

2-MHz Automotive SEPIC Reference Design



Description

Due to customer demand, this SEPIC converter is designed for 2-MHz switching frequency. Applying such a fairly high switching frequency to a hard switched topology results in increased switching losses at FET and rectifier as well as increased core losses and AC losses at the windings. To minimize those losses the FET and dual inductor must be carefully selected – and by doing so, an efficiency of almost 90% at peak current 2 A by non-synchronous rectification was achieved.

Furthermore, this converter is designed for pulsed load, switching from 0.2 A to 2 A continuously, a **current transient of 90%**. For best load regulation the loop bandwidth has been tuned achieving a load step response around **1% deviation** of output voltage.

Features

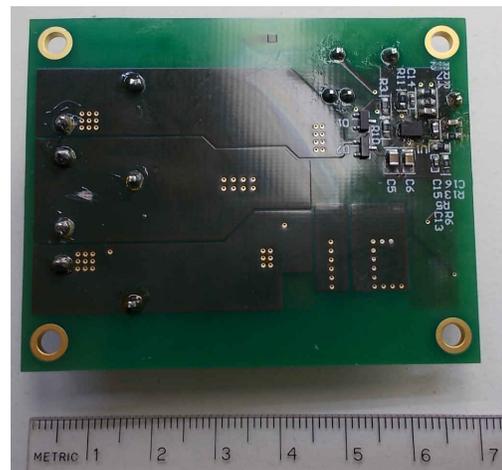
- SEPIC topology is able to step up **and** step down wide input to output voltage of 12 V
- Withstands cold cranking as low as 4.5 V and load dump up to 36 V_{PEAK}
- Due to continuous input current SEPIC topology, low conducted emissions and high switching frequency of 2 MHz were achieved which is beyond the AM broadcast band
- High switching frequency also provides small inductance to support dynamic loads, means loop bandwidth around 10 kHz results in transient response 1% for 90% load transient
- The prototype supports as-it-is up to 1.5-A continuous load and up to 2-A pulsed load

Applications

- [Driver monitoring](#)



Top Photo



Bottom Photo

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage Range	6 V to 18 V
Output Voltage	12 V
Maximum Output Current	2 A peak
Switching Frequency	2 MHz
Topology	SEPIC
IC	LM51551-Q1

1.2 Considerations

- Unless otherwise indicated, a resistor was used as load, output current was adjusted to 2 A, and the input voltage was set to 12 V
- The circuit starts to switch around 5.7 V_{IN} and stops with switching around 4.3 V_{IN}
- The switching frequency of the prototype was measured at 2.02 MHz
- Long term measurements at maximum load 2 A_{PK} were done with forced cooling

Note

Due to availability reasons, the BSC340N08NS3 G was used for transistor Q1.

1.3 Dimensions

The size of the PMP30676 board is 63.5 mm × 50.17 mm. The four-layer board was manufactured with 35-μm copper thickness on each layer.

2 Testing and Results

2.1 Efficiency Graph

Efficiency is shown in the following figure.

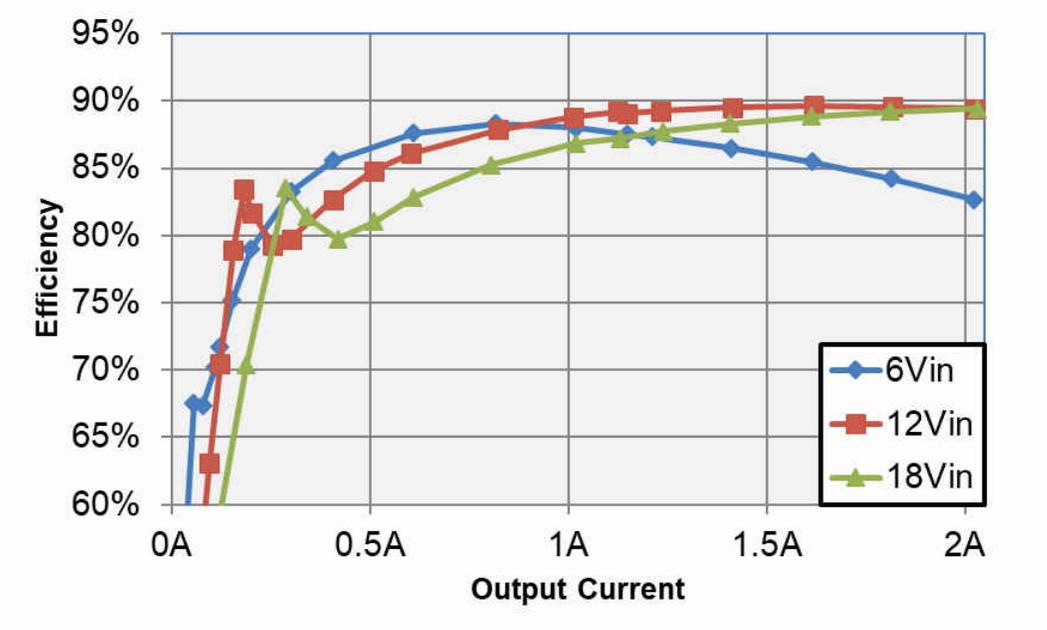


Figure 2-1. Efficiency vs Output Current

Note

Almost 90% efficiency at such a high switching frequency of 2 MHz.

