)]	T_{OP}		−40	—	85	°C

[(1)] Must be used in the range of thermal derating. For details, refer to the NR111E data sheet.
[(2)] Low ESR ceramic capacitors can be used for C4 and C5.

5.2 Circuit Diagram

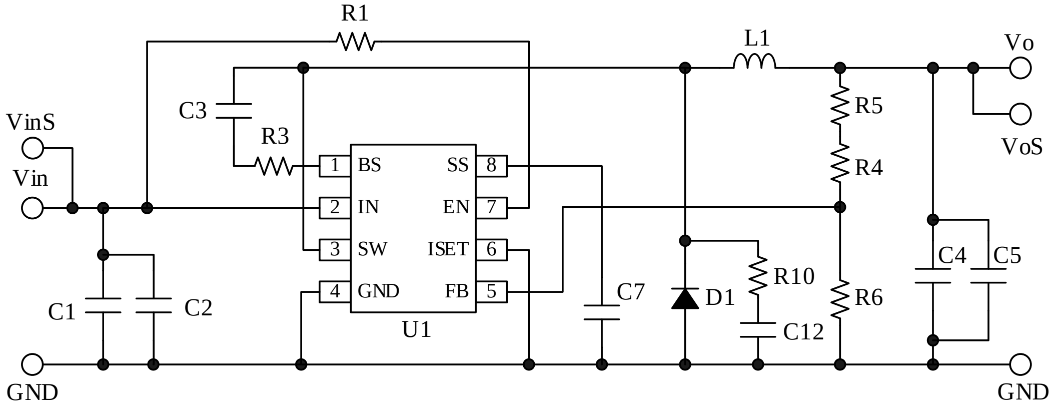


Figure 5-1. Circuit Diagram

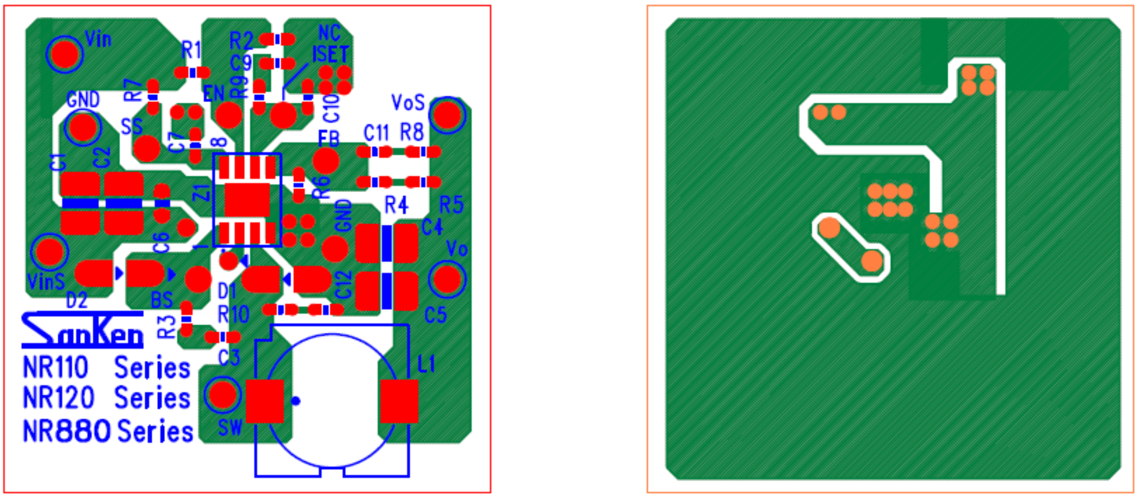
5.3 Bill of Materials

Part Symbol	Part Type	Ratings	Remarks
C1	Chip ceramic capacitor	10 µF, 50 V, 3216	
C2	Chip ceramic capacitor	10 µF, 50 V, 3216	
C3	Chip ceramic capacitor	0.1 µF, 50 V, 1608	
C4	Chip ceramic capacitor	22 µF, 25 V, 3225	Low ESR type
C5	Chip ceramic capacitor	22 µF, 25 V, 3225	Low ESR type
C7	Chip ceramic capacitor	0.1 µF, 50 V, 1608	
C12	Chip ceramic capacitor	Open	Adjustment capacitor
D1	Schottky diode	40 V, 5.0 A	SJPW-T4 (Sanken)
L1	Inductor	10 µH	SLF12575T-100M5R4-P (TDK)
R1	Chip resistor	510 kΩ, 0.1 W, 1608	
R3	Chip resistor	22 Ω, 0.1 W, 1608	
R4	Chip resistor	10 kΩ, 0.1 W, 1608	
R5	Chip resistor	1.5 kΩ, 0.1 W, 1608	
R6	Chip resistor	2.2 kΩ, 0.1 W, 1608	
R10	Chip resistor	Open	Adjustment resistor
U1	Buck Converter IC	eSOIC8	NR111E (Sanken)

5.4 Pattern Layout Example

PCB dimensions: 40 mm × 40 mm.

