Application Note

TLE8110EE

External Clamping with the TLE8110EE

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1 Abstract

The objective of this application note is to demonstrate the external clamping behavior of the TLE8110EE with external Zener Diode. The other two possibilities (external free wheeling diode and external free wheeling resistor) are not the focus of this application note - but they are briefly illustrated. The test conditions, the lab setup, the measurements and differences between the methods are described.

The clamping energy which can be safely dissipated inside the TLE8110EE is restricted to the energy values given in the data sheet. When there are loads with a higher clamping energy it is necessary to have an external clamping unit. For an overview of the permitted loads for the TLE8110EE, please refer to the relevant section of the data sheet.

The TLE8110EE is a member of the Flex family and is a smart 10 channel low-side switch for engine management loads (injectors, solenoids, relays, unipolar stepper motors…).

For a more detailed appreciation of the capabilities of the TLE8110EE, please refer to the data sheet.

2 Introduction

Note:

- All measurements in this application note have been undertaken accurately but the results are not guaranteed. This application note can be changed without prior notification
- Please refer to the official TLE8110EE data sheet for detailed technical descriptions.

2.1 Basic setup and graphical calculation of the clamping energy

Figure 1 shows the circuit with the TLE8110EE for the first measurements to declare the internal clamping behavior. The colored marked signals in Figure 1 are plotted in Figure 2.

Basic setup (this setup is used as basic setup for all circuits in this application note):

- Vbat…14 V
- Vdd…5 V
- Vcc...5 V
- R…9 Ohm
- L…15 mH
- Channel under test is Ch2
- Output current is in the range of 1.55 A

The reason to choose this load was that we are able to compare the behaviors from external clamping in a direct way with the TLE8110EE clamping. There are no problems for the TLE8110EE without external clamping with this load.

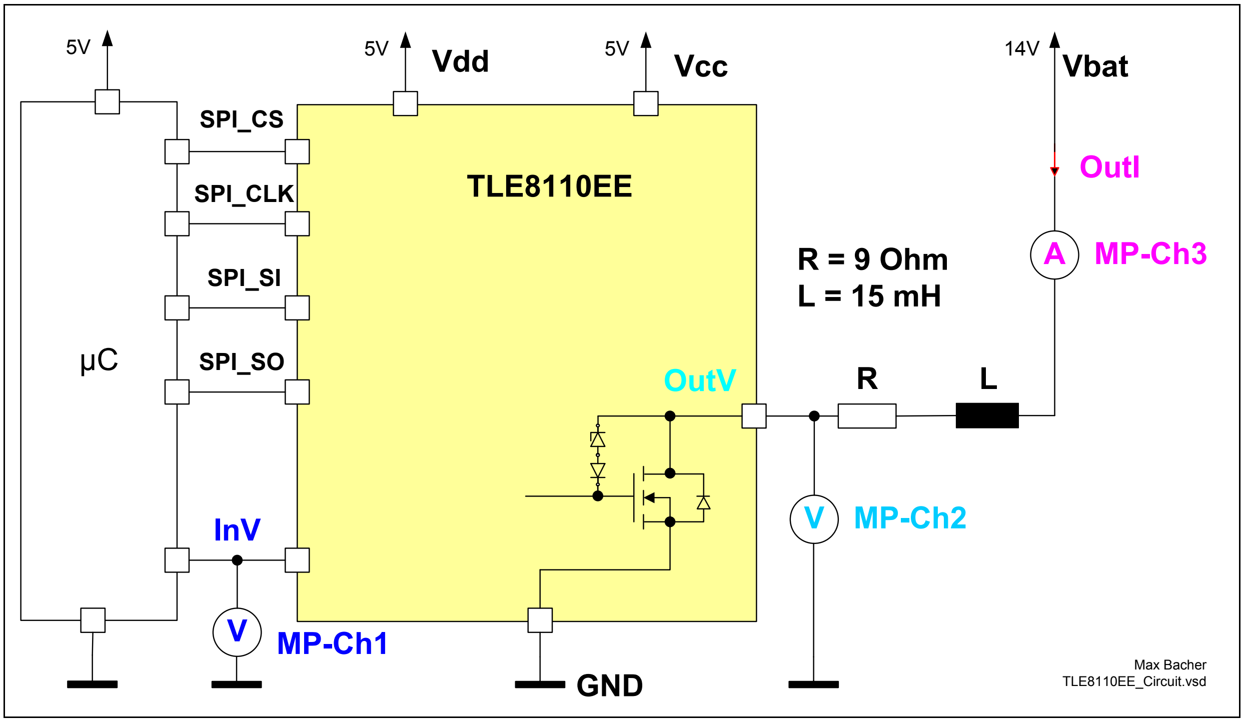

Figure 1 TLE8110EE connected to a load

Figure 2 shows the clamping behavior. The “Math Channel” (the red one) describes the clamping power and is calculated as channel 2 (output voltage) multiplied by channel 3 (the output current).

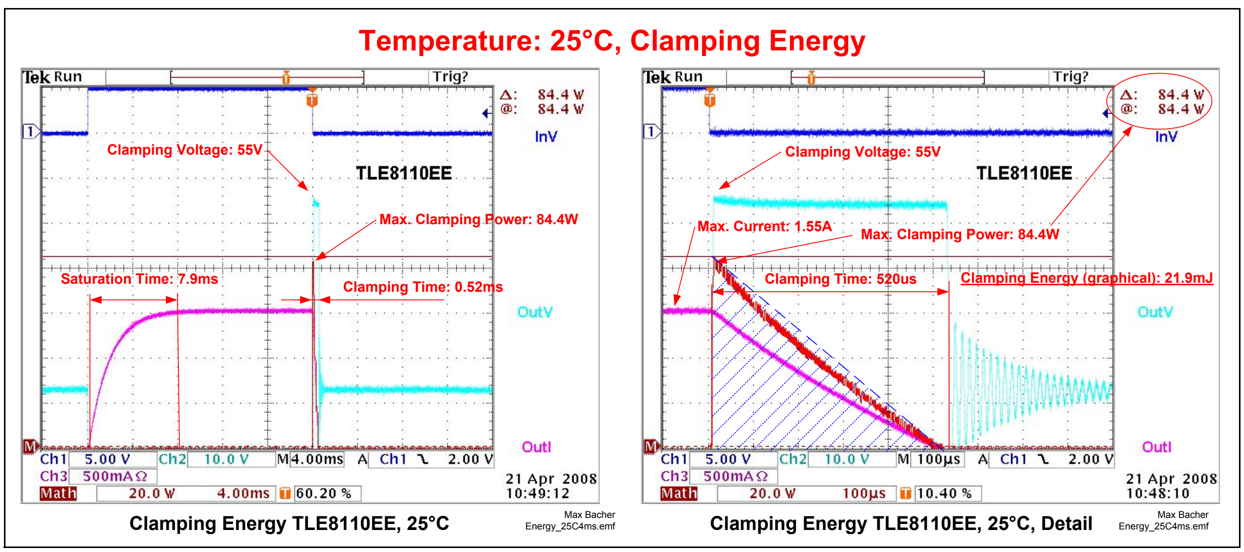

Figure 2 Clamping with inductive and ohmic load to show the clamping energy

The clamping energy can be calculated in a graphical way. The approximate clamping energy which is easy to calculate is the area below the dashed blue line marked with dotted blue lines, seen on the right side of Figure 2. When we calculate the energy graphical we get this value: **E = 21.94mJ** (Max. clamping power * 0.5 * clamping time = 84.4W * 520µs * 0.5).

2.2 Calculate clamping energy

There are two well-known equations to calculate the clamping energy for an inductive load. Equation 1 has to be used when there is also an ohmic part for the load. Equation 2 could be used when there is no ohmic part - or the ohmic part is near zero - for the load.

Abbreviations for the Equations:

- V_{AZ}…Voltage Active Zener Clamping (for low side switches: $V_{AZ} = V_{DS(CL)}$)
- $V_{DS(CL)}$…Voltage Drain Source during Clamping
- V_{bat}..Battery Voltage
- I_0…Saturation Current

$$E = V_{DS(CL)} \cdot \left[\frac{V_{bat} - V_{DS(CL)}}{R} \cdot \ln\left(1 - \frac{R \cdot I_0}{V_{bat} - V_{DS(CL)}}\right) + I_0 \right] \cdot \frac{L}{R}$$

Equation 1 For the clamping energy of a low side switch with an ohmic part of the inductive load

$$E = \frac{1}{2} \cdot L \cdot I_0^{\,2} \cdot \frac{V_{DS(CL)}}{V_{DS(CL)} - V_{bat}}$$

Equation 2 For the clamping energy of a low side switch with no ohmic part of the inductive load

For the basic setup - shown in Figure 1 - we calculate with the Equation 1 the clamping energy: **E = 19.79mJ**. Please be aware: We have to use the Equation 1 because there is an ohmic part for the load. When we calculate with Equation 2 than we get: **E = 24.17mJ**.

An overview about the different possibilities to get a result for the clamping energy:

- With graphical calculation: **E = 21.94mJ**
- With Equation 1: **E = 19.79mJ**
- With Equation 2: **E = 24.17mJ**

3 External Zener diode

3.1 Application circuit

Figure 3 shows the circuit of the TLE8110EE with Zener diode for external clamping. The colored marked signals in Figure 3 are plotted in Figure 4 to Figure 15 to have a better overview.