2.2 Loss Graph

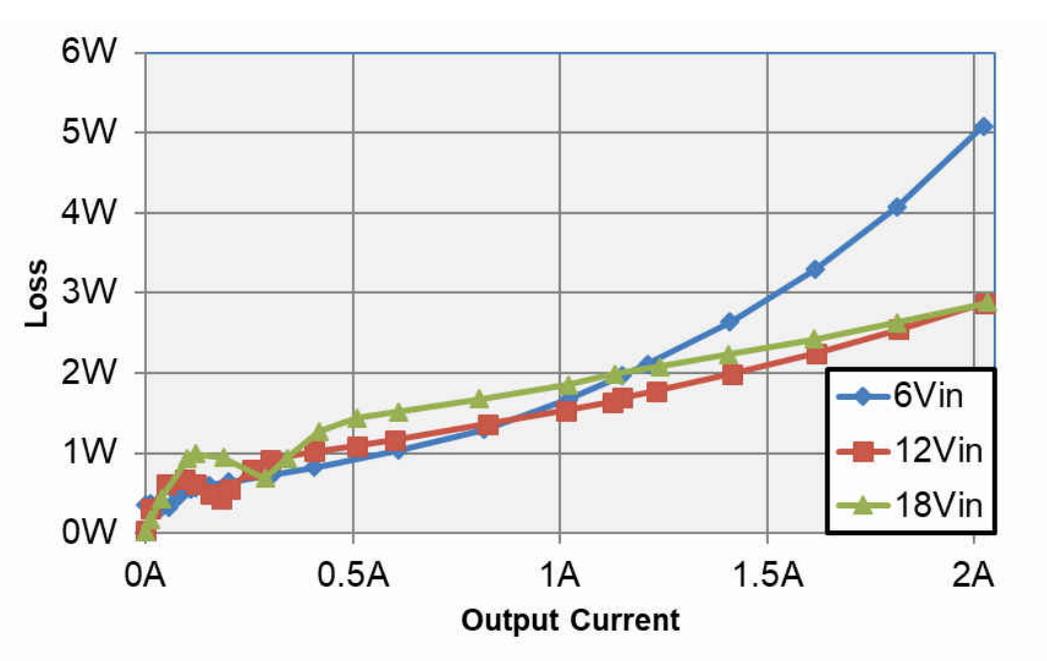


Figure 2-2. Loss vs Output Current

2.3 Load Regulation

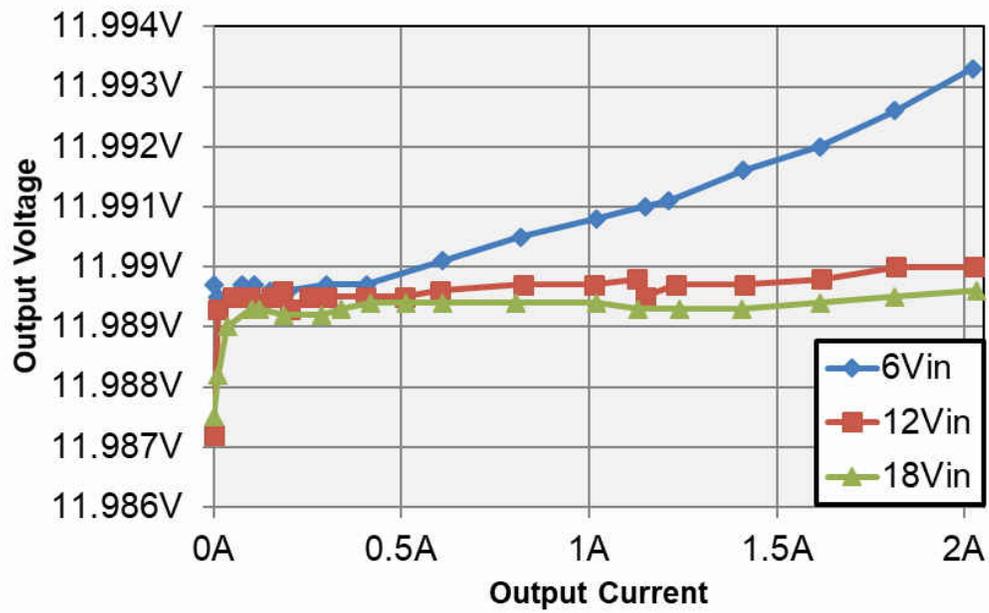


Figure 2-3. Output Voltage vs Output Current

2.4 Line Regulation

The graph in Figure 2-4 shows the result for 2-A output current. Figure 2-5 shows the influence of the input voltage on efficiency and loss.

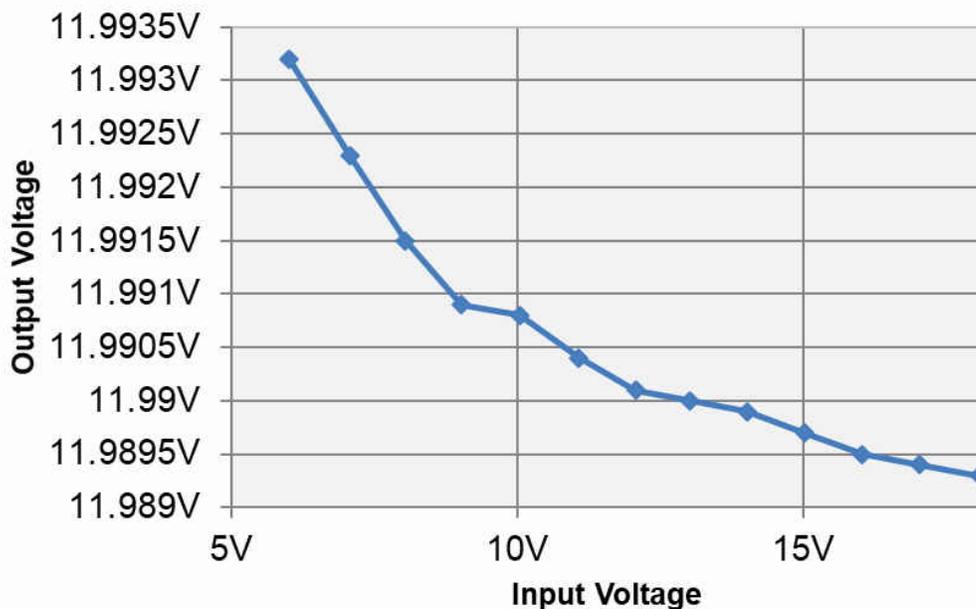


Figure 2-4. Output Voltage vs Input Voltage

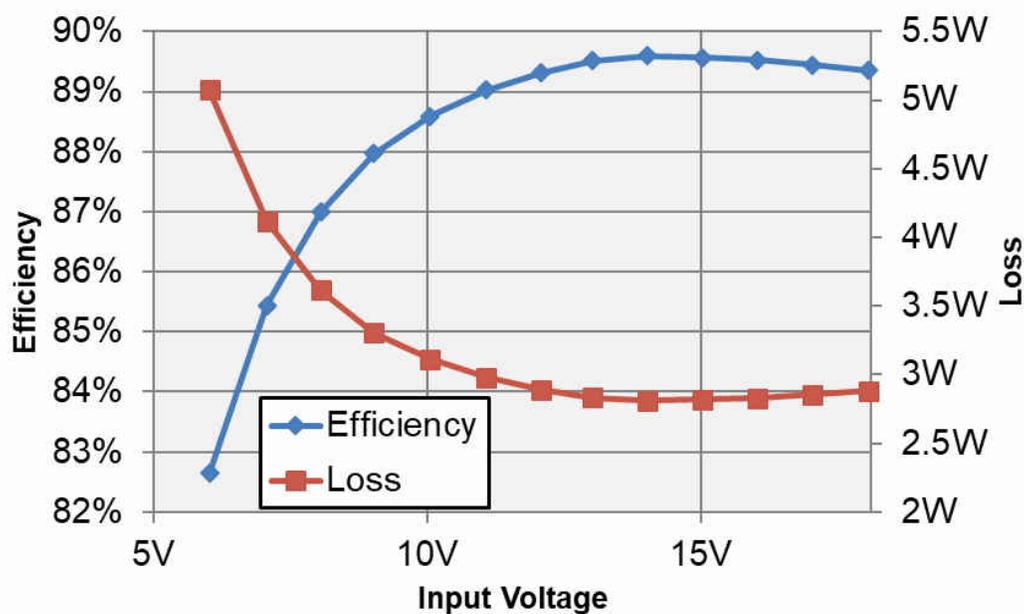


Figure 2-5. Efficiency and Loss vs Input Voltage

2.5 Thermal Images

The thermal images are shown in the following figures.

Table 2-1. Thermal Markers

Name	0.5 A	1 A	1.5 A	2 A	Pulsed Load
D3	42.1°C	54.0°C	68.1°C	86.1°C	42.8°C
L1	42.3°C	50.2°C	60.5°C	74.5°C	43.3°C
Q1	45.1°C	55.2°C	68.3°C	88.2°C	44.5°C
R1	45.5°C	56.8°C	67.5°C	83.8°C	43.3°C
R101	42.2°C	51.0°C	60.3°C	76.3°C	42.4°C