Note that the pattern layout example only uses the parts illustrated in the circuit diagram below because this board is used for some other products.



(A) Top View (B) Bottom View

Figure 5-2. Pattern Layout Example

6. Performance Data

All the performance data contained in this document were measured at a room temperature. Unless specifically noted, V_{IN} = 12 V, V_{OUT} = 5 V.

6.1 Start/Stop Operation

The NR111E has the undervoltage lockout. Figure 6-1 shows the startup characteristics of output voltage vs. input voltage (i.e., the IN pin voltage). When V_{OUT} = 5 V, the input voltage must be set to ≥8 V.

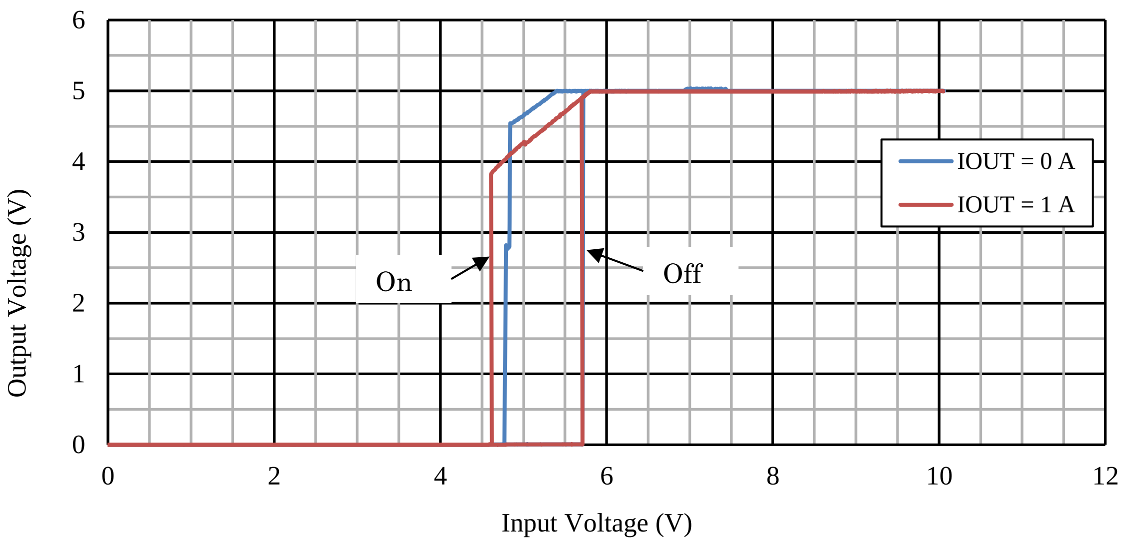


Figure 6-1. Output Voltage vs. Input Voltage

6.2 Overcurrent Protection

The NR111E has the drooping overcurrent characteristic. Figure 6-2 shows the overcurrent characteristics according to the input voltage.

