

NCP3133A Reference Design User's Guide

Design of an Evaluation Board for a 3 A, Integrated Synchronous Buck Converter

TND6414/D

Introduction

This Reference Design describes the operation and performance of the NCP3133A, a fully integrated synchronous buck converter for typical 3.3 V and 5 V input step-down applications. It can provide up to 3 A load current. The NCP3133A supports high efficiency, fast transient response and provides power good indicator. The control scheme includes two operation modes: Forced Continuous Conduction Mode (FCCM) and automatic Continuous Conduction Mode/Discontinuous Conduction Mode (CCM/DCM). In automatic CCM/DCM mode, the controller switches smoothly between CCM and DCM, where the converter runs at reduced switching frequency with much higher efficiency.

This paper presents the design of an evaluation board which is used to carry out measurements on the device as well as the results of these measurements. It describes the different steps that are carried out before presenting the results of the different measurements. Bode plots and load transient responses characterize the device in a transient state whereas efficiency curves and output ripple characterize the steady state of the device. Some thermal measurements are also conducted.

Keywords

- Buck Converter with input voltage ranging from 2.5 V to 5.5 V
- Jumper selectable output voltage (1.2 V or 3.3 V)
- Jumper selectable configuration (FCCM or auto CCM/DCM)
- Enable pin accessible
- Fixed 1.1 MHz switching frequency
- Four-layer PCB design

Table 1. NCP3133A SPECIFICATIONS

Device	NCP3133A
Application	Set Down voltage regulation
Input Voltage	5 V
Maximum Output Current	3 A
Output Voltage	1.2 V