2.5.1 0.5-A Output Current

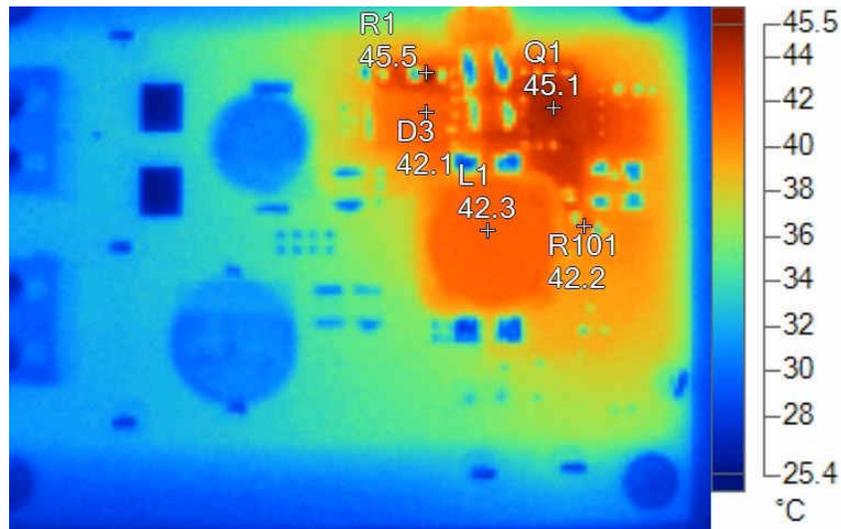


Figure 2-6. IR Photo With 0.5-A Output Current

2.5.2 1-A Output Current

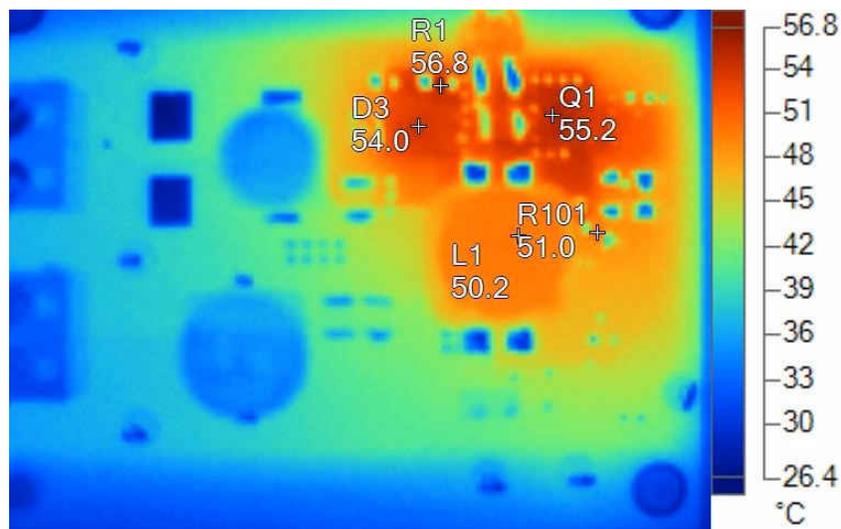


Figure 2-7. IR Photo With 1-A Output Current

2.5.3 1.5-A Output Current

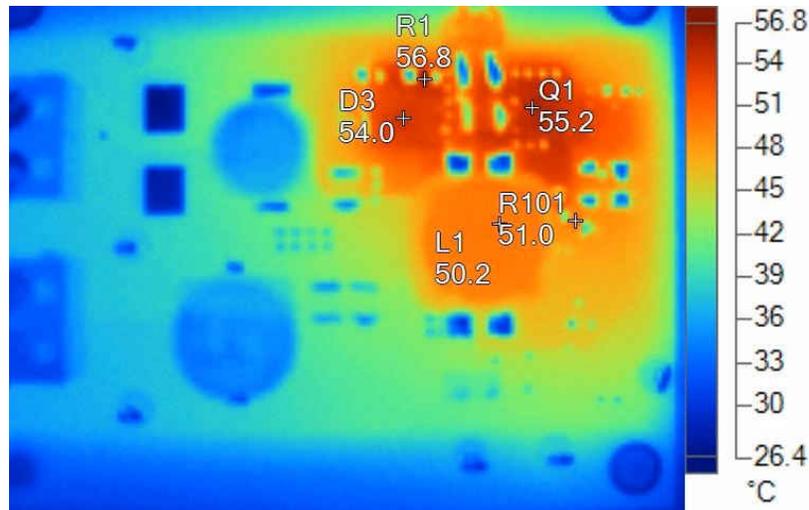


Figure 2-8. IR Photo With 1.5-A Output Current

2.5.4 2-A Output Current



Figure 2-9. IR Photo With 2-A Maximum Output Current

Note

The thermal measurements show that the power stage itself is able to withstand a continuous load higher than 1 A.

At [custom pulsed load](#), the temperature rise of the power stage is around $dT = +20K$.

2.5.5 Pulsed Output Current

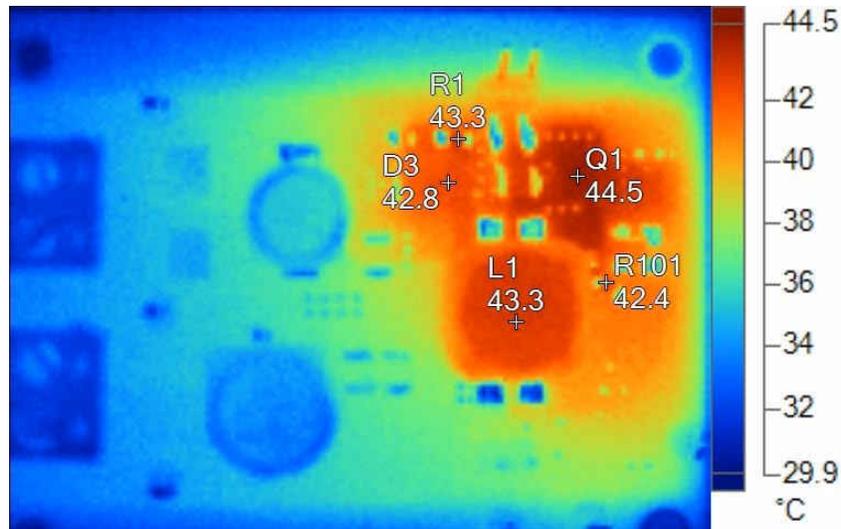


Figure 2-10. IR Photo with Custom Pulsed Load

Figure 2-11 is a drawing of the applied custom pulsed load.

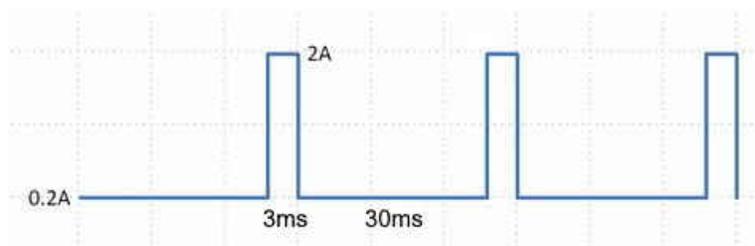


Figure 2-11. Custom Pulsed Load

2.6 Bode Plots

Note

Bode plot measurement with the network analyzer (NWA) is just a small signal analysis in frequency domain, while [transient measurement](#) is large signal analysis in the time domain.

Table 2-2. Summary of the Bode Plots

	6 V _{IN}	12 V _{IN}
Bandwidth (kHz)	6.56	12.2
Phase margin	74°	76°
Slope (20 dB / decade)	-0.97	-1.06
Gain Margin (dB)	-18.1	-28.4
Slope (20 dB / decade)	-1.13	-0.19
Freq (kHz)	45	202