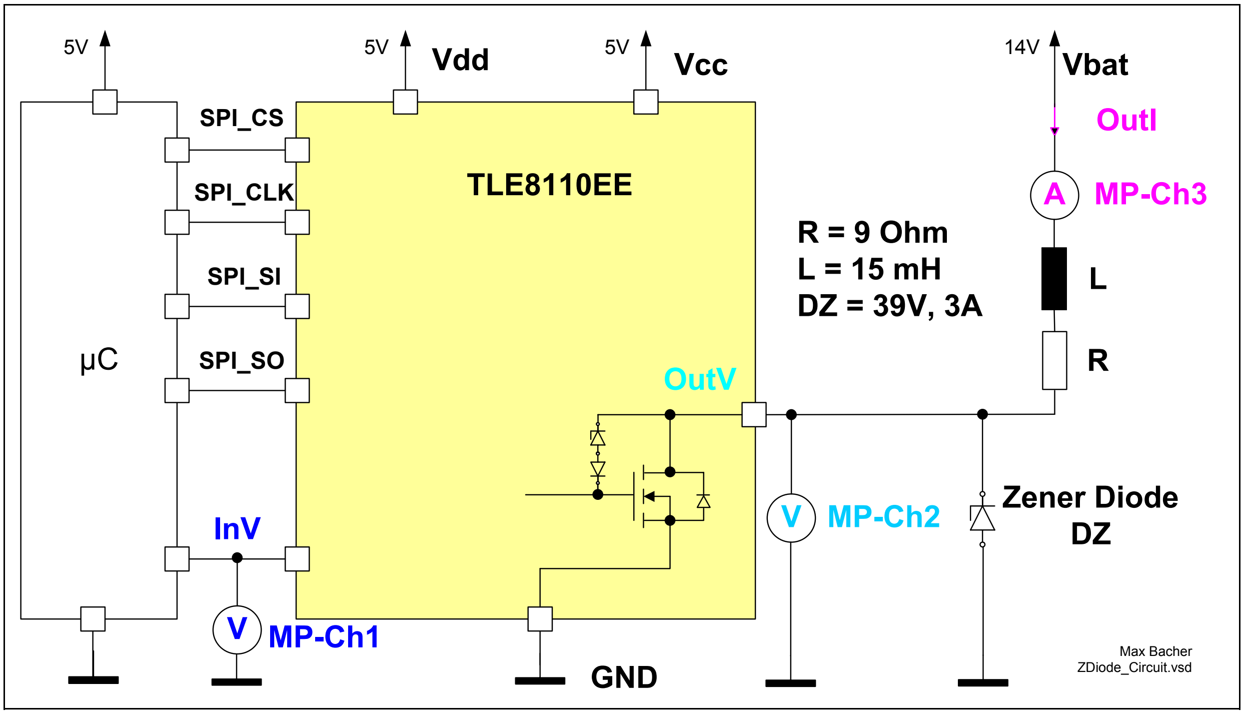

Figure 3 TLE8110EE with Zener diode for external clamping

3.2 Measurements

Figure 4 to Figure 6 show the clamping behavior with the Zener diode for -40°C. This is the temperature for the TLE8110EE and also for the Zener diode. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

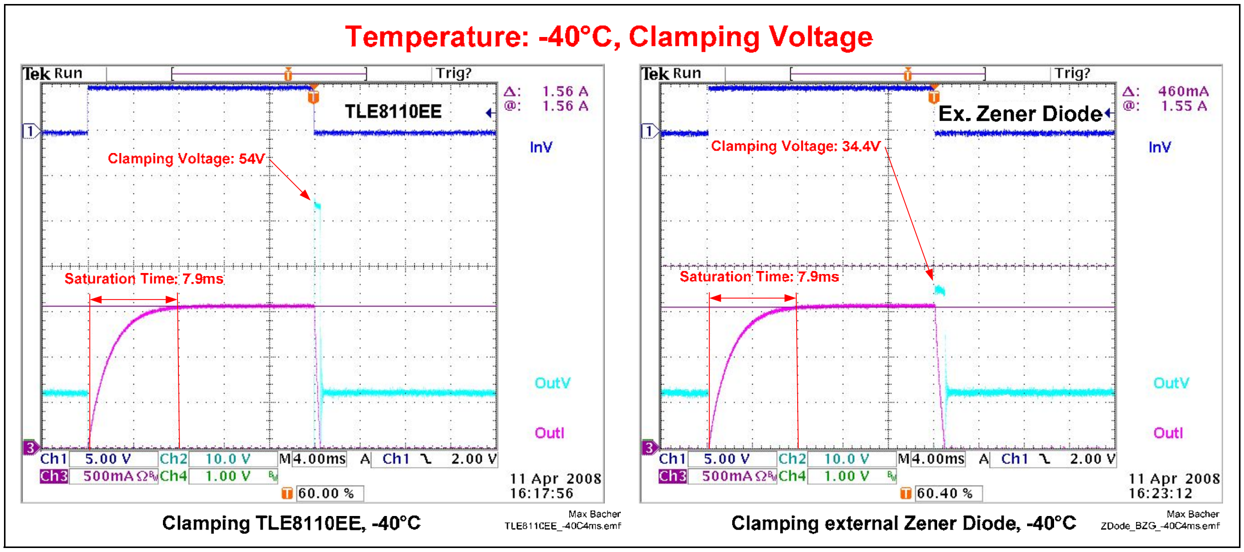

Figure 4 Comparing the clamping voltages for internal and external clamping with Zener diode at -40°C

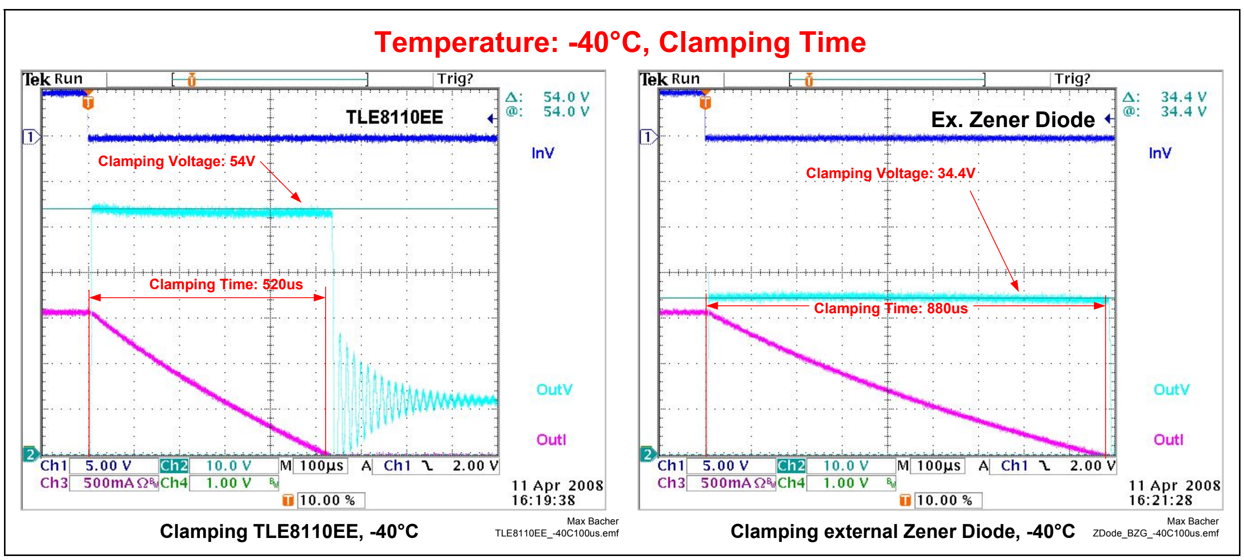

Figure 5 Comparing the clamping time for internal and external clamping with Zener diode at -40°C

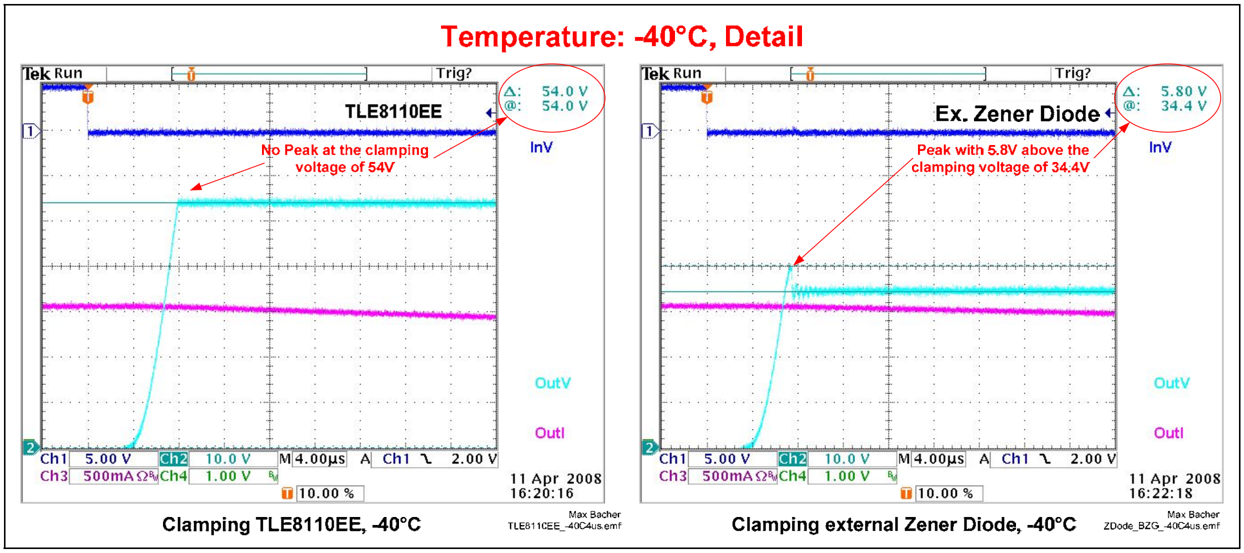

Figure 6 Comparing the voltage peak for internal and external clamping with Zener diode at -40°C