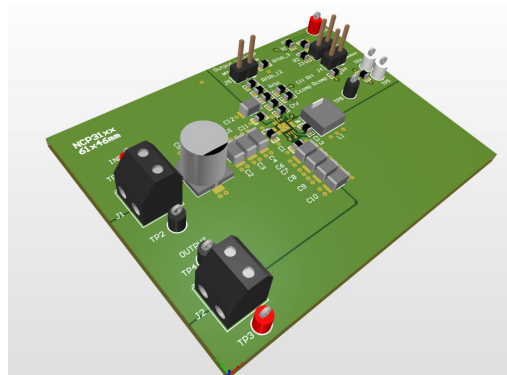


Figure 1. NCP3133A Board

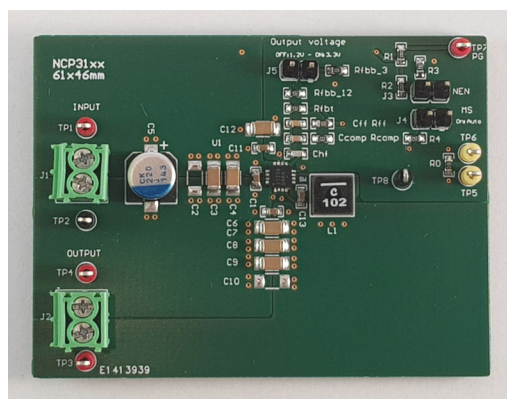


Figure 2. NCP3133A Board Photo

NCP3133A

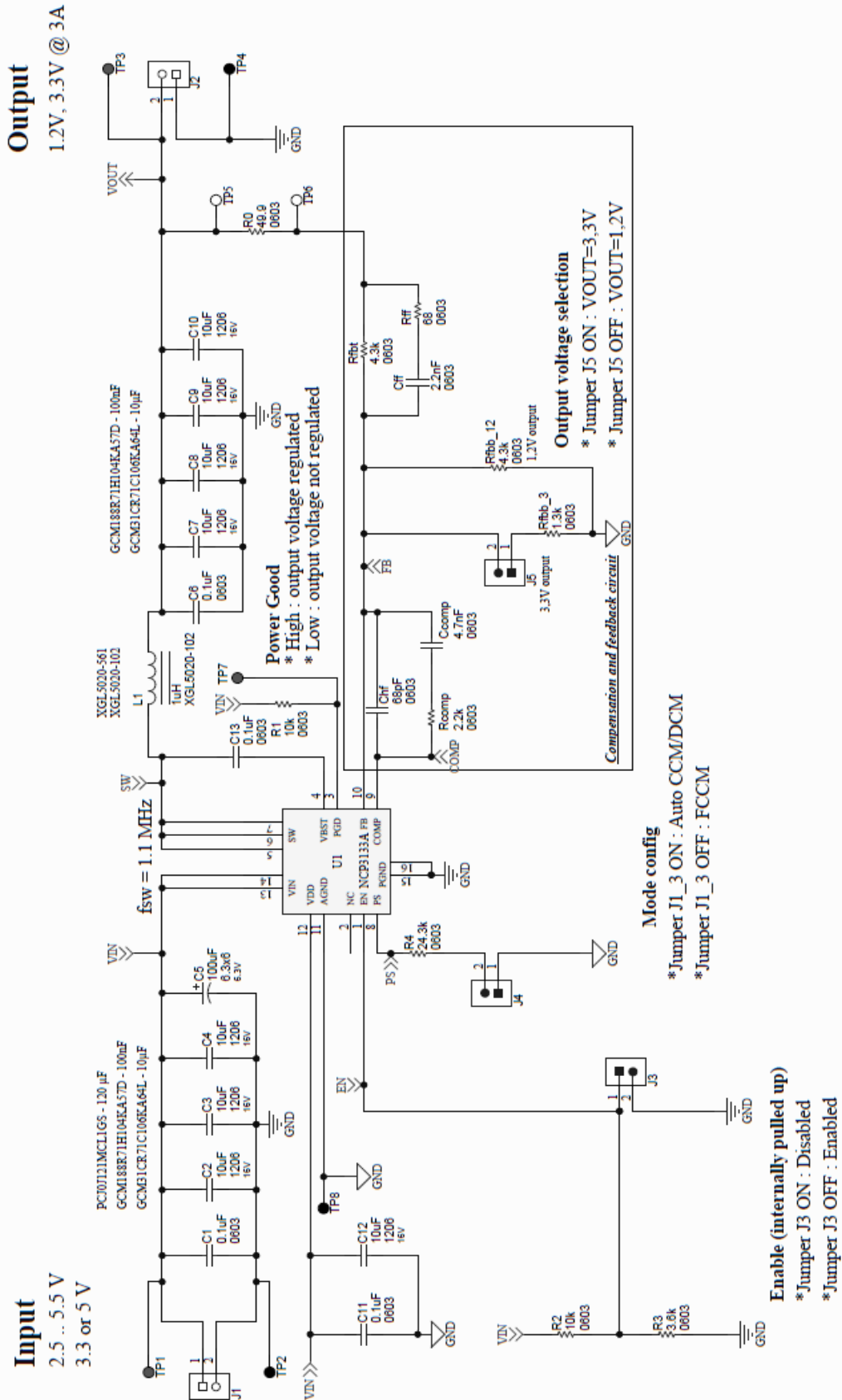


Figure 3. NCP3133A Schematic 1 – Conservative Compensation

NCP3133A

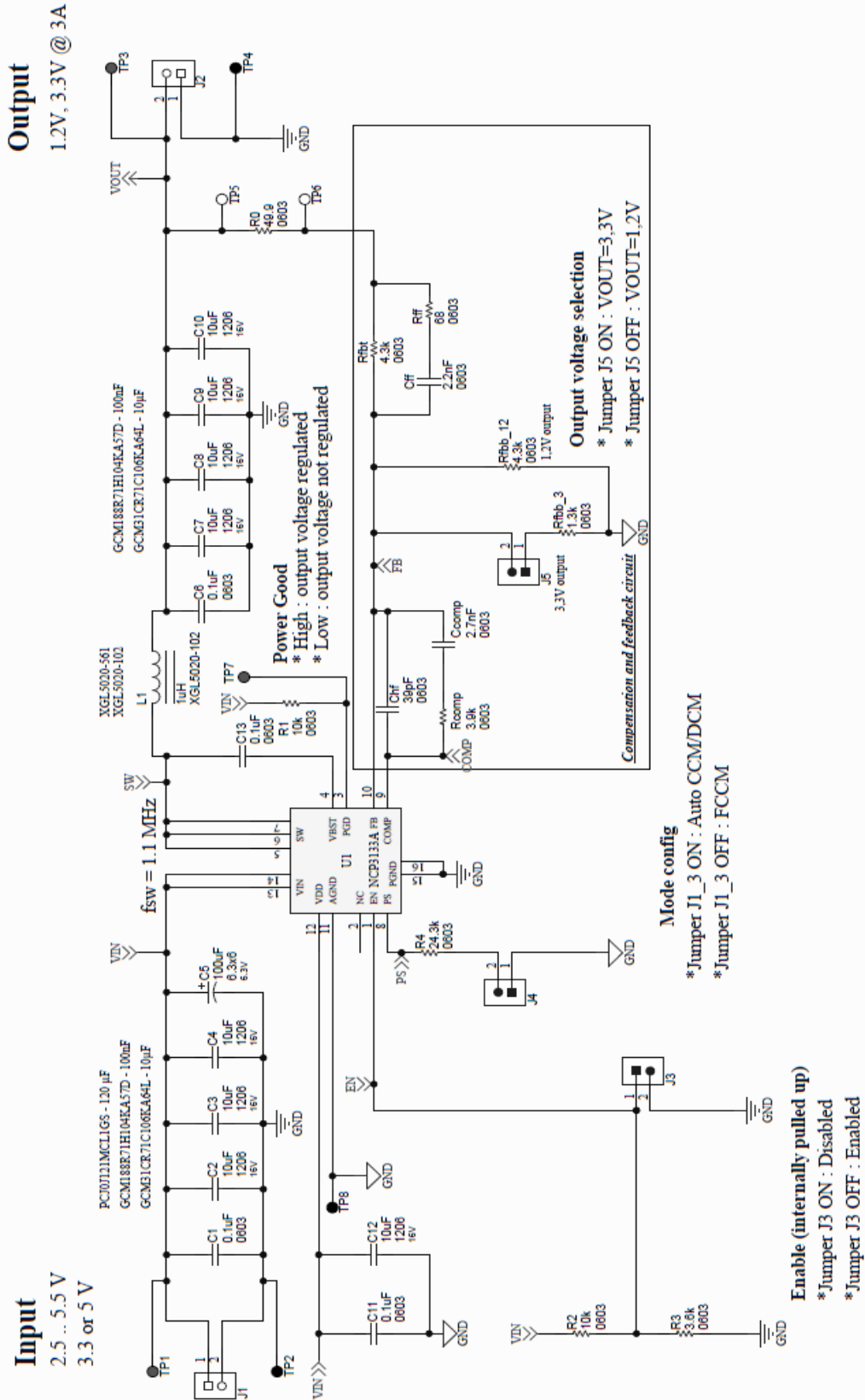


Figure 4. NCP3133A Schematic 1 – Aggressive Compensation

BOARD LAYOUT

Figures 4, 5, 6 and 7 show the four layers of the PCB. The dimensions of the PCB are as follows: 61 mm x 46 mm. A few important rules are followed here. One of them is making sure that the input and output capacitances are as close as possible of the IC.

This way, the current path is reduced. The inductor should be close to IC as well. This minimizes the area of the switching node allowing less noise to be radiated from it. Analog signals should also be kept away from this node for the same reason.