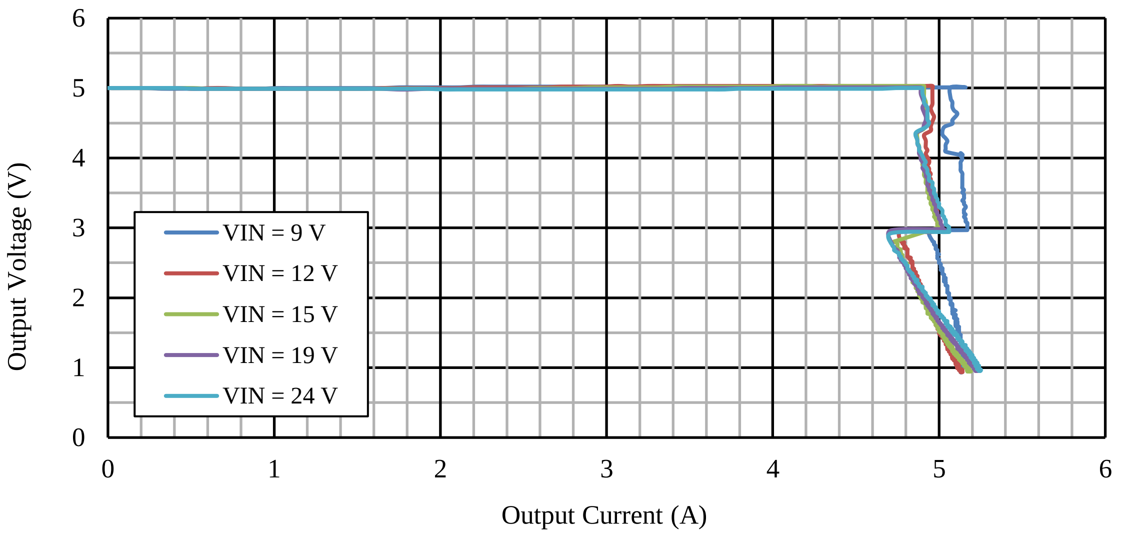


Figure 6-2. Overcurrent Protection Characteristics

6.3 Circuit Current at No Load

Figure 6-3 and Figure 6-4 show the IN pin input voltage dependance at no load (V_{OUT} = 5 V, I_{OUT} = 0 A) in operation and non-opetation, respectively.

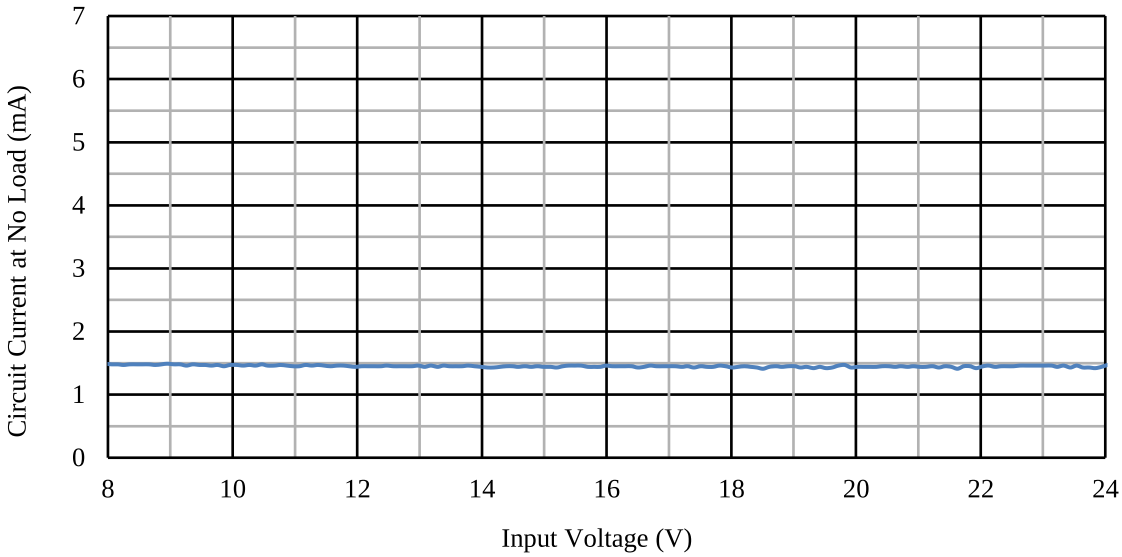


Figure 6-3. Circuit Current at No Load vs. Input Voltage in Operation

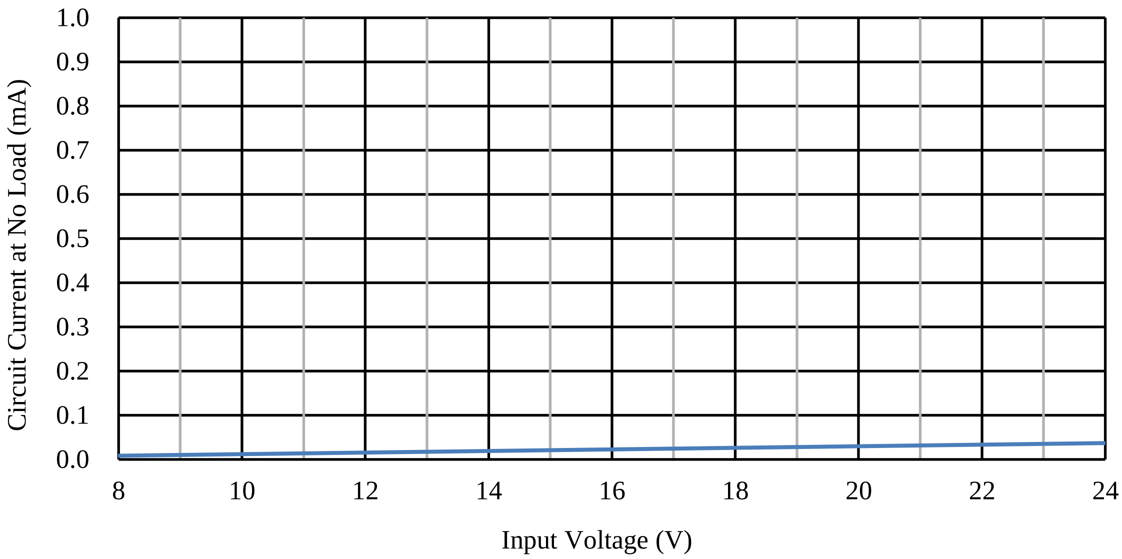


Figure 6-4. Circuit Current at No Load vs. Input Voltage in Non-opetation

6.4 Efficiency

Figure 6-5 shows the characteristics of power supply efficiency vs. output current.