2.6.1 6-V Input Voltage

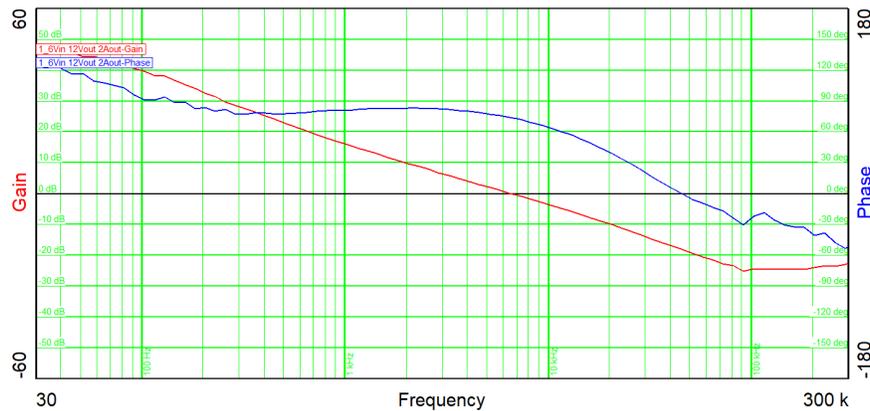


Figure 2-12. Bode Plot for 6-V Input Voltage

2.6.2 12-V Input Voltage

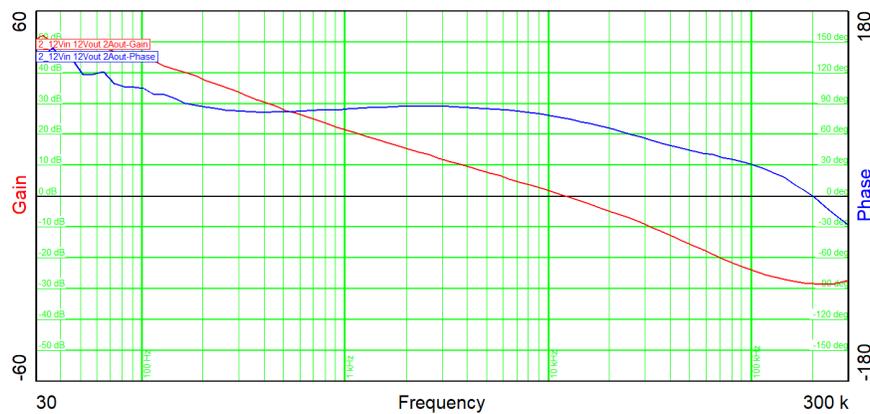


Figure 2-13. Bode Plot for 12-V Input Voltage

3 Waveforms

3.1 Switching

3.1.1 Transistor Q1

3.1.1.1 Drain - Source

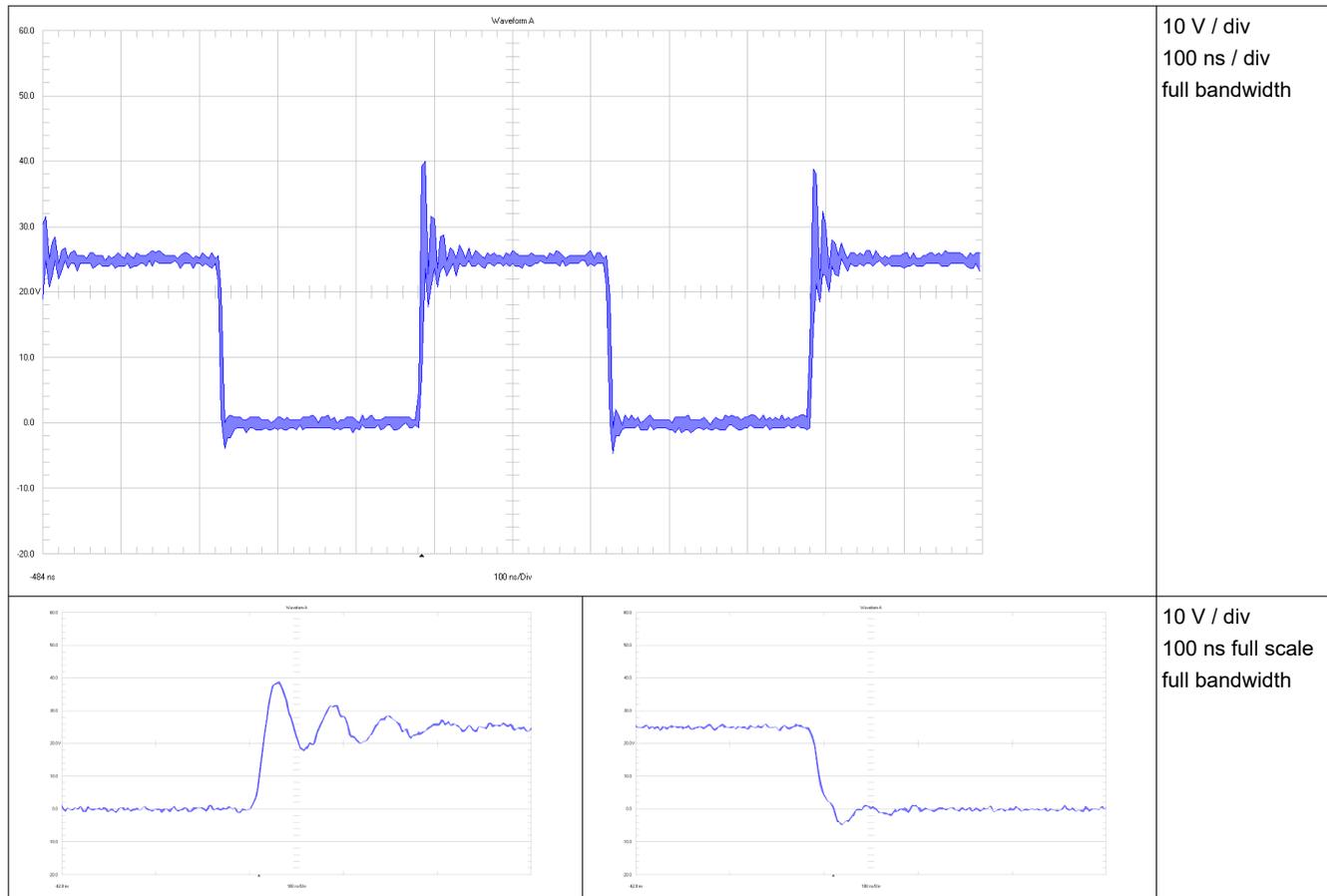


Figure 3-1. Waveform Q1 (Drain-Source)

3.1.1.2 Gate - Source

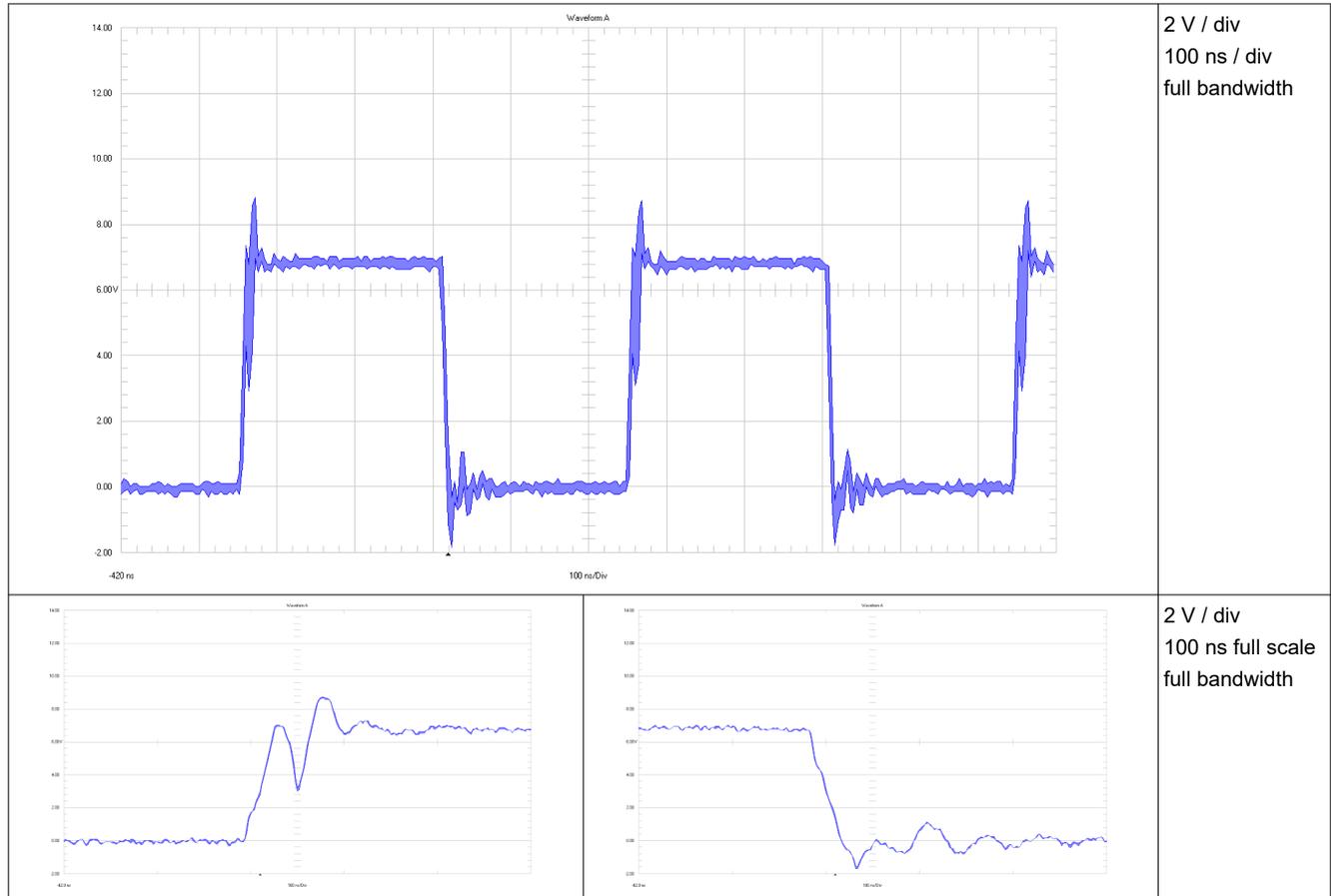


Figure 3-2. Waveform Q1 (Gate-Source)