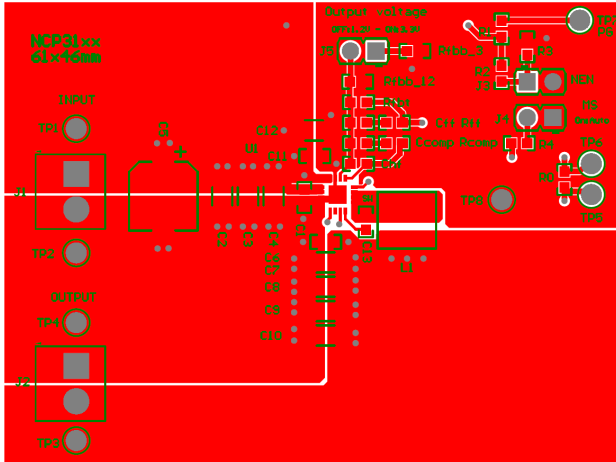


Figure 5. Top Layer of PCB

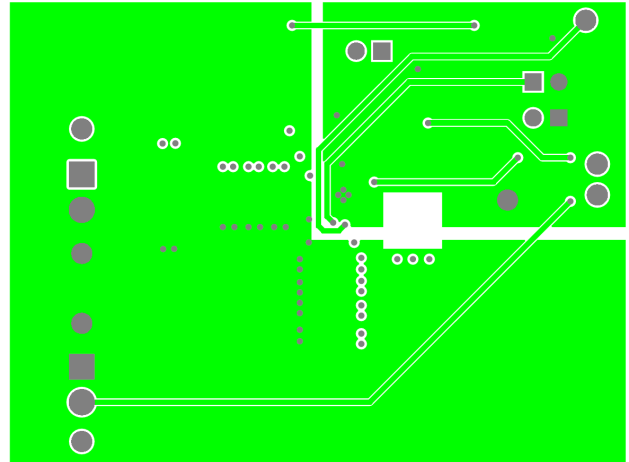


Figure 7. Inner 2 Layer of PCB

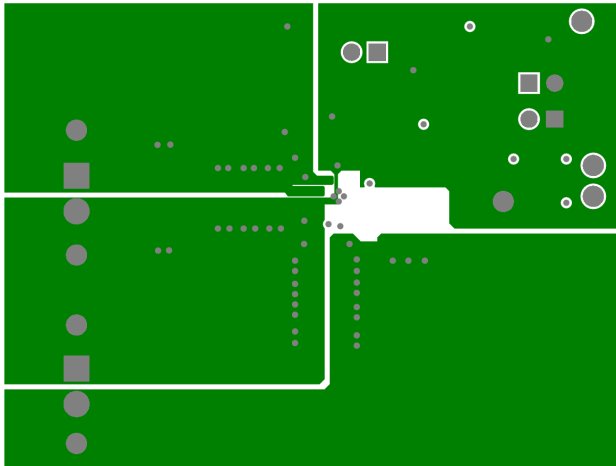


Figure 6. Inner 1 Layer of PCB

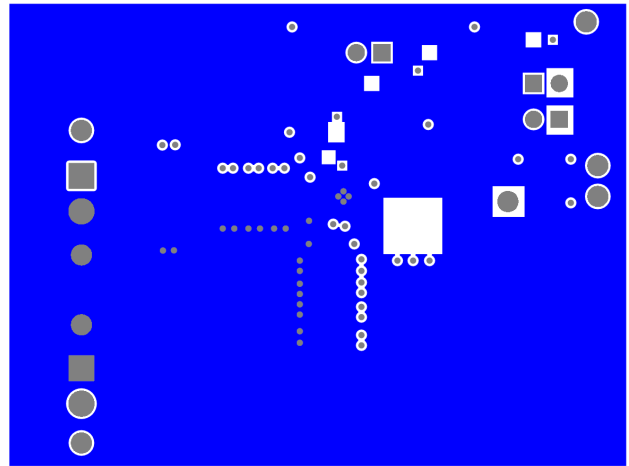


Figure 8. Bottom Layer of PCB

COMPONENT SIZING

To determine an approximate value for the inductor, the following formula is used:

$$L = \frac{V_{out} (V_{in} - V_{out})}{V_{in} \cdot f_{sw} \cdot I_{ripple}}$$

A good rule of thumb is to try and get a current ripple of 30% or lower. To obtain a 30% current ripple one would need a 0.92 μ H inductor, here a 1 μ H inductor is selected for a current ripple of 27%.

The input capacitor ladder consists of:

- Two 10 μ F 1206 ceramic capacitors (to handle current ripple)
- One 0.1 μ F 0603 ceramic capacitor (for high frequency noise decoupling)
- One 100 μ F bulk capacitor

The output capacitance impacts the overshoot and undershoot during a load transient as well as the output voltage ripple. The following formula is used to design the

output capacitance in regard to the response to a load transient:

$$C_{out} > \frac{L \cdot I_{step}^2}{2 \cdot \Delta V \cdot V_{out}}$$

Where ΔV is the output voltage variation during the load transient.

The output capacitor ladder consists of:

- Three 10 μF 1206 ceramic capacitors (to handle load transients and output voltage ripple)
- One 0.1 μF 0603 ceramic capacitor (for high frequency noise decoupling)

The NCP3133A does not have any internal compensation, which means the compensation networks will be on the board as well, between pins FB and COMP of the IC. This next section describes the calculations that were done in order to determine the values of the components used in this network. The compensation network is a type 3 which adds a double zero, a double pole and a pole at the origin.