Figure 7 to Figure 9 show the clamping behavior with the Zener diode for 25°C. This is the temperature for the TLE8110EE and also for the Zener diode. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

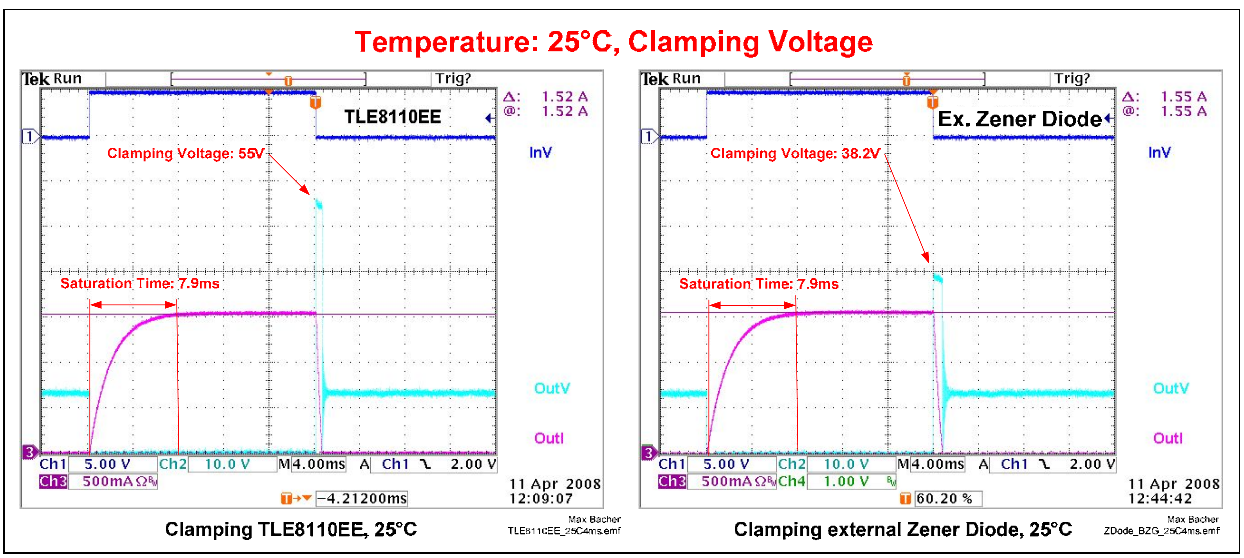

Figure 7 Comparing the clamping voltages for internal and external clamping with Zener diode at 25°C

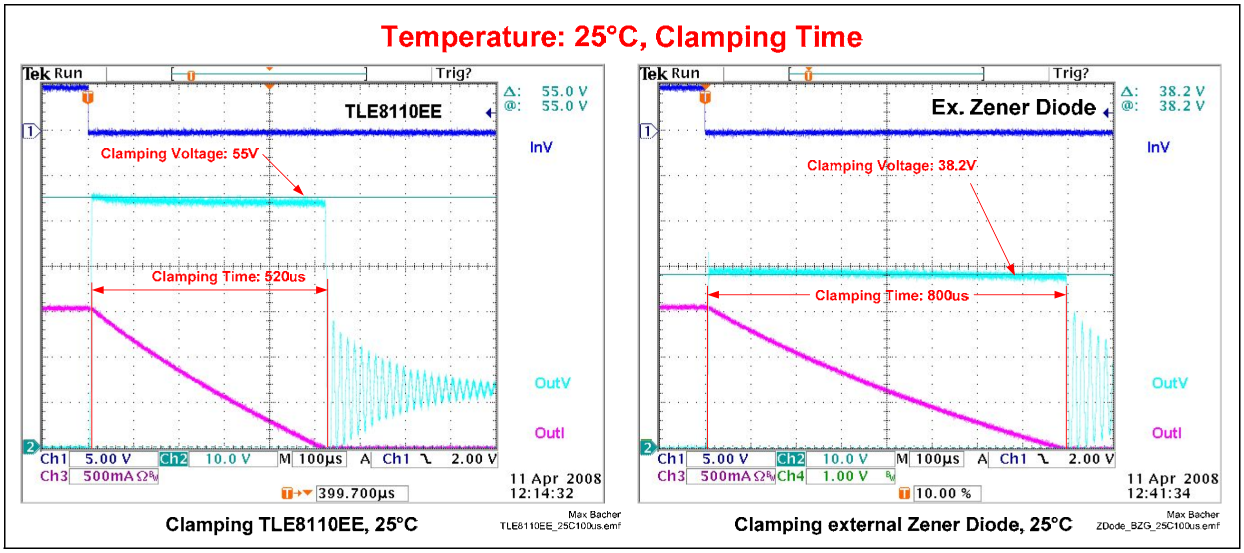

Figure 8 Comparing the clamping time for internal and external clamping with Zener diode at 25°C

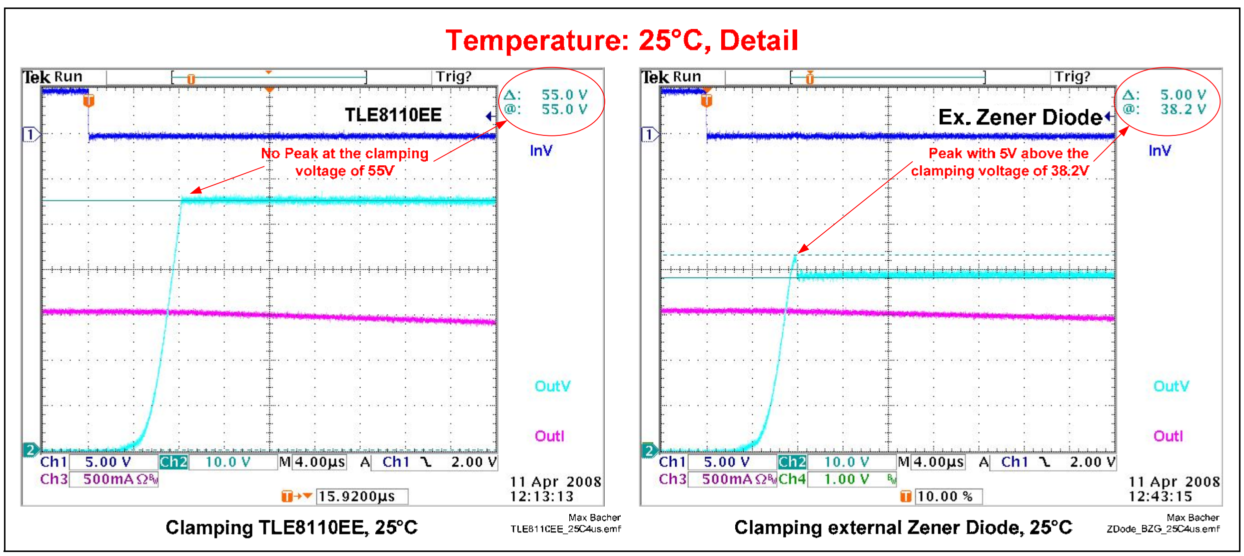

Figure 9 Comparing the voltage peak for internal and external clamping with Zener diode at 25°C

Figure 10 to Figure 12 show the clamping behavior with the Zener diode for 125°C. This is the temperature for the TLE8110EE and also for the Zener diode. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

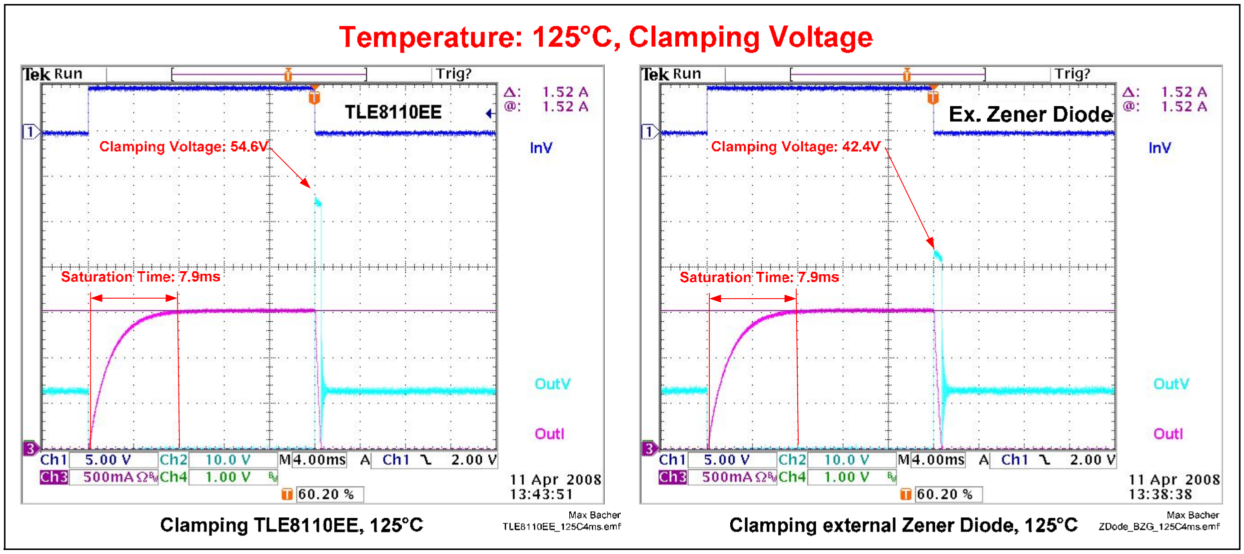

Figure 10 Comparing the clamping voltages for internal and external clamping with Zener diode at 125°C