3.1.2 Diode D3

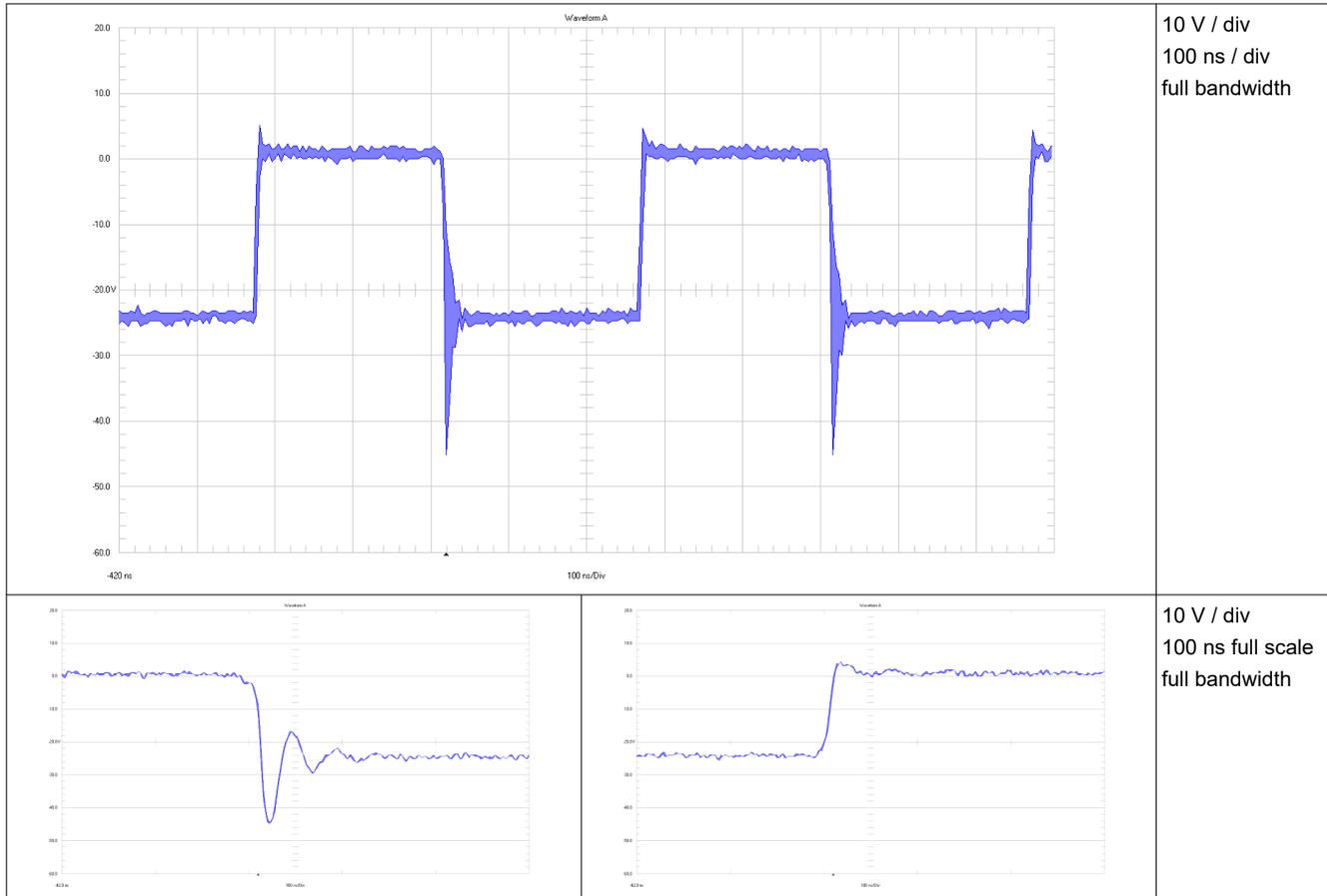


Figure 3-3. Waveform D3 Referenced to V_{OUT}

3.2 Input Voltage Ripple

3.2.1 20-MHz Bandwidth

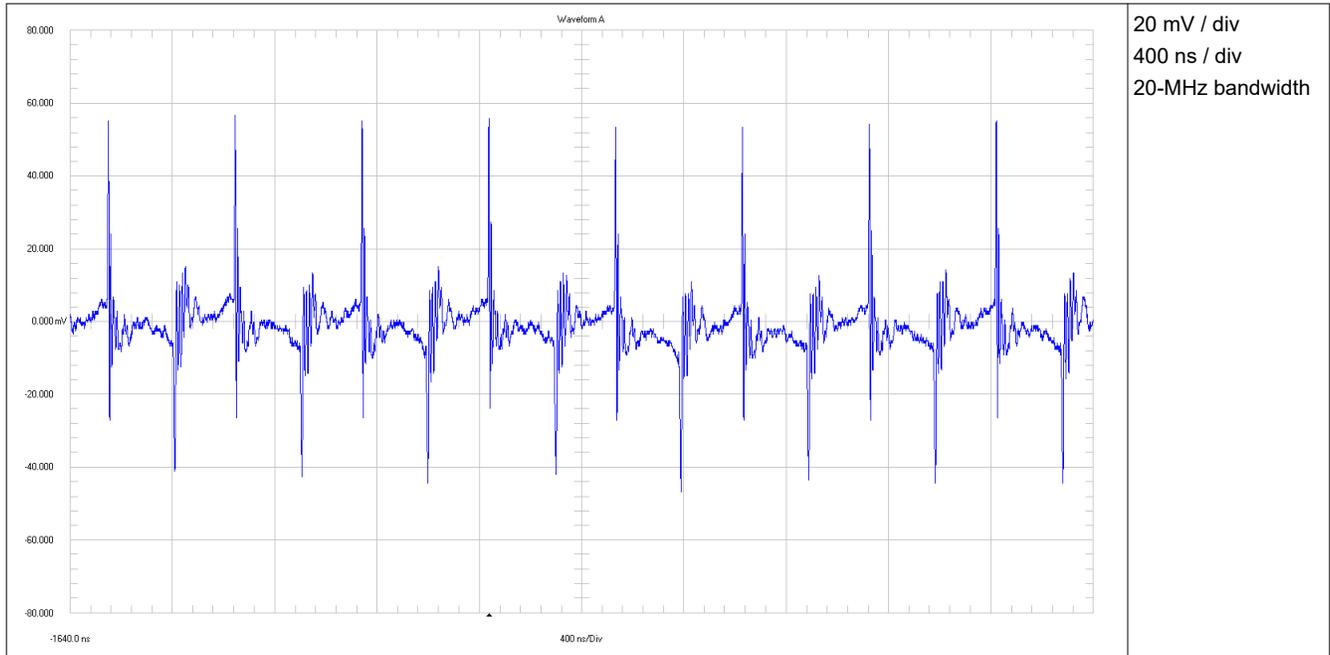


Figure 3-4. Input Voltage Ripple (20-MHz Bandwidth)