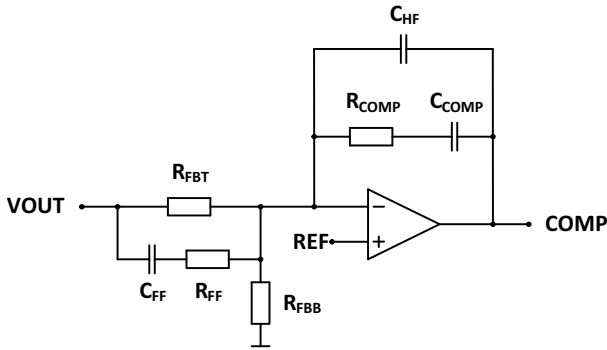


Figure 9. Type 3 Compensation Network

The first step in calculating a compensation network is selecting the desired crossover frequency. It is usually selected between 1/10 and 1/5 of the switching frequency. Here, we will choose 1/10, i.e. $f_{co} = 110$ kHz.

The location of the poles and zeros is set as follows, considering only ceramic capacitors on the output of the converter:

- Poles @ switching frequency, $f_p = f_{sw} = 1.1$ MHz
- Zeros @ half LC resonant frequency,

$$f_z = \frac{1}{2} \cdot \frac{1}{2\pi \cdot \sqrt{L \cdot C}}$$

In order to adjust the gain of the compensation network, the value of the modulator gain needs to be known:

$$G_{mod} = 20 \cdot \log\left(\frac{V_{in}}{V_{ramp}}\right)$$

Most devices adjust the ramp voltage to keep the ratio between V_{in} and V_{ramp} constant. It is the case for this device which keeps $V_{ramp} = V_{in} / 4$. Therefore, the modulator gain is $G_{mod} = 12$ dB.

Once the gain is known the gain at the desired crossover frequency (110 kHz) can be determined:

$$\frac{g_{mod}}{g_{fco}} = \left(\frac{f_{co}}{f_{LC}}\right)^2 \leftrightarrow G_{fco} = 20 \cdot \log\left[\left(\frac{f_{LC}}{f_{co}}\right)^2 \cdot 10^{\frac{G_{mod}}{20}}\right]$$

$$G_{fco} = -11 \text{ dB}$$

This means the compensation network needs to have a gain of +11 dB at 110 kHz.

Finally, the gain of the bode plot at the frequency of the double zero is calculated, which equals the DC gain of the compensation.

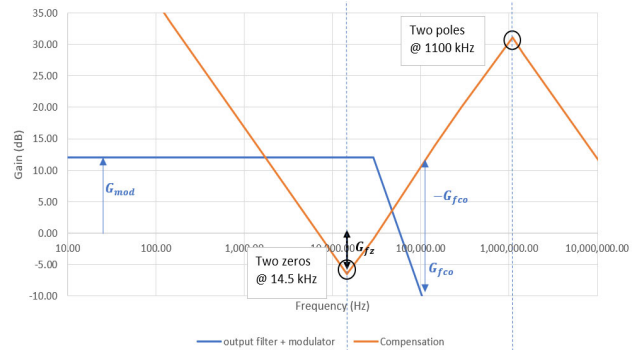


Figure 10.

$$\frac{g_{fz}}{g_{fco}} = \frac{f_z}{f_{co}} \leftrightarrow G_{fz} = 20 \cdot \log\left[\left(\frac{f_z}{f_{co}}\right)^2 \cdot 10^{\frac{G_{fco}}{20}}\right]$$

$$G_{fz} = -6.5 \text{ dB}$$

Once this gain is known, R_{fbt} is set and R_{comp} can be calculated:

$$G_{fz} = \frac{R_{comp}}{R_{fbt}} = -6.5 \text{ dB}$$

R_{fbt} is set at 4.3 k Ω :

$$R_{comp} = g_{fz} \cdot R_{fbt} = 10^{\frac{G_{fz}}{20}} \cdot R_{fbt} \sim 2.2 \text{ k}\Omega$$

Now, all values of the other components can be calculated from the formulas of the poles and zeros:

- $f_{z1} = \frac{1}{2 \cdot \pi \cdot (R_{fbt} \cdot C_{ff})} = 14.5 \text{ kHz}$
- $f_{z2} = \frac{1}{2 \cdot \pi \cdot (R_{comp} \cdot C_{comp})} = 14.5 \text{ kHz}$
- $f_{p1} = \frac{1}{2 \cdot \pi \cdot (R_{ff} \cdot C_{ff})} = 1100 \text{ kHz}$
- $f_{p2} = \frac{1}{2 \cdot \pi \cdot (R_{comp} \cdot C_{hf})} = 1100 \text{ kHz}$

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Final values:

- $R_{fbt} = 4.3 \text{ k}\Omega$
- $R_{fbb} = 4.3 \text{ k}\Omega$
- $R_{ff} = 68 \text{ }\Omega$
- $C_{ff} = 2.2 \text{ nF}$
- $R_{comp} = 2.2 \text{ k}\Omega$
- $C_{comp} = 4.7 \text{ nF}$
- $C_{hf} = 68 \text{ pF}$

PERFORMANCE SUMMARY

Part 1 – Efficiency (at 3.3 V Output)