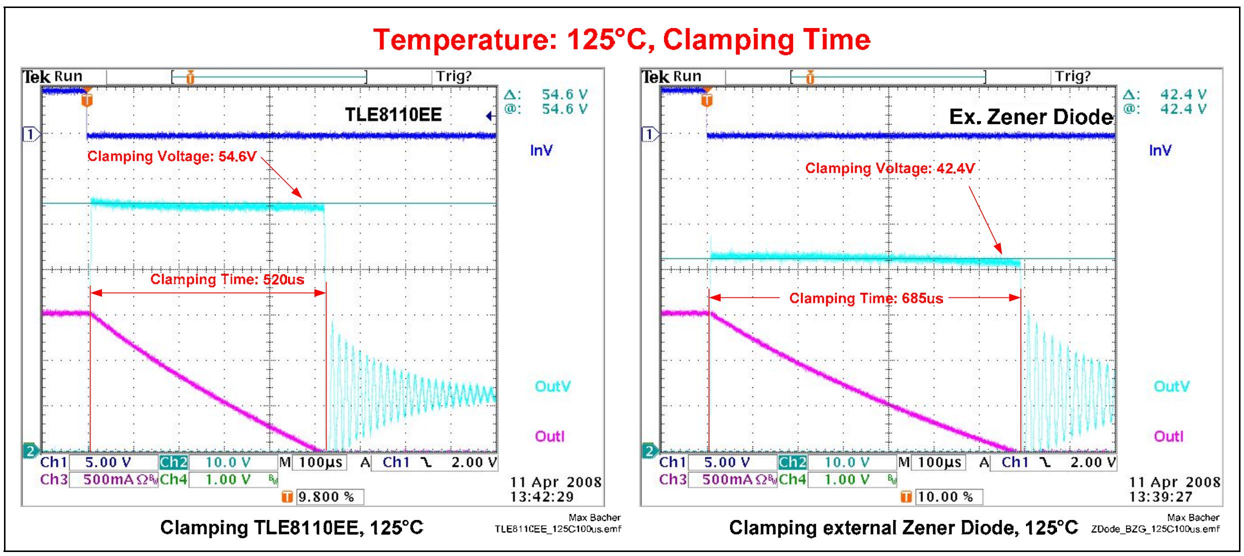

Figure 11 Comparing the clamping time for internal and external clamping with Zener diode at 125°C

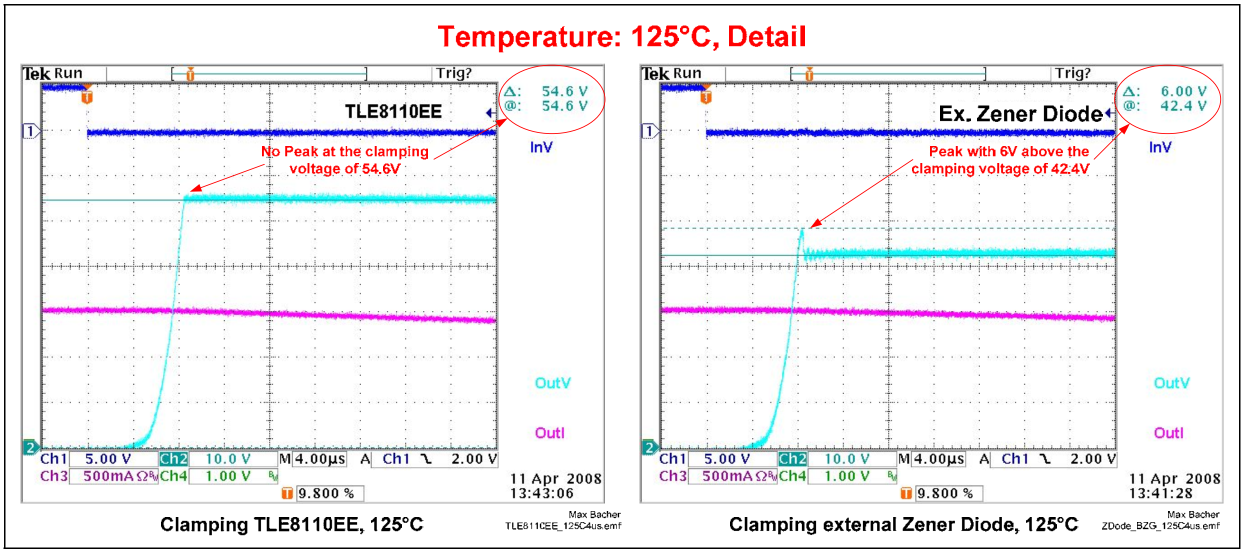

Figure 12 Comparing the voltage peak for internal and external clamping with Zener diode at 125°C

Figure 13 to Figure 15 show the clamping behavior with the Zener diode for 150°C. This is the temperature for the TLE8110EE and also for the Zener diode. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

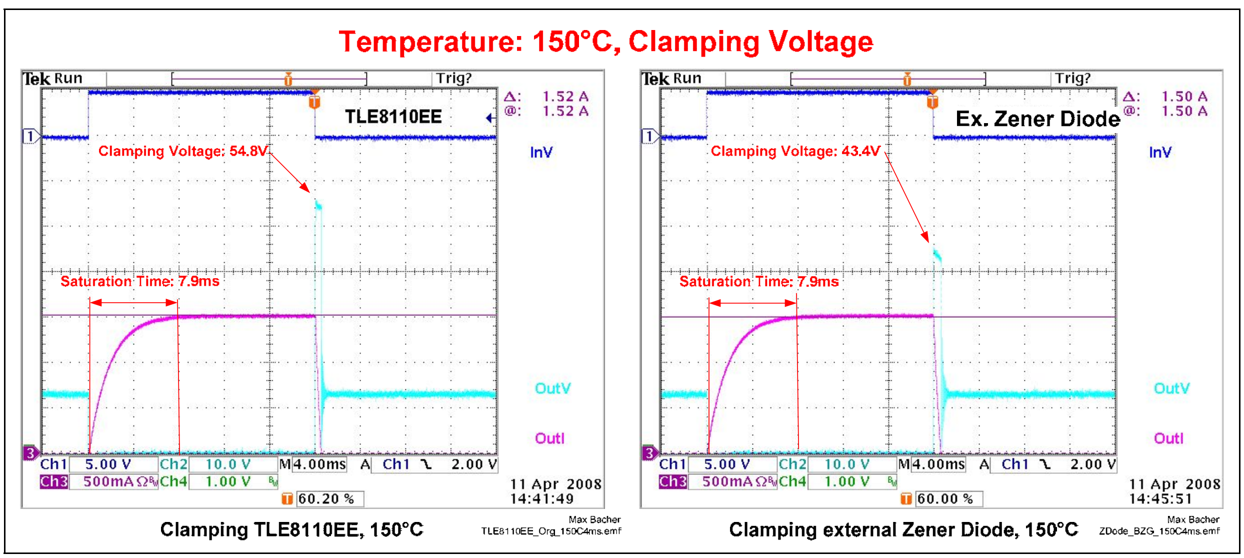

Figure 13 Comparing the clamping voltages for internal and external clamping with Zener diode at 150°C

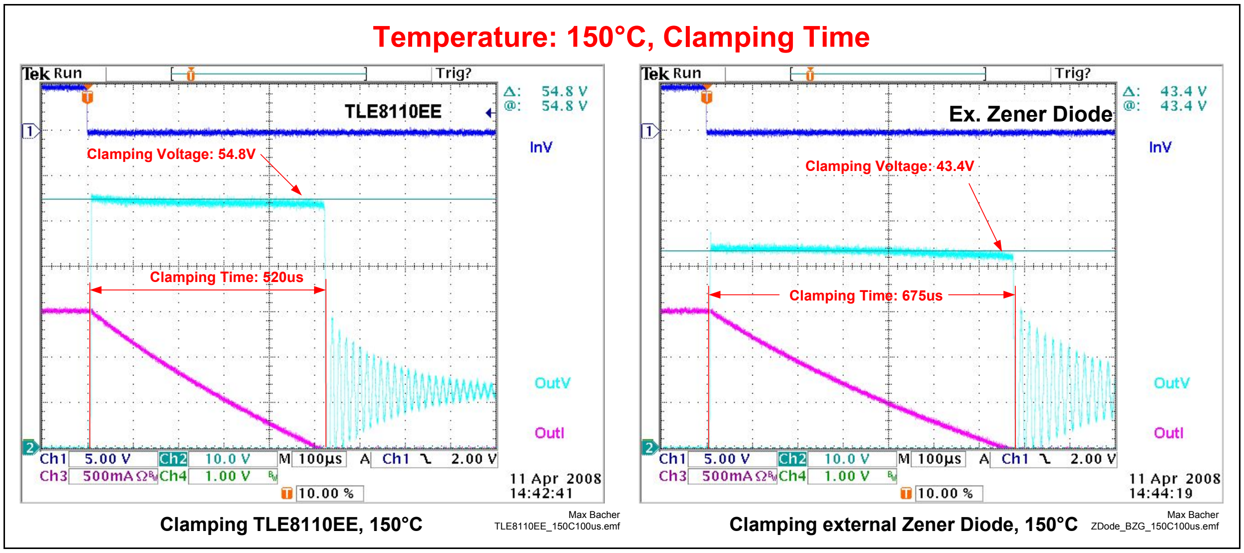

Figure 14 Comparing the clamping time for internal and external clamping with Zener diode at 150°C