3.2.2 Full Bandwidth

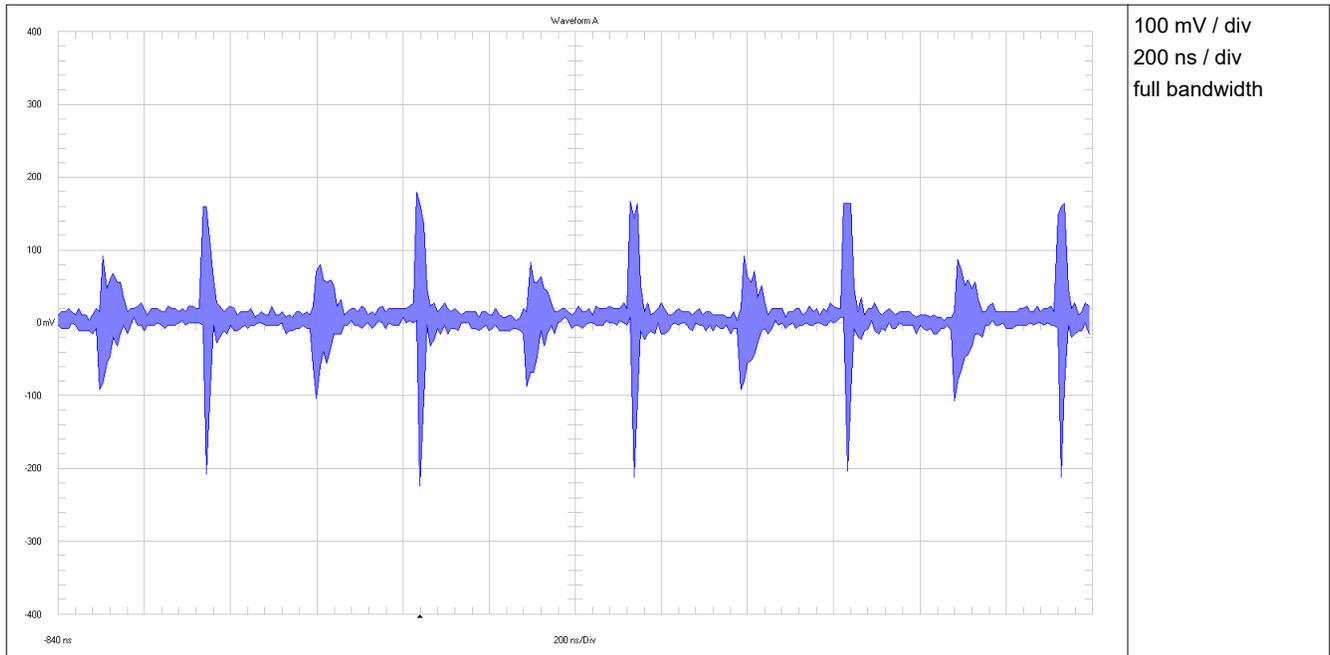


Figure 3-5. Input Voltage Ripple (Full Bandwidth)

3.3 Output Voltage Ripple

Output voltage ripple is shown in the following figure.

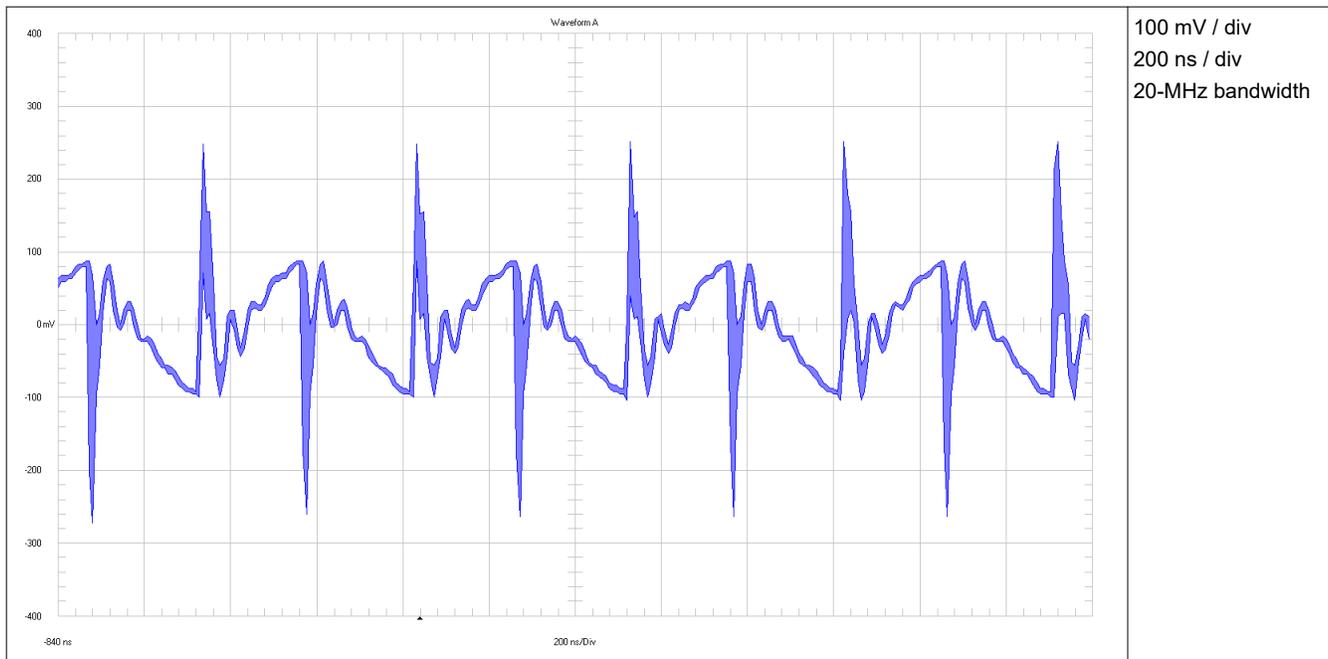


Figure 3-6. Output Voltage Ripple

3.4 Load Transients

Figure 3-7 shows a photo from the measurement setup for the transient response.

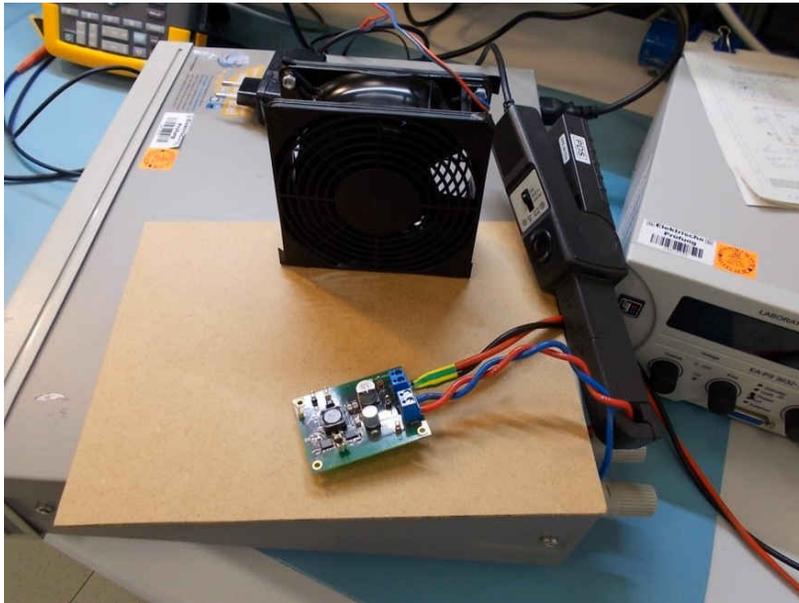


Figure 3-7. Photo From the Transient Setup

3.4.1 Switching Load From 1 A to 2 A

In Figure 3-8 the output voltage waveform has a deviation of about 0.5% with bandwidth setting of 10 kHz.

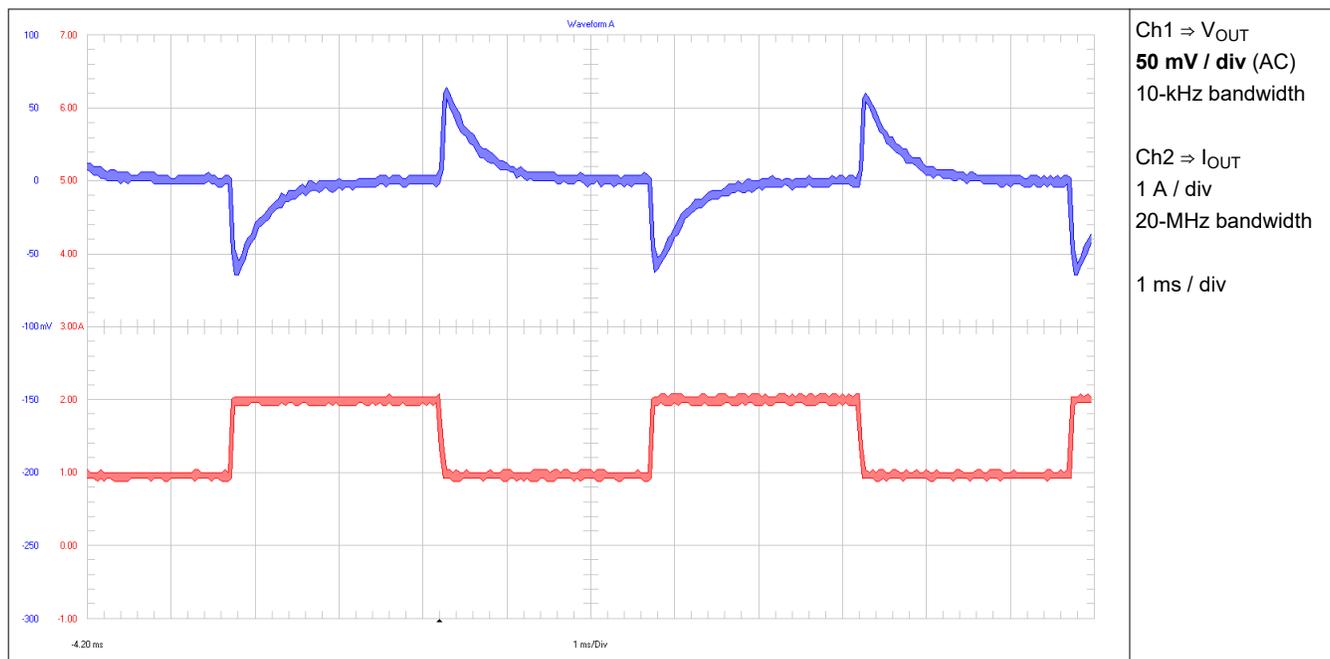


Figure 3-8. Load Transient 1 A to 2 A

3.4.2 Switching Load From 0.2 A to 2 A

3.4.2.1 50% Duty Cycle

In [Figure 3-9](#), the output voltage waveform has a deviation of about 1% with bandwidth setting of 10 kHz.