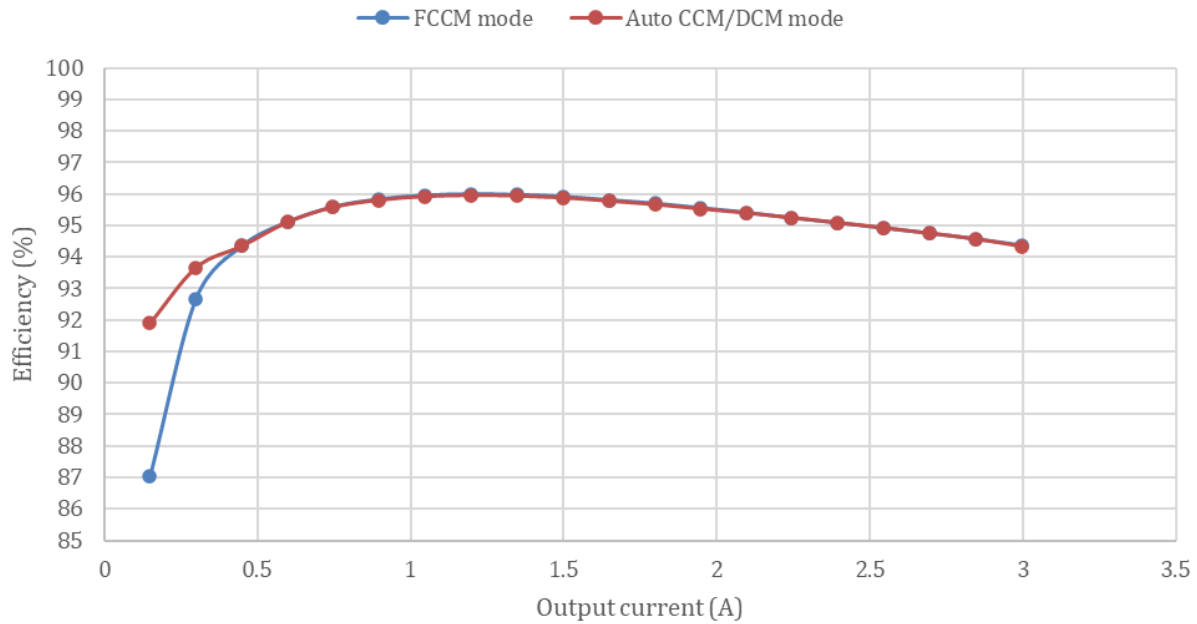


**Figure 11. Efficiency – Auto CCM/DCM Mode and FCCM Mode
5.0 V Input Voltage, 3.3 V Output Voltage**

Figure 11 presents the efficiency of the device measured at a 3.3 V output. The peak efficiency is 96% for both modes at an output current of 1.2 A. Auto CCM/DCM mode improves efficiency by reducing switching losses due to the transition to DCM when the load current is low enough. If

the load current decreases even more, the converter will enter power saving mode in which the converter skips switching and operates at reduced frequency, which minimizes the quiescent current and maintains high efficiency.

Part 2 – Bode Plots

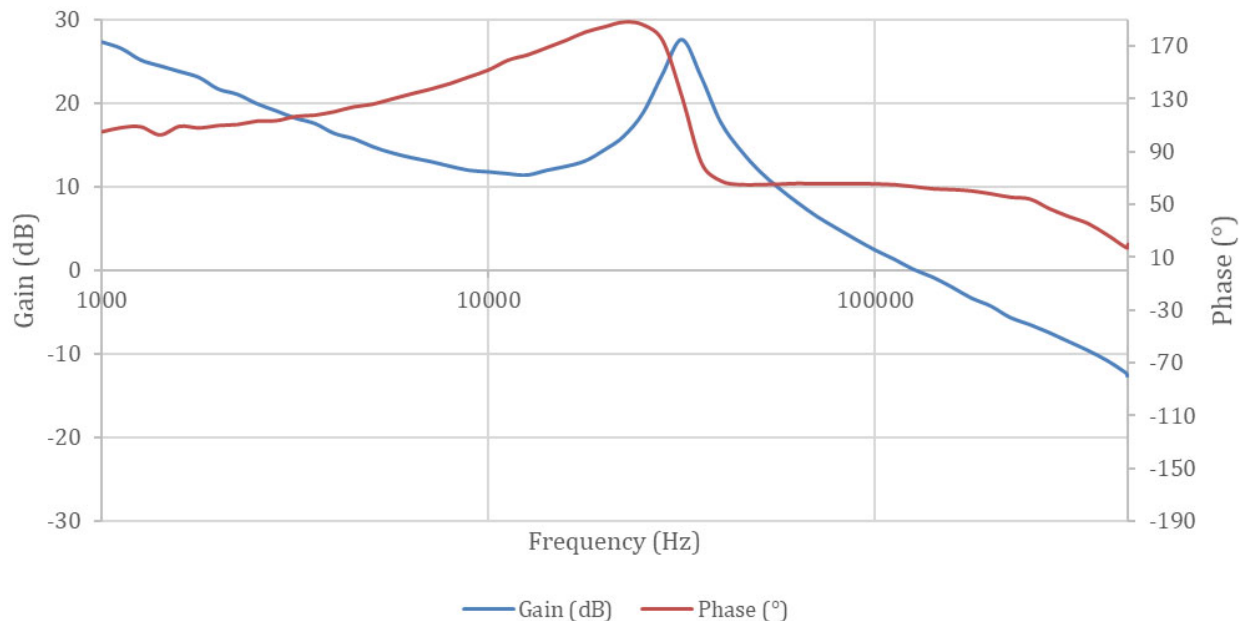


Figure 12. Bode Plot – Conservative Compensation
5.0 V Input Voltage, 1.2 V Output Voltage, 3.0 A Load Current