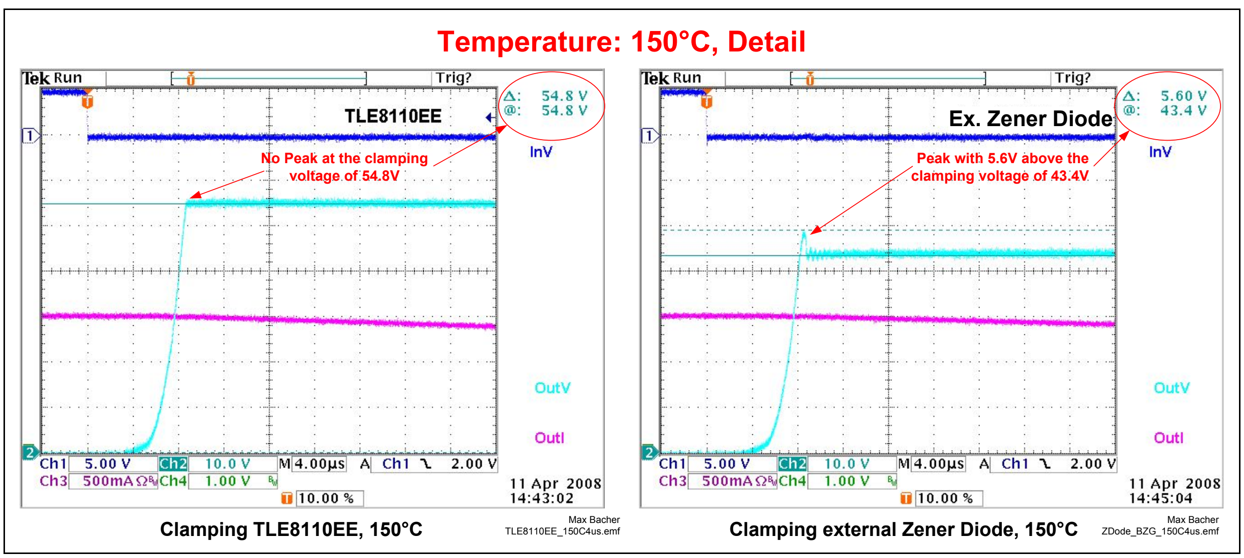

Figure 15 Comparing the voltage peak for internal and external clamping with Zener diode at 150°C

3.3 Conclusion

A temperature-dependant behavior for external clamping with a Zener diode can be observed. Figure 16 shows the characteristic curve of the used Zener diode over temperature. Zener voltage increases with temperature, but clamping time decreases. There is always a voltage peak for 1µs with near 5.5V overvoltage when the clamping with Zener diode starts.

The worst behavior with the Zener diode for external clamping is measured at -40°C. With this temperature a clamping voltage in the range of 34.4 Volt is obtained. This voltage could be a problem with load dump when there is no lower load-dump protection such as additional clamping. Also the clamping time at 880µs is much longer than the clamping time of the TLE8110EE which is 520µs.

The use of this circuit is, however, not common. The use of a (schottky) diode in series to the Zener diode is highly recommended. With this circuit it is possible to avoid problems with reverse currents – just like wrong polarity with the battery. In case of a reverse current it is possible destroy the Zener diode without the polarity protection of an additional diode.

A Zener diode with nominal 3A and 39V was selected to ensure operation is always below the minimum clamping voltage of the TLE8110EE. For the normal operating temperature of 125°C a clamping voltage in the range of 42.5V is obtained from the 39V Zener diode. With 150°C a clamping voltage in the range of 43.4 Volt is obtained - rather near the minimum clamping voltage for the TLE8110EE. For exact values and thresholds for the clamping voltages of the device, please refer to the data sheet of the TLE8110EE. The maximum clamping voltage of the Zener diode must not reach or exceed the minimum clamping voltage of the TLE8110EE. Calculation and comparison of the possible thresholds of the clamping voltages, to avoid destruction of the TLE8110EE through use of a setup which could reach a higher energy than permitted in the data sheet, is strongly recommended.

No distinct temperature-dependant behavior for the TLE8110EE clamping parameters, such as current behavior, clamping time and clamping voltage, was observed.

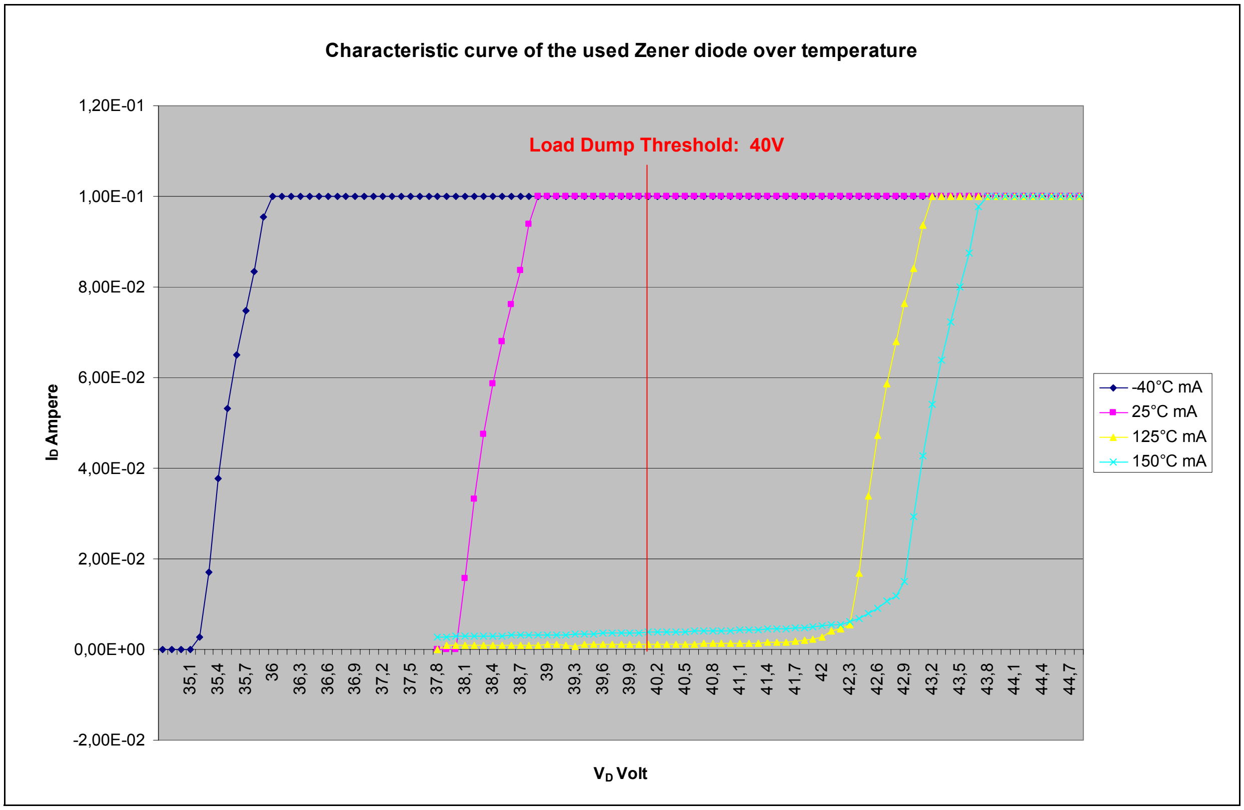

Figure 16 Characteristic curve of the used Zener diode over temperature

4 External free wheeling diode

4.1 Application circuit

Figure 17 shows the circuit of the TLE8110EE with FWD (**F**ree **W**heeling **D**iode) for external clamping. The colored marked signals in Figure 17 are plotted in Figure 18 and Figure 19 to have a better overview.