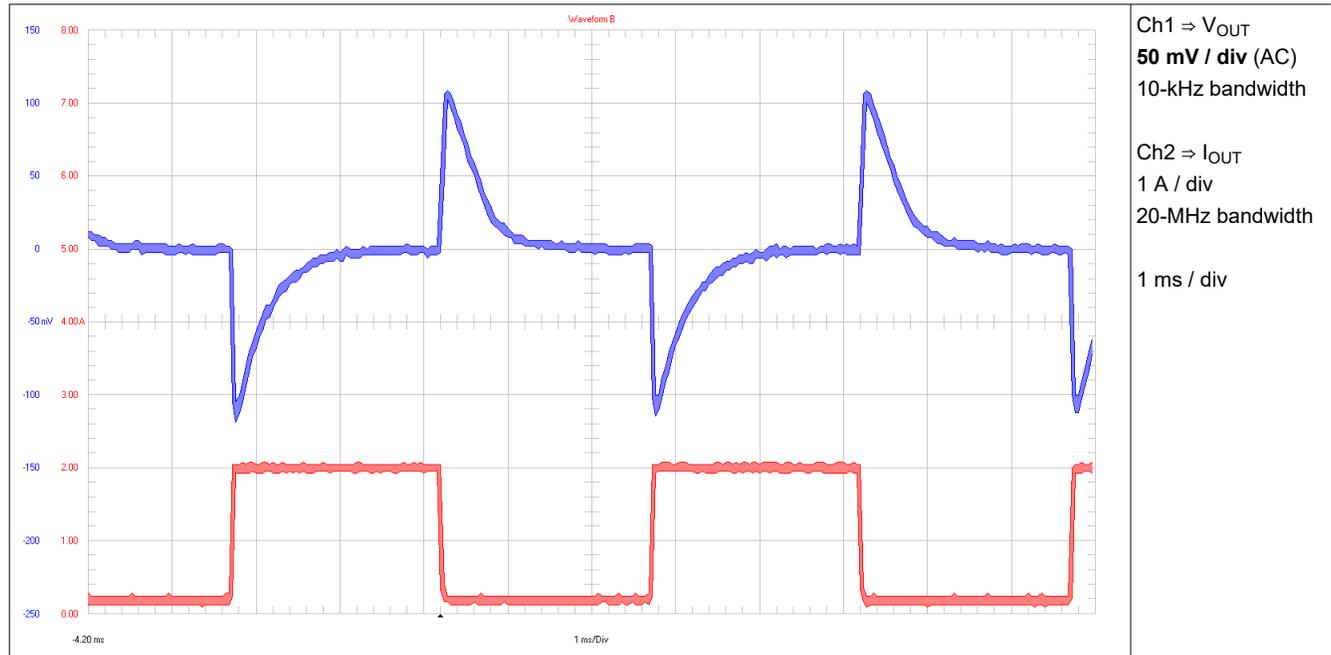


Figure 3-9. Load Transient 0.2 A to 2 A (50% Duty Cycle)

3.4.2.2 Low Duty Cycle ($T_{ON} = 3\text{ ms}$; $T_{OFF} = 30\text{ ms}$)

The requested custom load transient was rebuilt with electronic load HP6060B, see [Figure 3-10](#).

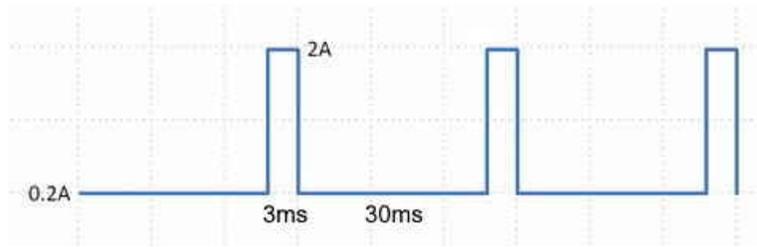


Figure 3-10. Requested Custom Load Transient

In [Figure 3-11](#) the output voltage waveform has a deviation of about 1% with bandwidth setting of 10 kHz.

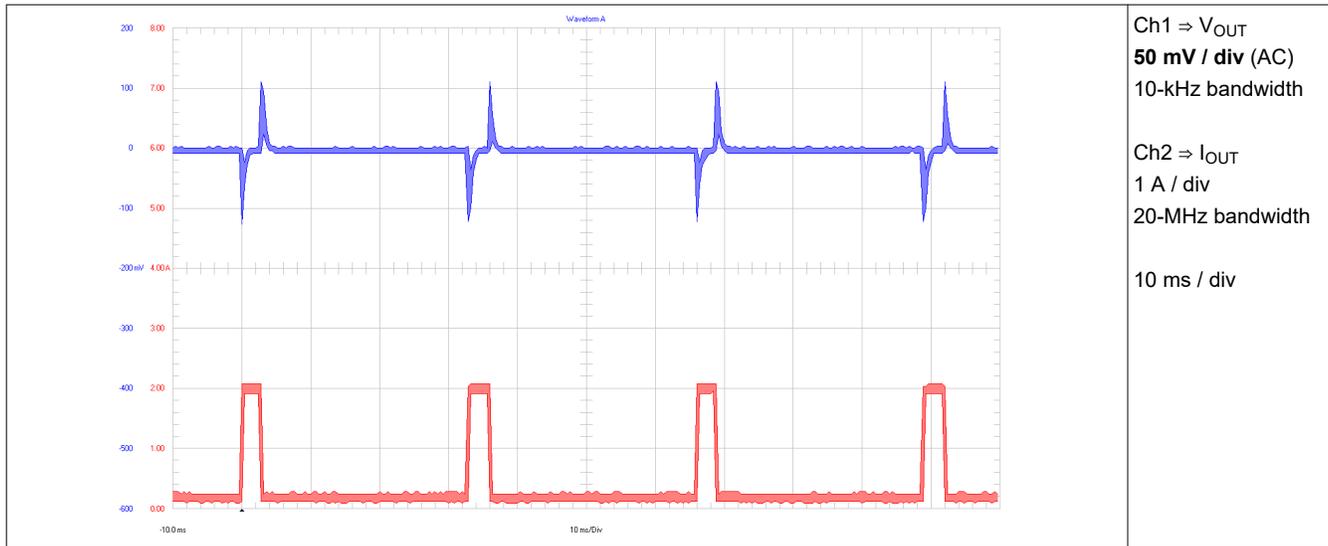


Figure 3-11. Load Transient 0.2 A to 2 A, Custom Waveform

The waveforms in [Figure 3-12](#) are the same waveforms as in [Figure 3-11](#) only with a different time scale.