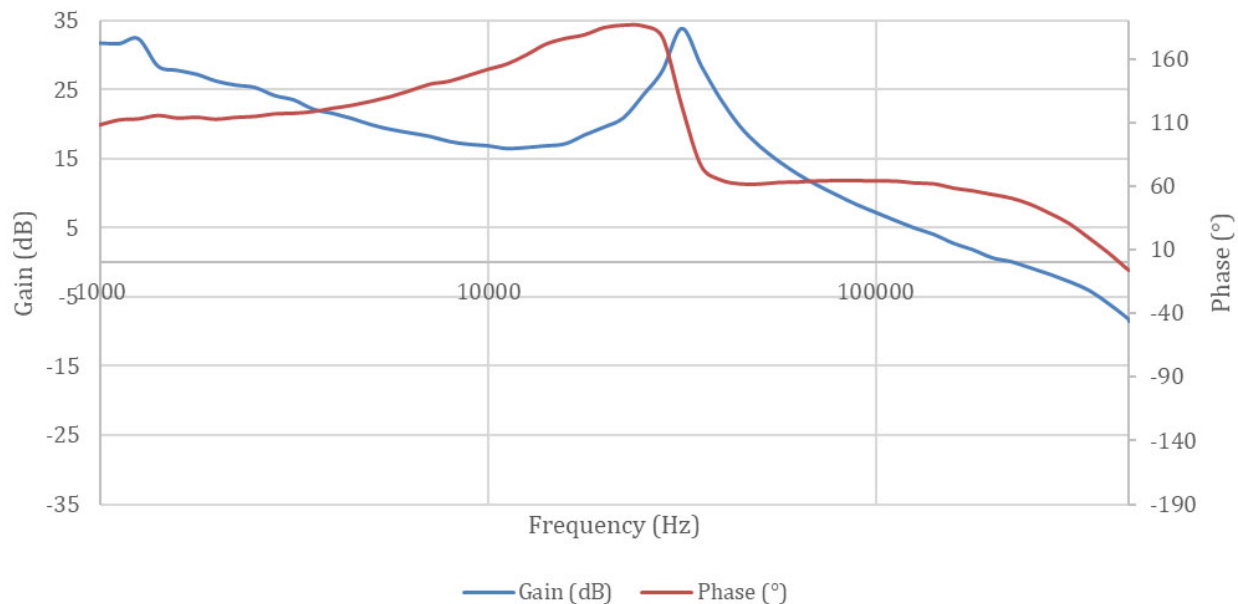


Figure 13. Bode Plot – Aggressive Compensation
5.0 V Input Voltage, 1.2 V Output Voltage, 3.0 A Load Current

Figures 12 and 13 show bode plots of the device. Two different compensations are tested resulting in two different plots and stability margins. Figure 13 shows the bode plot for the conservative compensation with higher phase and gain margin. This is the compensation that is calculated previously in this paper.

Conservative compensation (Figure 12):

- Phase margin = 64.3°
- Gain margin = -15.3 dB
- Bandwidth = 125 kHz

In order to achieve higher bandwidth, a different compensation gain is implemented. It is derived from the first compensation by increasing the gain of the compensation network. In order to achieve higher gain, the ratio R_{comp}/R_{bft} is increased (by increasing R_{comp}) and then the values of C_{comp} and C_{hf} are adjusted so that the frequencies of the poles and zeros remain the same.

Aggressive compensation (Figure 13):

- Phase margin = 51.7°
- Gain margin = -6.9 dB
- Bandwidth = 222 kHz

Part 3 – Load Transient Response

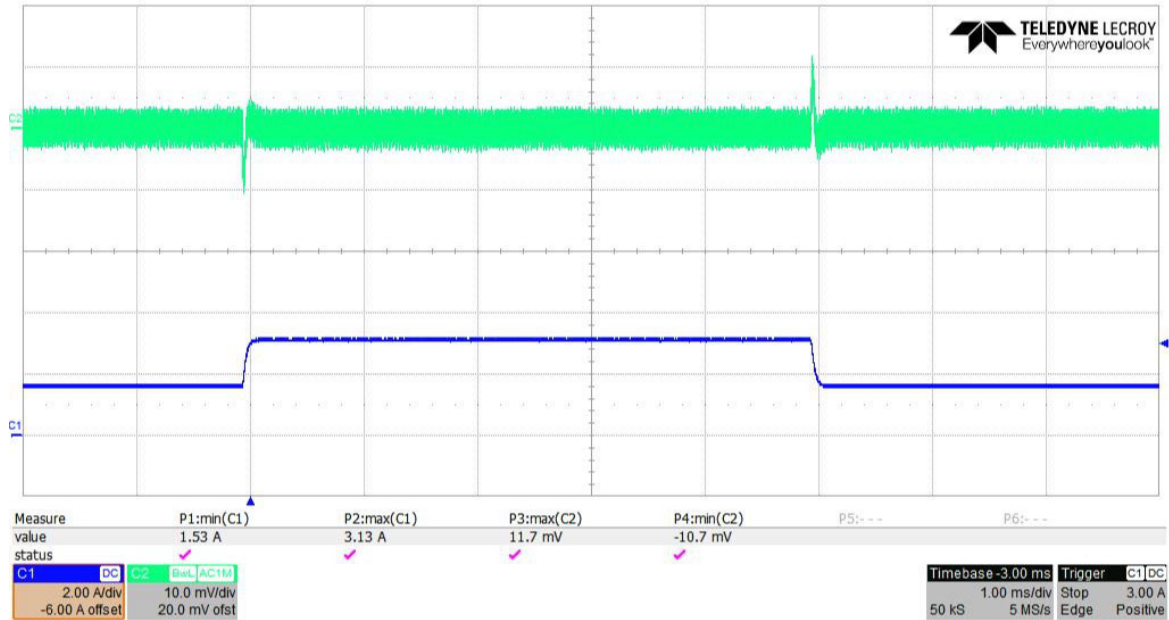


Figure 14. Load Transient Response – Conservative Compensation
5.0 V Input Voltage, 1.2 V Output Voltage