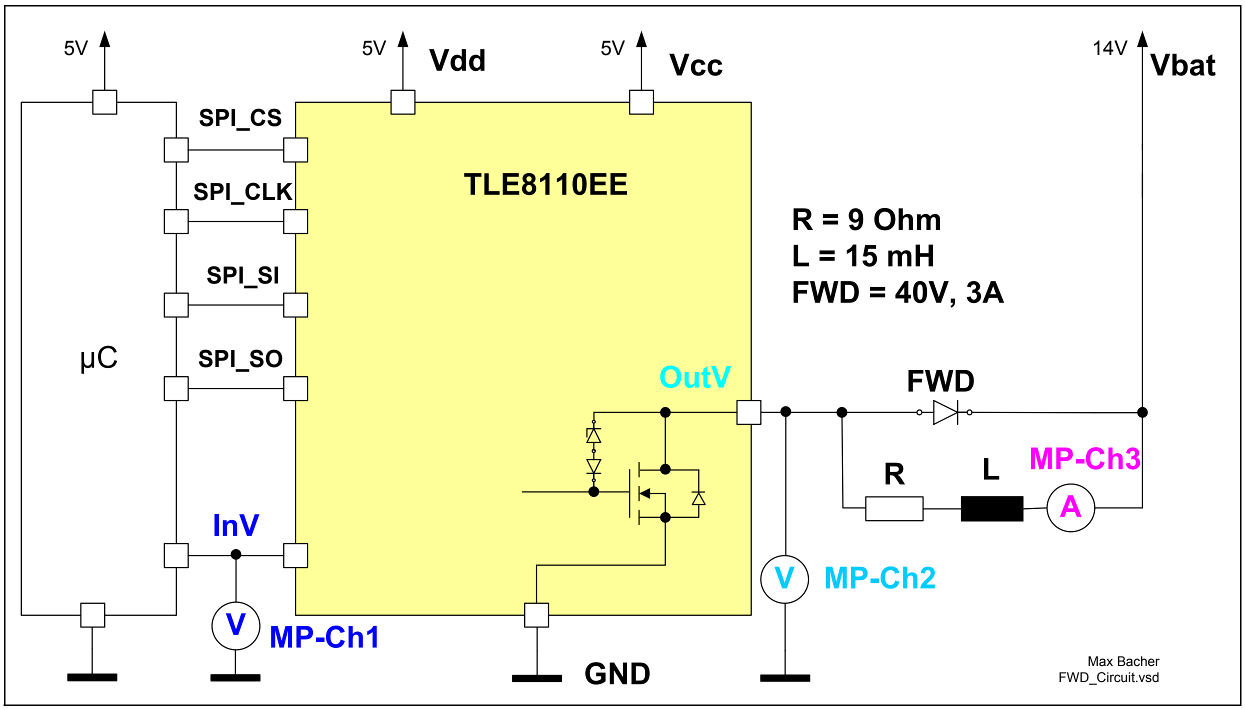

Figure 17 TLE8110EE with FWD for external clamping

4.2 Measurements

Figure 18 and Figure 19 show the clamping behavior with the FWD for 25°C. This is the temperature for the TLE8110EE and also for the FWD. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

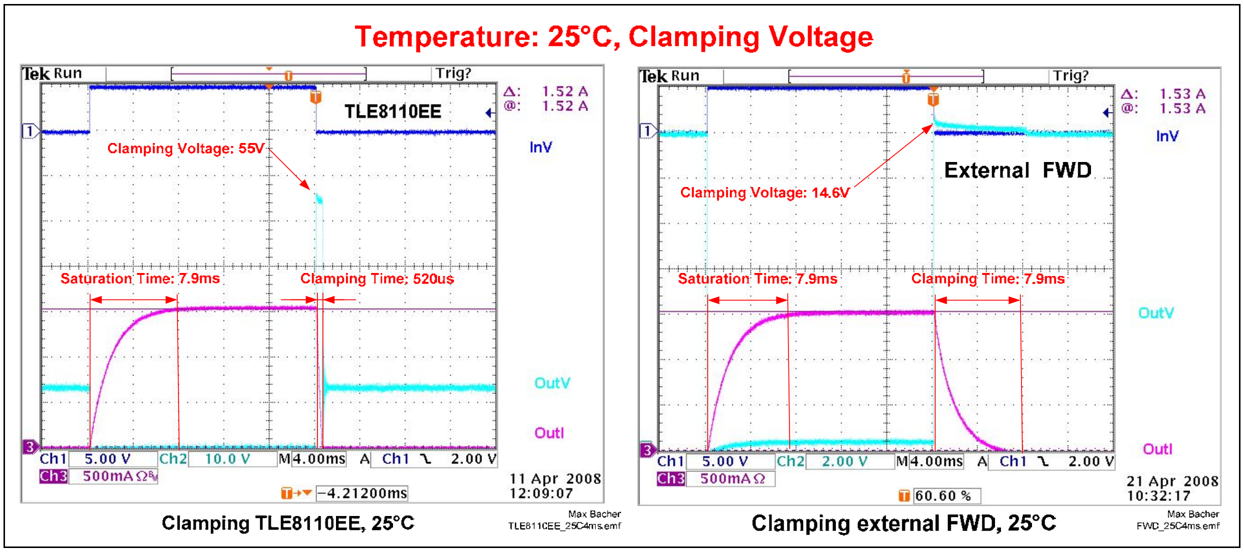

Figure 18 Comparing the clamping voltages for internal and external clamping with FWD at 25°C

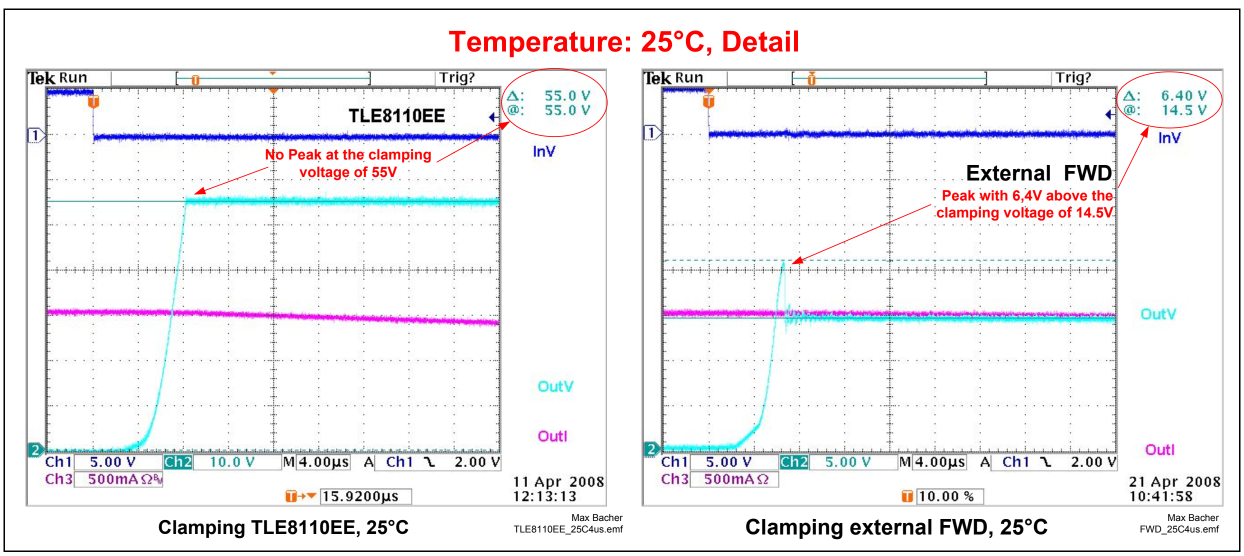

Figure 19 Comparing the voltage peak for internal and external clamping with FWD at 25°C

4.3 Conclusion

With FWD the expected behavior was observed. A 3A schottky diode with a maximum repetitive reverse voltage in the range of 40V was used. Figure 20 shows the characteristic curve of this schottky diode for 25°C and from 0 to 1A.

The clamping time has increased by an order of magnitude (15 times, to be more exact) compared to TLE8110EE and is now in the same range as the saturation time. However, the clamping voltage is very small. There is always a voltage peak for 1µs with near 6.5V overvoltage when the clamping with the FWD starts.

The use of this circuit is, however, not common. In case of wrong polarity of the battery there could be a large reverse current which could destroy the devices.

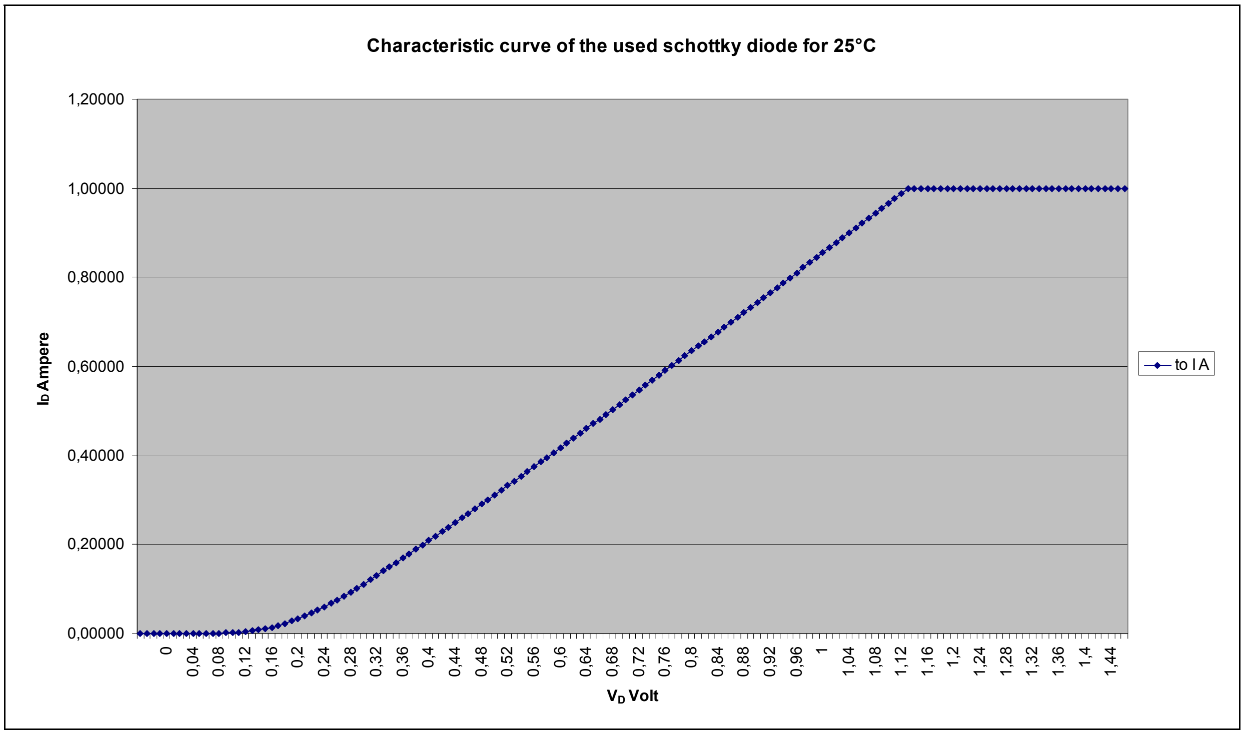

Figure 20 Characteristic curve of the used schottky diode

5 External resistor

5.1 Application circuit

Figure 21 shows the circuit of the TLE8110EE with parallel resistor (Rp) for external clamping. The colored marked signals in Figure 21 are plotted in Figure 22 to Figure 27 to have a better overview.