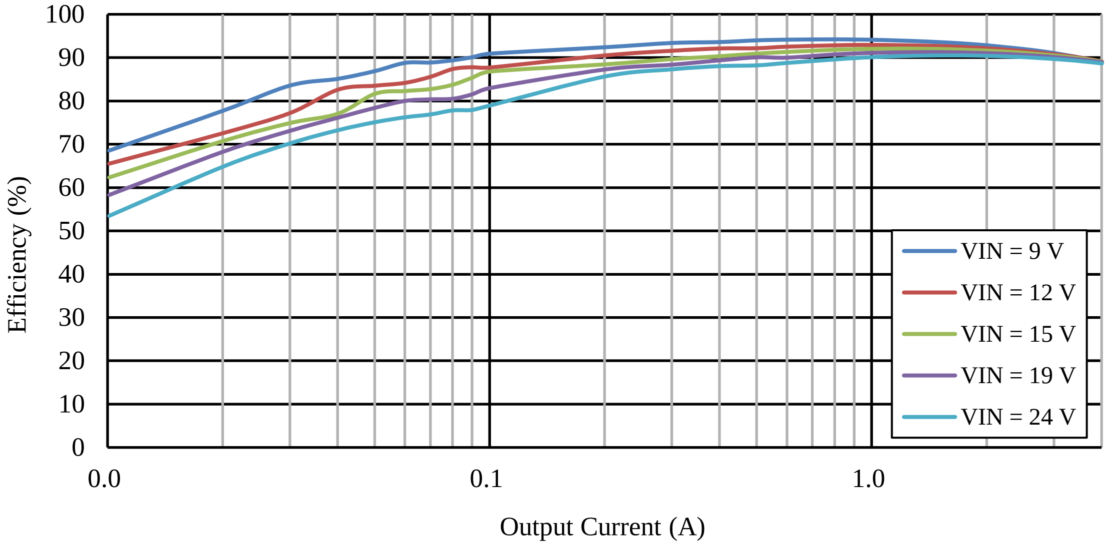


Figure 6-5. Efficiency vs. Output Current

6.5 Load Regulation

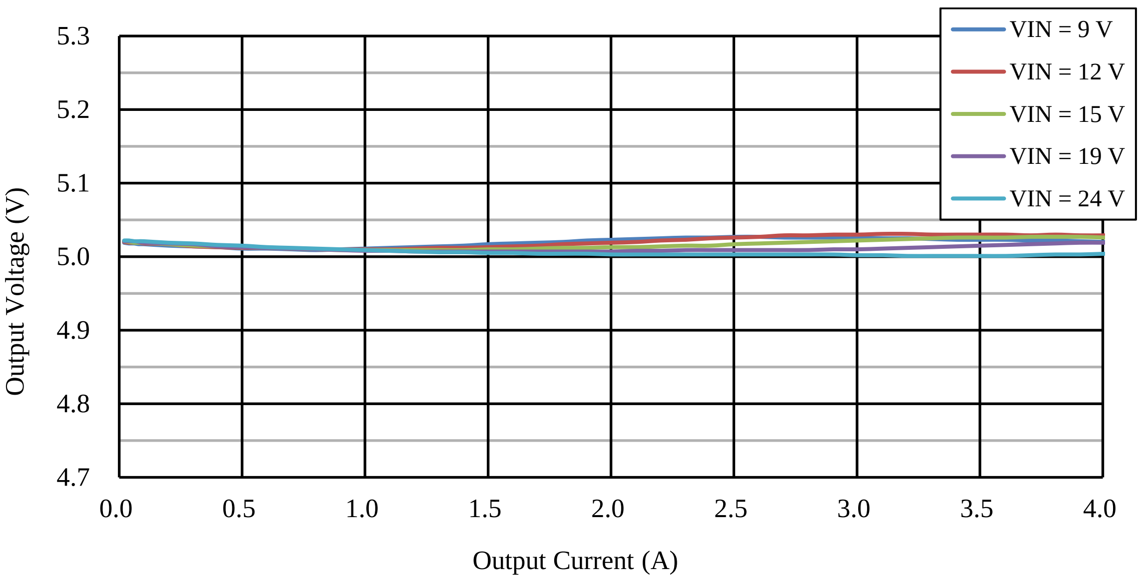


Figure 6-6. Output Voltage vs. Output Current

7. Operation Check

All the performance data contained in this document were measured at a room temperature. Unless specifically noted, V_{IN} = 12 V, V_{OUT} = 5 V.