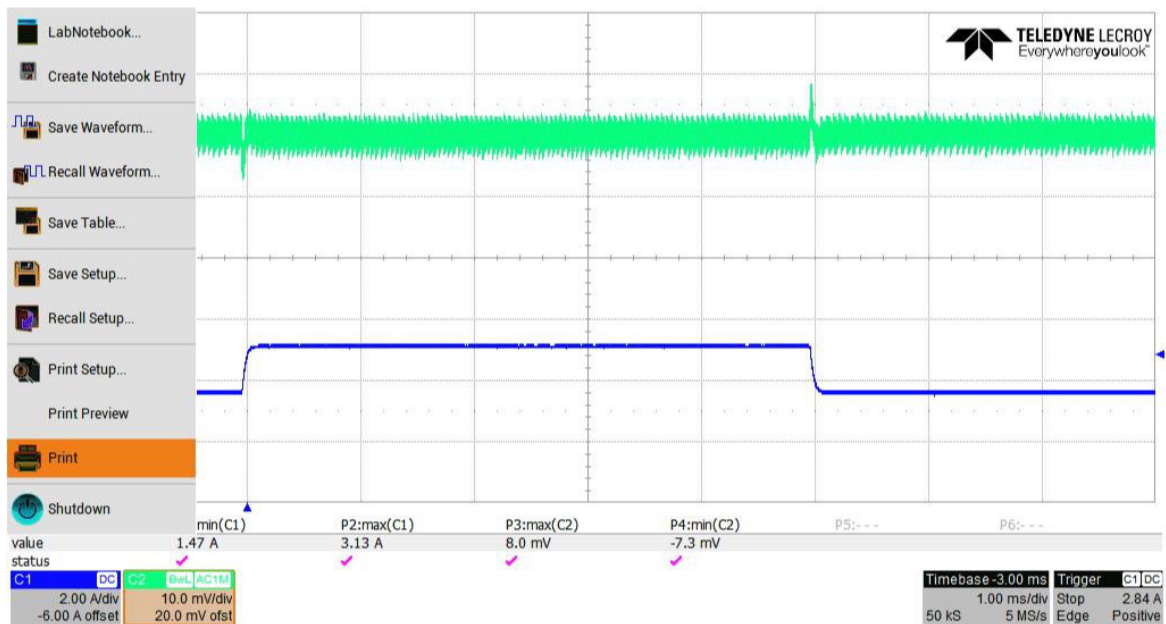


Figure 15. Load Transient Response – Aggressive Compensation
5.0 V Input Voltage, 1.2 V Output Voltage

The response to a load step from 1.5 A to 3.0 A and from 3.0 A back to 1.5 A at 1.2 V output is shown in Figures 14 and 15 for both conservative and aggressive compensations.

Channel 1:

- Output current, load step 1.5 A to 3.0 A
- 2 A/div, 1 ms/div

Channel 2, conservative comp:

- Output voltage, -10.7 mV undershoot, 11.7 mV overshoot → 1.8% variation
- 10 mV/div, AC coupled

Channel 2, aggressive comp:

- Output voltage, -7.3 mV undershoot, 8.0 mV overshoot → 1.3% variation
- 10 mV/div, AC coupled

With both compensations the overall deviation is lower than 2%. The aggressive compensation has a slightly lower deviation of the output voltage due to its higher bandwidth.

To measure load transient response, the current step produced by the electronic load that is used must be as steep as possible, usually devices that can produce slew rates of at least than 1 A/μs are preferred.

Part 4 – Output Voltage Ripple

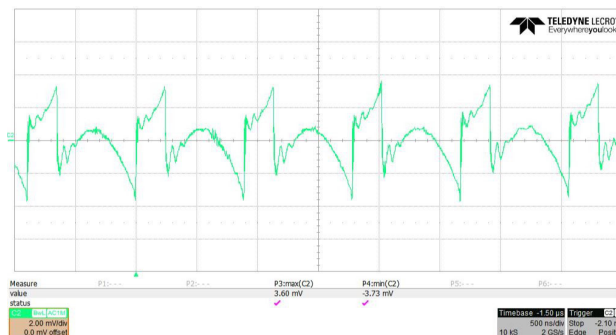


Figure 16. Output Ripple – Conservative Compensation 5.0 V Input, 1.2 V Output, 1.5 A Output Current

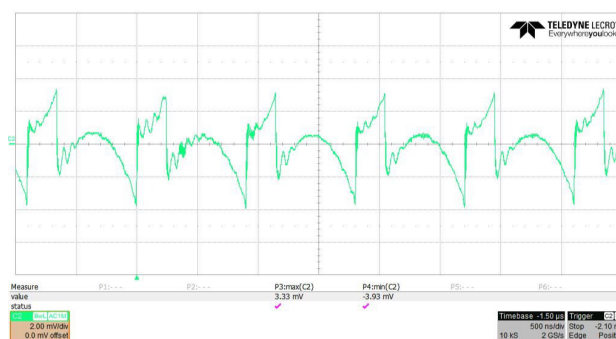


Figure 17. Output Ripple – Aggressive Compensation 5.0 V Input, 1.2 V Output, 1.5 A Output Current

Figures 16 and 17 present the output ripple for both compensations at a 1.2 V output and at half of max output current (1.5 A). For both, the ripple is approximately 7 mV.

The compensation has no effect on the output ripple in steady state operation, which is only affected by the value of the current in the inductor, the switching frequency, the output capacitance and its ESR and ESL.