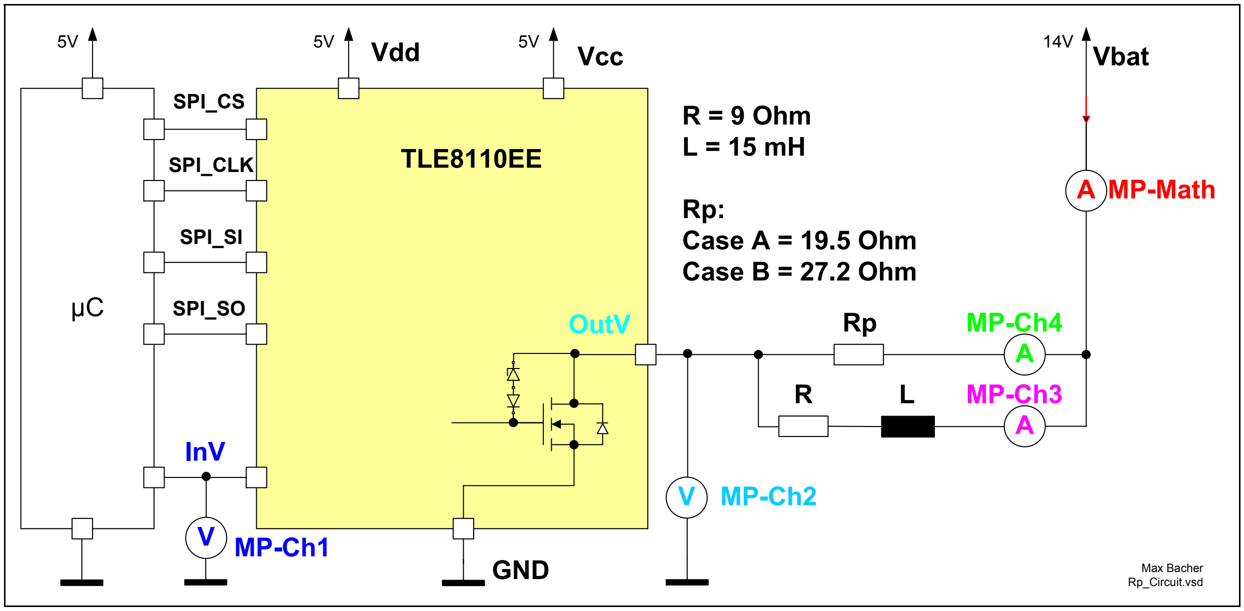

Figure 21 TLE8110EE with parallel resistor for external clamping

5.2 Measurements

Figure 22 to Figure 24 show the clamping behavior with parallel resistor of 19.5 Ohm at 25°C. This is the temperature for the TLE8110EE and also for Rp. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

The “Math Channel” (the red one) describes the current “MP-Math” in Figure 21 and is calculated as channel 3 (MP-Ch3 – the load current) plus channel 4 (MP-Ch4 – the Rp current).

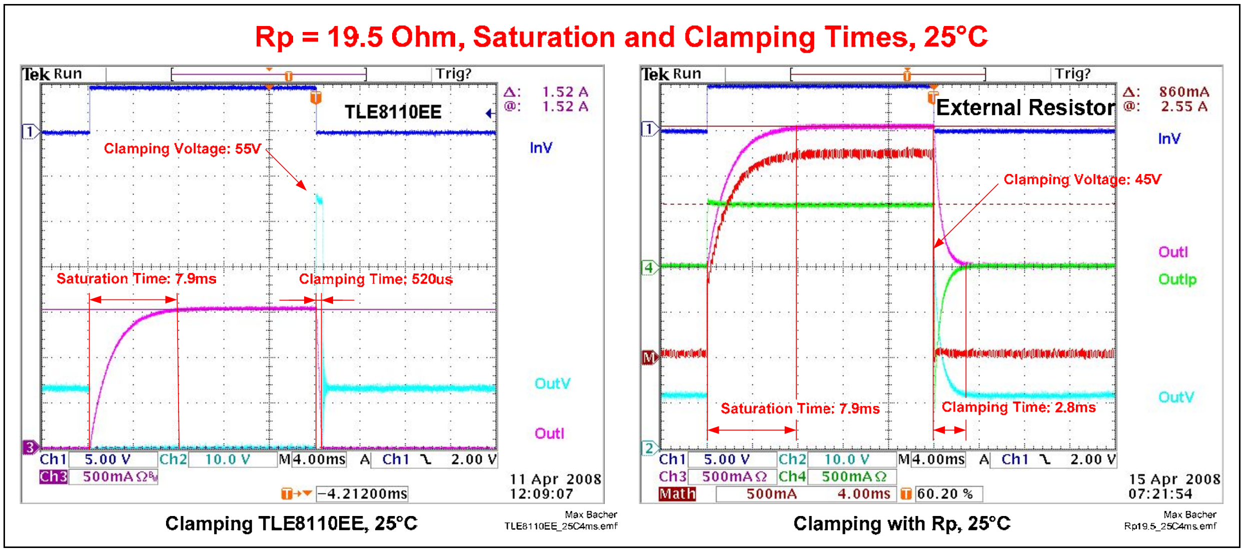

Figure 22 Comparing the clamping time for internal and external clamping with Rp=19.5Ohm

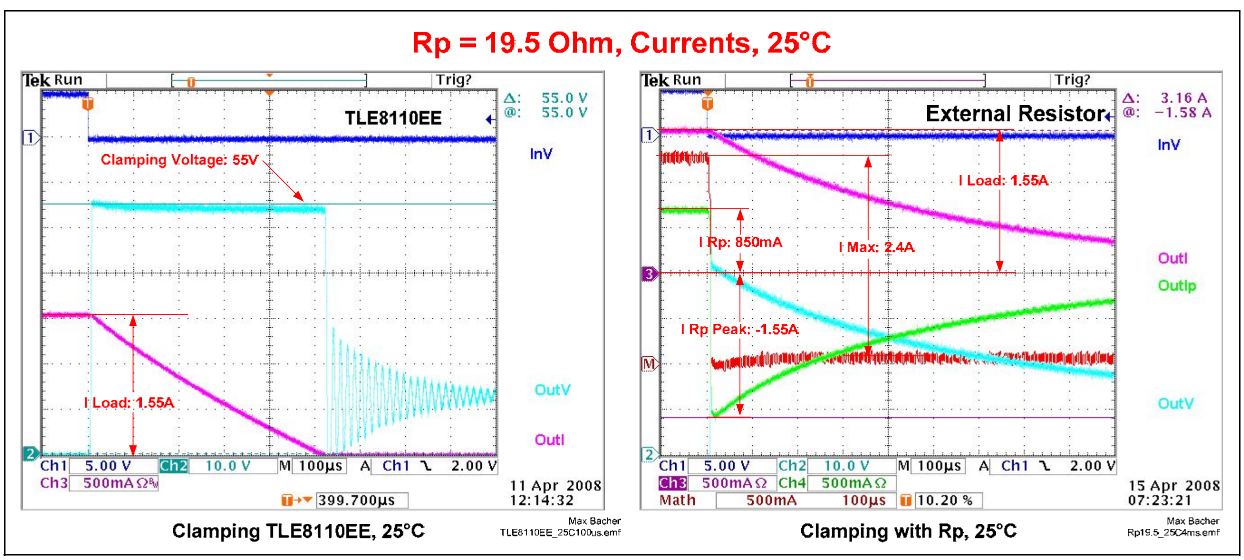

Figure 23 Comparing the currents for internal and external clamping with Rp=19.5Ohm

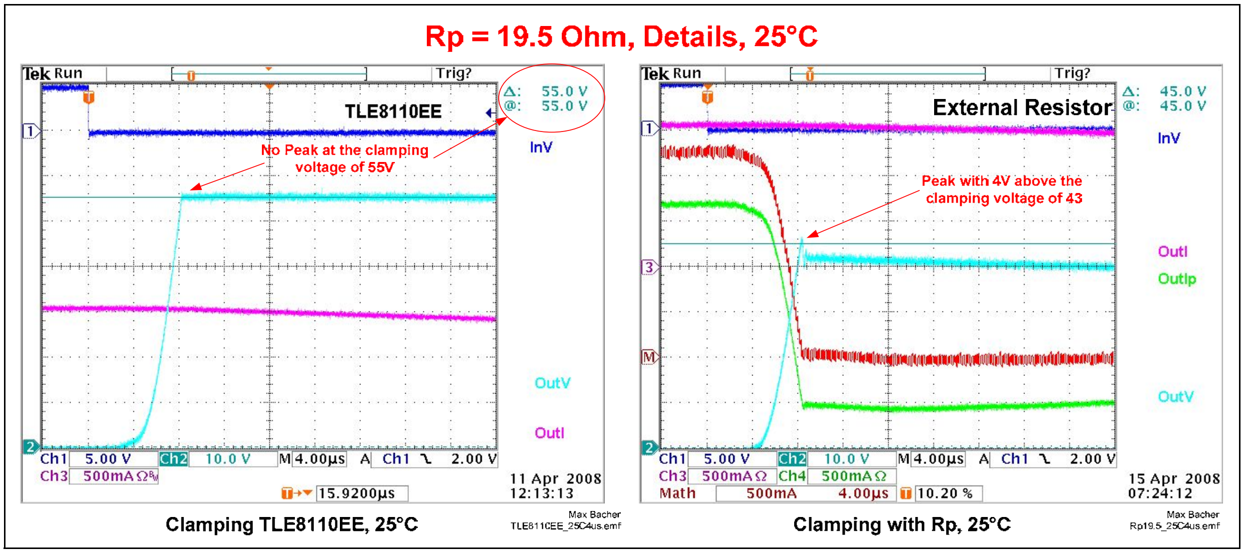

Figure 24 Comparing the voltage peak for internal and external clamping with Rp=19.5Ohm

Figure 25 to Figure 27 show the clamping behavior with parallel resistor of 27.2 Ohm at 25°C. This is the temperature for the TLE8110EE and also for Rp. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

The "Math Channel" (the red one) describes the current "MP-Math" in Figure 21 and is calculated as channel 3 (MP-Ch3 – the load current) plus channel 4 (MP-Ch4 – the Rp current).