For more details on the NR111E such as electrical characteristics and operational descriptions, refer to the data sheet.

7.1 Startup Operation

The soft start function is activated at power-on. The soft start period depends on the capacitance of the capacitor connected to the SS pin. Even when the IC starts with the enable function, the soft start function is activated.

Figure 7-1 and Figure 7-2 show the startup waveforms with the UVLO (the EN pin is pulled up to the IN pin) and enable function (external signal is input to the EN pin), respectively.

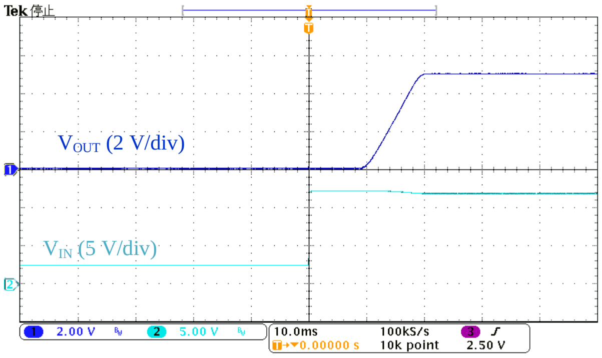


Figure 7-1. Operational Waveforms at Startup by UVLO (I_{OUT} = 1 A, C_{SS} = 0.1 µF)

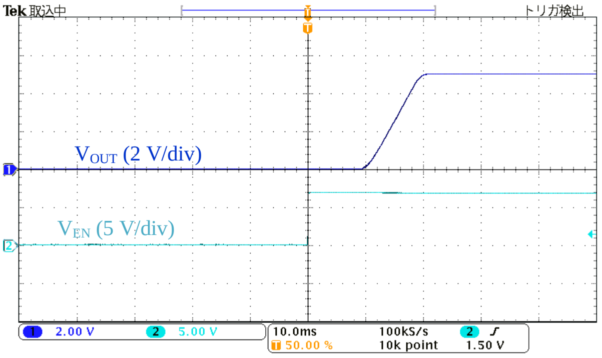


Figure 7-2. Operational Waveforms at Startup by Enable Function (I_{OUT} = 1 A, C_{SS} = 0.1 µF)

7.2 Switching Operation

Figure 7-7 to Figure 7-3 show the operational waveforms according to the load.
The NR111E regulates the output voltage with the current mode PWM control. In a heavy load condition, the circuit operates in the continuous conduction mode of PWM frequency of 350 kHz (typ.). In a light load condition, the circuit operates in the discontinuous conduction mode because the turn-off timing is controlled depending on the load. The minimum on-time is limited to 150 ns (typ.).

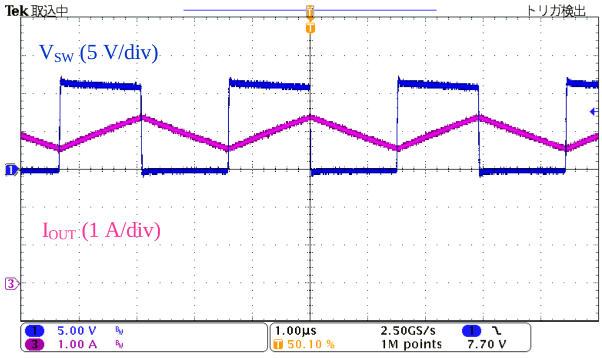


Figure 7-3. Operational Waveforms in Normal Operation (I_{OUT} = 4 A)

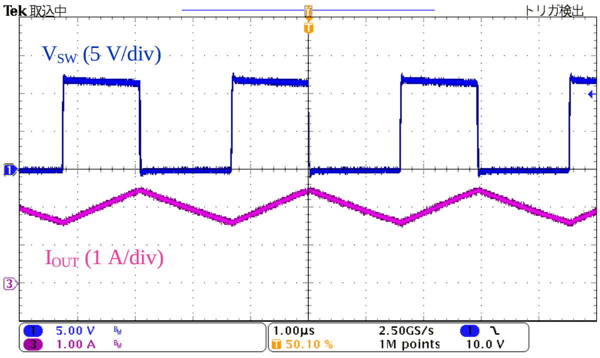


Figure 7-4. Operational Waveforms in Normal Operation (I_{OUT} = 2 A)