Part 5 – Thermal Image

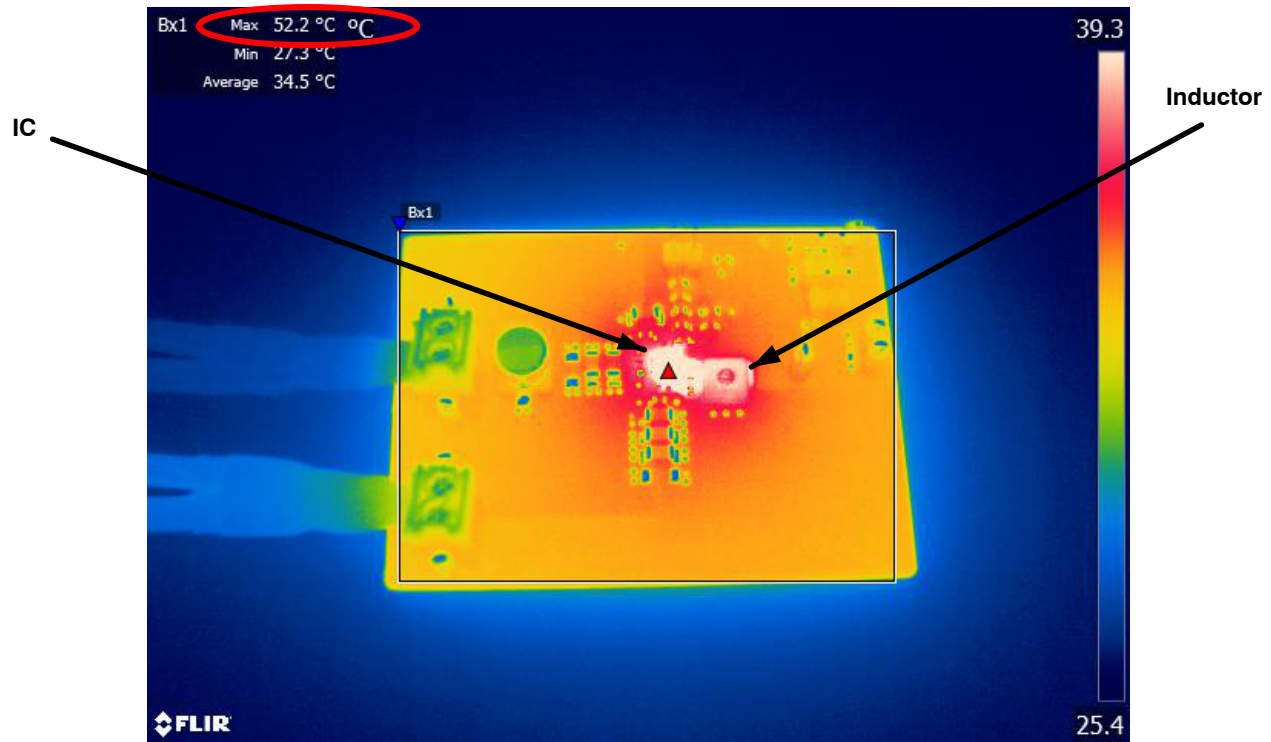


Figure 18. Thermal Image @ 3.0 A

This thermal image shows the circuit at an ambient temperature of 25.4°C with an input voltage of 5.0 V, an output voltage of 1.2 V at a load current of 3.0 A.

The maximum temperature on the board is 52.2°C, at the location of the IC. The inductor heats up to approximately 40°C.

CONCLUSION

This paper describes a schematic and layout design to test the performance of the NCP3133A Buck converter. The utility of the FCCM is illustrated by the efficiency measurements at light load conditions.

Two different compensations are calculated, and their performance is shown and compared. Finally, voltage ripple measurements and thermal measurements complete this application note.

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BILL OF MATERIALS

Table 2. BOM

Designator	Quantity	Description	Value	Footprint	Manufacturer	Part Number
C1, C6, C11	3	Decoupling capacitor	0.1 μ F	603	Murata	GCM188R71H104KA57D
C2, C3, C7, C8, C9, C12	6	Input and output capacitor	10 μ F	1206	Murata	GCM31CR71C106KA64L
C4, C10	DNP					
C5	1	Bulk Input Capacitor	100 μ F	HXBF80	Nichicon	PCJ0J121MCL1GS
L1	1	Inductor	1 μ H	XGL5020	Coilcraft	XGL5020-102
C13	1	Bootstrap capacitor	0.1 μ F	603	Murata	GCM188R71H104KA57D
R1, R2	2	Power good and enable resistor	10 k Ω	603	Vishay	CRCW060310K0FKEA
R3	1	Enable resistor	3.6 k Ω	603	Vishay	CRCW06033K60FKEA
R4	1	Pin select resistor	24.3 k Ω	603	Vishay	CRCW060324K3FKEA
R0	1	Feedback resistor	49.9 Ω	603	Vishay	CRCW060349R9FKEA
Chf	1	Feedback network capacitor	68 pF 39 pF	603	Murata	GCM1885C2A121JA16
Ccomp	1	Feedback network capacitor	4.7 nF 2.7 nF	603	Murata	GCM1885C1H472JA16
Rcomp	1	Feedback network resistor	2.2 k Ω 3.9 k Ω	603	Vishay	CRCW06032K15FKEA
Rftb, Rfbb_12	2	Feedback network resistor	4.3 k Ω	603	Vishay	CRCW06034K53FKEA
Cff	1	Feedback network capacitor	2.2 nF 2.2 nF	603	Murata	GCM1885C1H222JA16
Rff	11	Feedback network resistor	68 Ω 68 Ω	603	Vishay	CRCW0603121RFKEA
Rfbb_33	1	Feedback network resistor	1.3 k Ω	603	Vishay	CRCW06031K30FKEA
J1, J2	2	Input/output screw terminal	/	ED555/2DS	On-Shore Technology	ED555/2DS
J3, J4, J5	3	Jumpers	/	61300211121	Würth Elektronik	61300211121
TP1, TP3, TP7	3	Red test points	/	Keystone5000	Keystone	5000
TP2, TP4	2	Black test points	/	Keystone5001	Keystone	5001
TP5, TP6	2	White test points	/	Keystone5002	Keystone	5002
U1	1	Integrated synchronous buck converter		QFN-16 3x3	onsemi	NCP3133AMNTXG

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