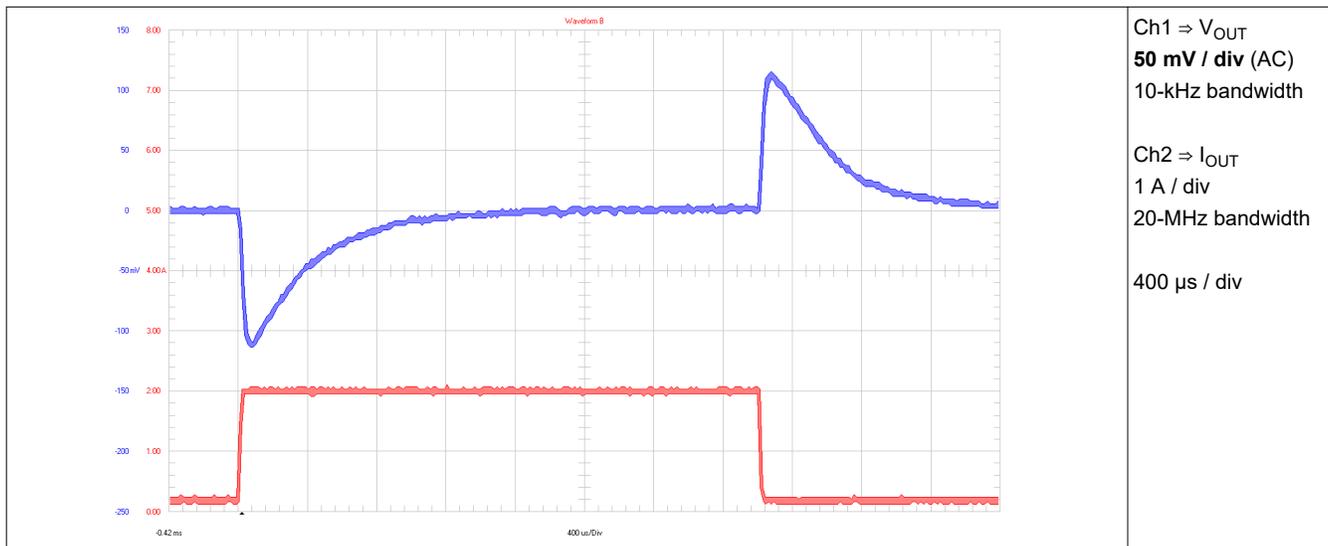


Figure 3-12. Load Transient 0.2 A to 2 A, Extracted Pulse 3 ms

3.5 Start-Up Sequence

For the waveforms in this section, the electronic load was set to 2 A and the power supply was plugged in. The soft start takes 10 ms at maximum load.

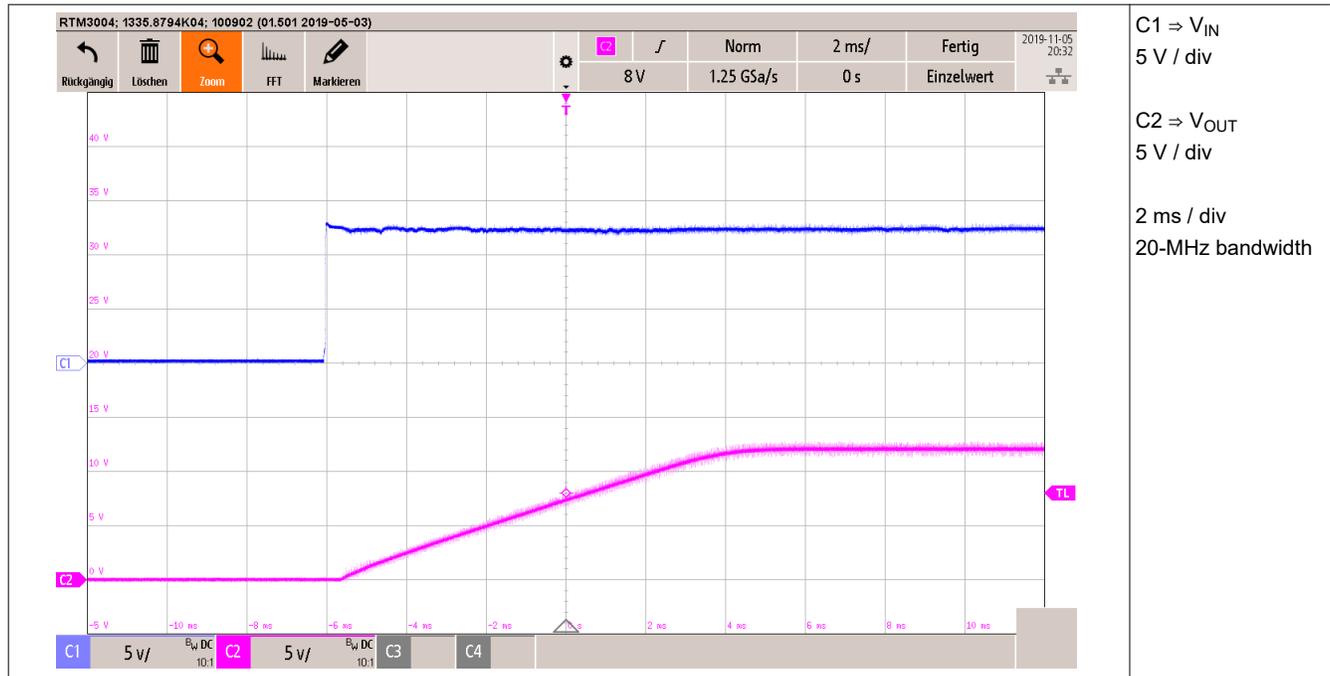


Figure 3-13. Start-up With 12-V Input Voltage

3.6 Shutdown Sequence

In the following waveform, the electronic load was set to 2 A and the power supply was disconnected.

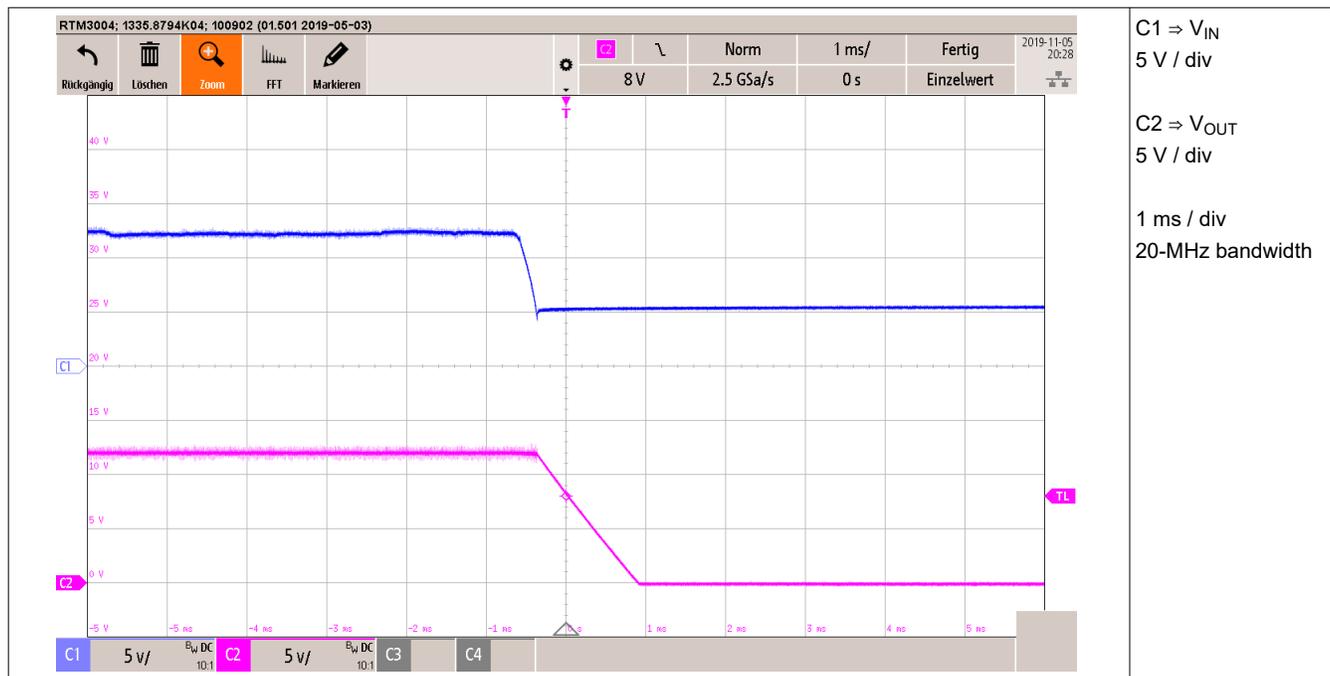


Figure 3-14. Shutdown With 12-V Input Voltage

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