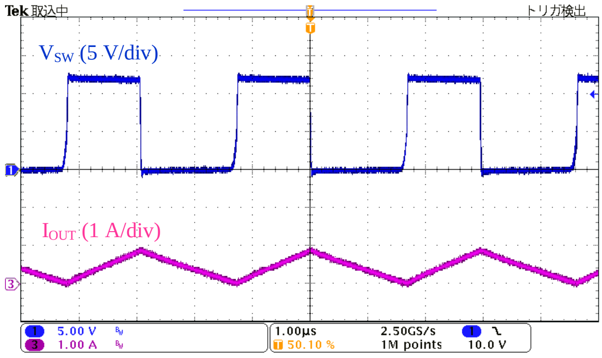


Figure 7-5. Operational Waveforms in Normal Operation (I_{OUT} = 0.4 A)

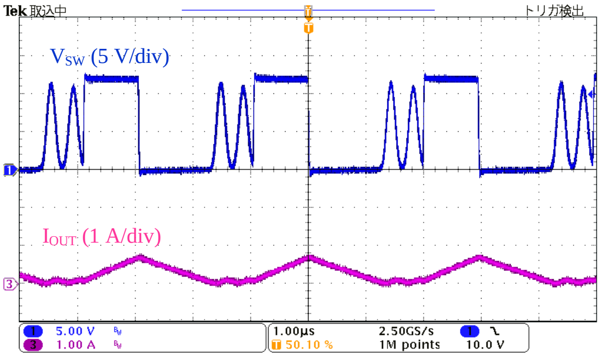


Figure 7-6. Operational Waveforms in Normal Operation (I_{OUT} = 0.25 A)

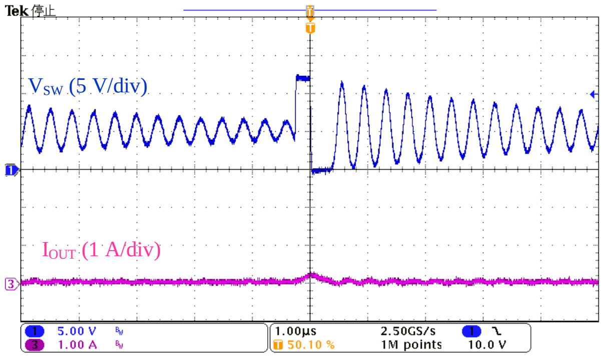


Figure 7-7. Operational Waveforms in Normal Operation (I_{OUT} = 10 mA)

7.3 Output Ripple Voltage

The design example has an output ripple voltage of about 20 mV$_{P-P}$. The bandwidth of the oscilloscope is set to 20 MHz.

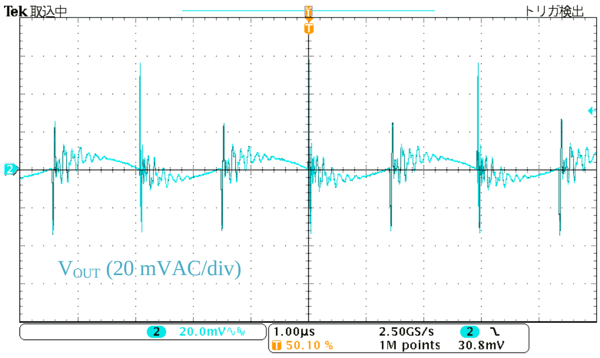


Figure 7-8. Output Ripple Voltage Waveform (I_{OUT} = 4 A)

7.4 Load Transient Response

Figure 7-11 to Figure 7-9 show the load transient response waveforms of output voltage when the change rate of the load current is 3 A/ms, 30 A/ms, and 300 A/ms, respectively.

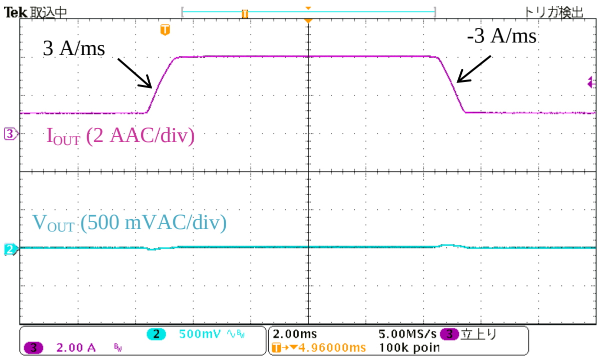


Figure 7-9. Load Transient Response Waveforms (3 A/ms)

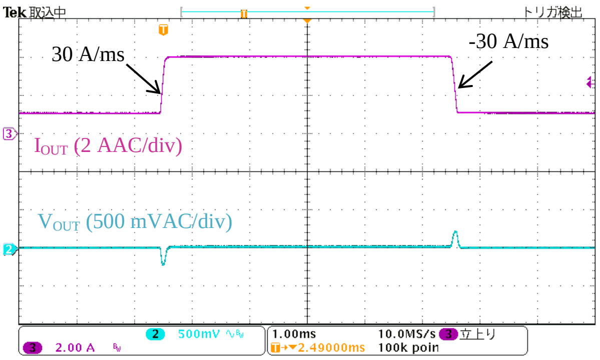


Figure 7-10. Load Transient Response Waveforms (30 A/ms)

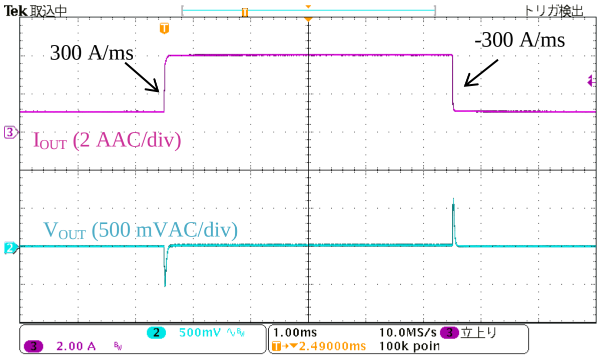


Figure 7-11. Load Transient Response Waveforms (300 ms/A)

8. Variable Output Voltage

The output voltage of the NR111E can be changed with the resistors, R4, R5, and R6 connected to the FB pin. For L1, select the appropriate inductance according to the output voltage. This section provides the guide for setting R4, R5, R6, and L1.

When removing or mounting the parts of the evaluation board, use a heat gun or hot tweezers, and pay extreme attention to the peel-off of the land pattern and thermal stress on other parts.

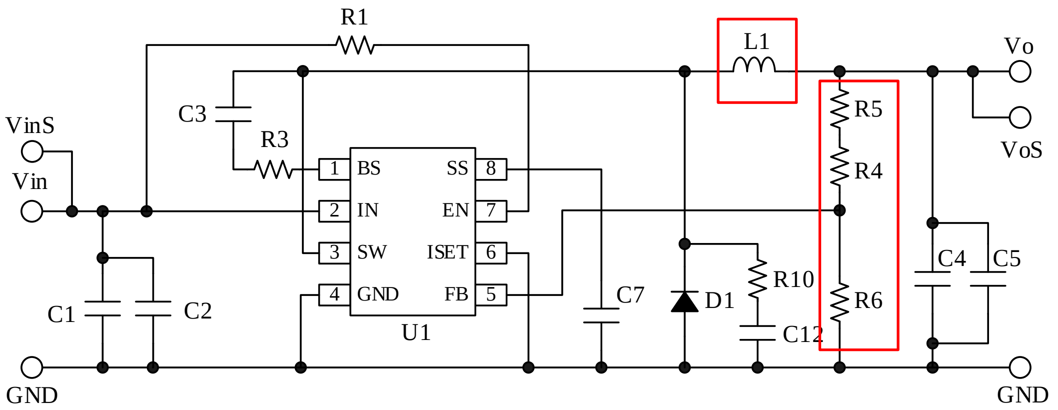


Figure 8-1. Circuit Diagram

Figure 8-2. Output Voltage Adjustment Resistors and Inductor

8.1 Selecting R4, R5, and R6

The FB pin is the feedback pin to compare the reference voltage and output voltage signal. This pin is connected between the voltage dividing resistors, R4, R5, and R6. The threshold voltage, V_{FB} is 0.8 V ± 2 %.

The output voltage, V_{OUT} is adjusted by these feedback resistors. When setting the feedback resistors, set the total current, I_{FB} flowing through these resistors to ≥0.2 mA. Note that if I_{FB} is too high, the efficiency is decreased due to the increased power dissipation.

Even when setting V_{OUT} to 0.8 V (the same voltage as V_{FB}), be sure to connect R6 for stable operation. The relationship between the input voltage and output voltage of the buck converter is determined by the SW pin on-time. The SW pin on-time should be set to ≥200 ns.

The following equation shows the relationship between R4, R5, and R6.

$$R4 + R5 = \frac{V_{OUT} - V_{FB}}{I_{FB}} \quad (1)$$

$$R6 = \frac{V_{FB}}{I_{FB}} \quad (2)$$

$$V_{OUT} = (R4 + R5) \times \frac{V_{FB}}{R6} + V_{FB} \ (V) \quad (3)$$

Where;
V_{OUT} is the output voltage setting value,
I_{FB} is the feedback current setting value, and
V_{FB} is the FB pin threshold voltage (0.8 V).

The following are examples of calculating the resistance of R4, R5, and R6 when V_{OUT} = 3.3 V and I_{FB} = 0.2 mA.

$$R6 = \frac{V_{FB}}{I_{FB}} = \frac{0.8}{0.2 \times 10^{-3}} = 4 \ (k\Omega) \quad (4)$$

$$R4 + R5 = \frac{V_{OUT} - V_{FB}}{I_{FB}} = \frac{3.3 - 0.8}{0.2 \times 10^{-3}} = 12.5 \ (k\Omega) \quad (5)$$

Table 8-1 shows an example of selecting feedback resistors at typical output voltages. You are responsible for examining and verifying conditions in actual use, such as input/output specifications, thermal derating, and resistance accuracy.

Table 8-1. Reference Values of Output Voltage and Feedback Resistors

Output Voltage (V)	R4 (kΩ)	R5 (kΩ)	R6 (kΩ)	Voltage across R6 (mV)	I_{FB} (mA)
2.5	3.9	2.2	2.4	800.00	0.33
3.3	3.9	3.6	2.4	800.00	0.33
5.0	7.5	3.0	2.0	800.00	0.40
9.0	15	7.5	2.0	801.62	0.40
12.0	30	3.6	2.4	800.00	0.36
15.0	27	12	2.2	800.97	0.36
19.0	30	20	2.2	800.77	0.36

8.2 Selecting L1

The NR111E employs current mode PWM control by peak detection current control. In the peak detection current control, when the duty cycle exceeds 50%, the inductor current may fluctuate in a period that is an integral multiple of the switching frequency. This is called subharmonic oscillation, which occurs in principle in the peak detection current control mode.

The NR111E compensates for the inductor current inside the IC to suppress the subharmonic oscillation. Since the compensation amount of inductor current depends on the output voltage, L1 must be set to an appropriate value according to the output voltage. Figure 8-3 shows the reference selection range of inductance to avoid subharmonic oscillation. Note that the upper limit of the inductance changes depending on the input/output conditions and load current.

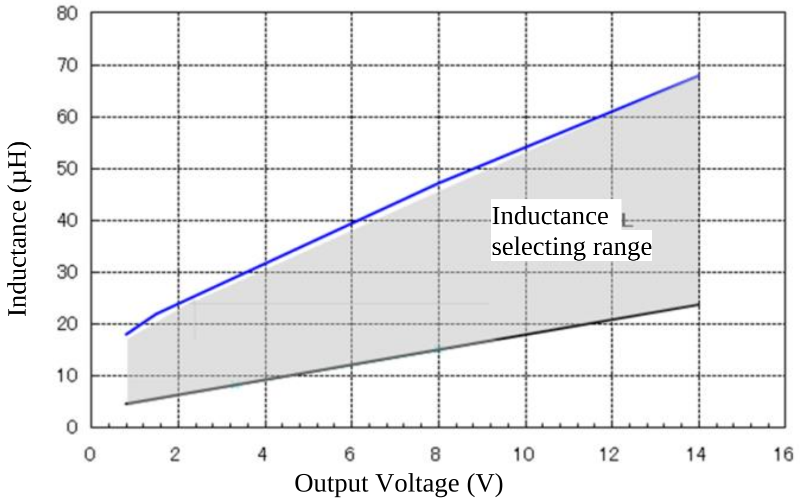


Figure 8-3. Reference Inductance Selection Range

For stable operation, set the inductance so that inductor ripple current, ΔI_L is 0.3 A to 1.2 A under the input/output conditions where the duty cycle is ≤50%. ΔI_L is calculated by the following equation.

$$\Delta I_L = \frac{(V_{IN} - V_{OUT})}{L \times V_{IN} \times f} \times V_{OUT} \qquad (6)$$

Where;
V_{IN} is the input voltage,
V_{OUT} is the output voltage,
L is the inductance, and
f is the oscillation frequency (350 kHz).

When the inductance is calculated directly from ΔI_L, the following equation can be used.

$$L = \frac{(V_{IN} - V_{OUT})}{\Delta I_L \times V_{IN} \times f} \times V_{OUT} \qquad (7)$$

The peak inductor current, I_{LP} can be calculated by the following equation using ΔI_L and the output current, I_{OUT}.

$$I_{LP} = \frac{\Delta I_L}{2} \times I_{OUT} \qquad (8)$$

When selecting an inductor, make sure that I_{LP} does not exceed the saturation current of the inductor.

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DSGN-CEZ-16003