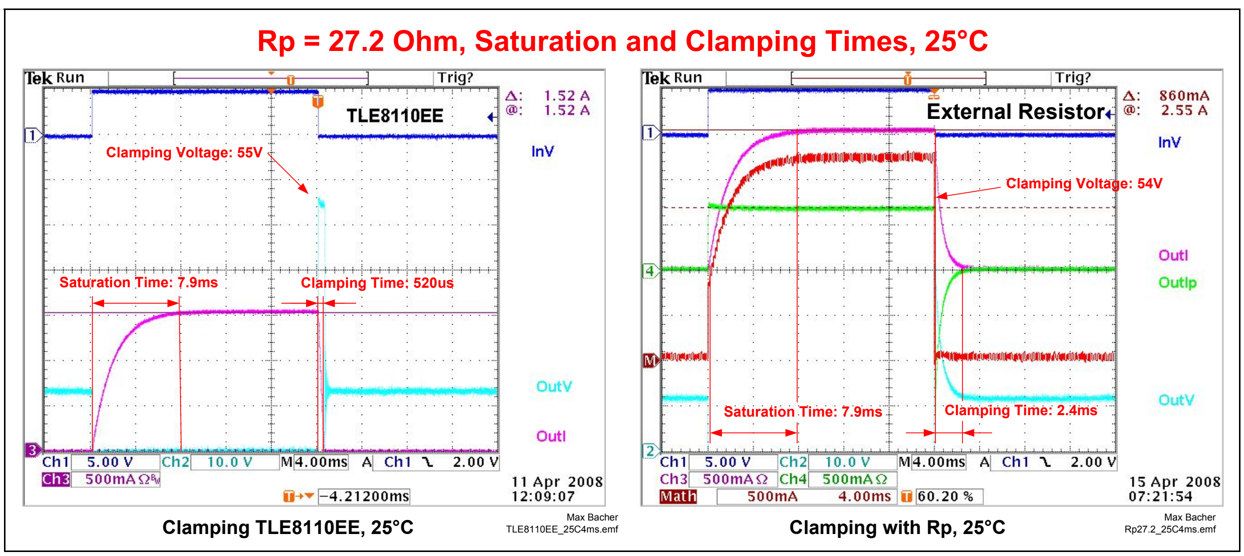

Figure 25 Comparing the clamping time for intern and external clamping with Rp=27.2Ohm

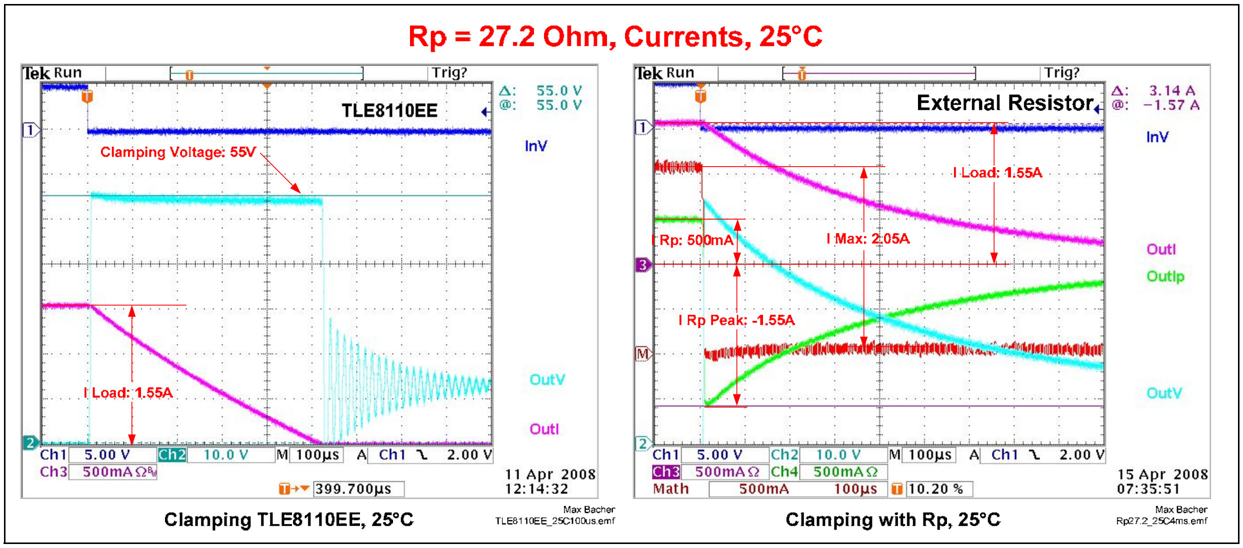

Figure 26 Comparing the currents for internal and external clamping with Rp=27.2Ohm

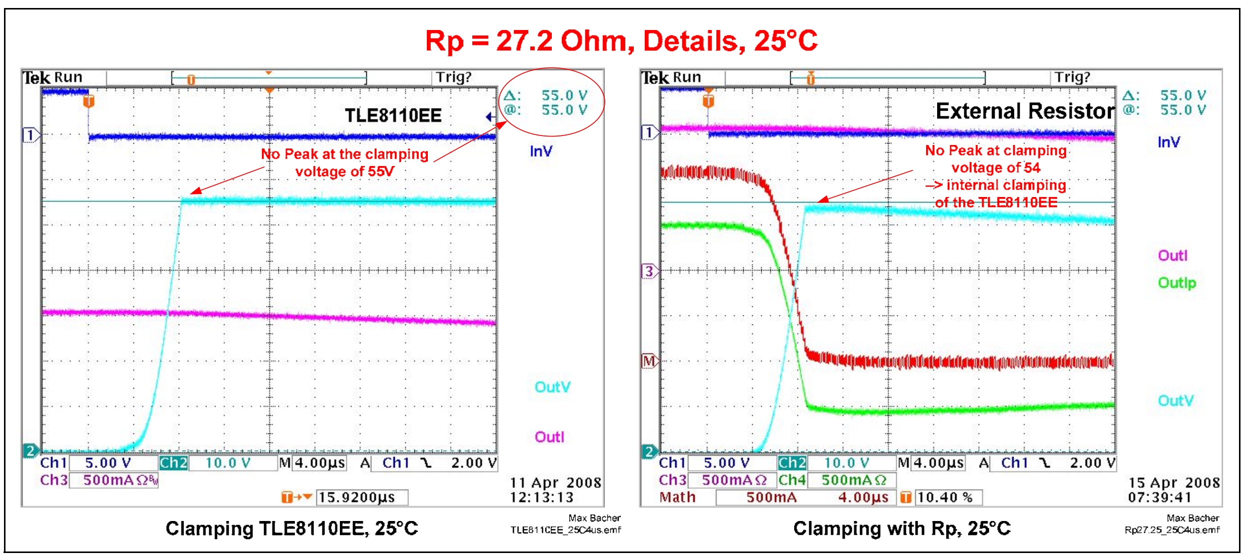

Figure 27 Comparing the voltage peak for internal and external clamping with Rp=27.2Ohm

5.3 Conclusion

The expected behavior with the parallel resistor was observed. The output current for the channel is much higher because there is now the additional current of the parallel resistor. The amount of the additional current depends upon the value of the used parallel resistor and is easy to calculate (IL/Ip=Rp/RL).

To observe the effects resulting from the presence of different amounts of parallel resistance, the behavior with two different parallel resistors was measured.

The values of the resistors are chosen:

A.) to be under the minimum clamping voltage of the TLE8110EE. Rp=19.5Ohm, which causes a clamping voltage of 43V.

B.) to be under the typical clamping voltage of the TLE8110EE. Rp=27.2Ohm, which causes a clamping voltage of 53V.

Case A (Rp=19.5Ohm)**:**

The clamping time has significantly increased (5.5 times, to be more exact) compared to TLE8110EE. The additional current is in the range of 850mA. A voltage peak for 1µs with near 5V overvoltage when the clamping with the parallel resistor starts, was observed.

Case B (Rp=27.2Ohm)**:**

The clamping time has significantly increased (4.5 times, to be more exact) compared to TLE8110EE. The additional current is in the range of 500mA. No voltage peak was observed in this case because above 55V the internal clamping from the TLE8110EE is activated.

6 External resistor with free wheeling diode

6.1 Application circuit

Figure 28 shows the circuit of the TLE8110EE with parallel resistor (Rp) and FWD for external clamping. The colored marked signals in Figure 28 are plotted in Figure 29 to Figure 34 to have a better overview.

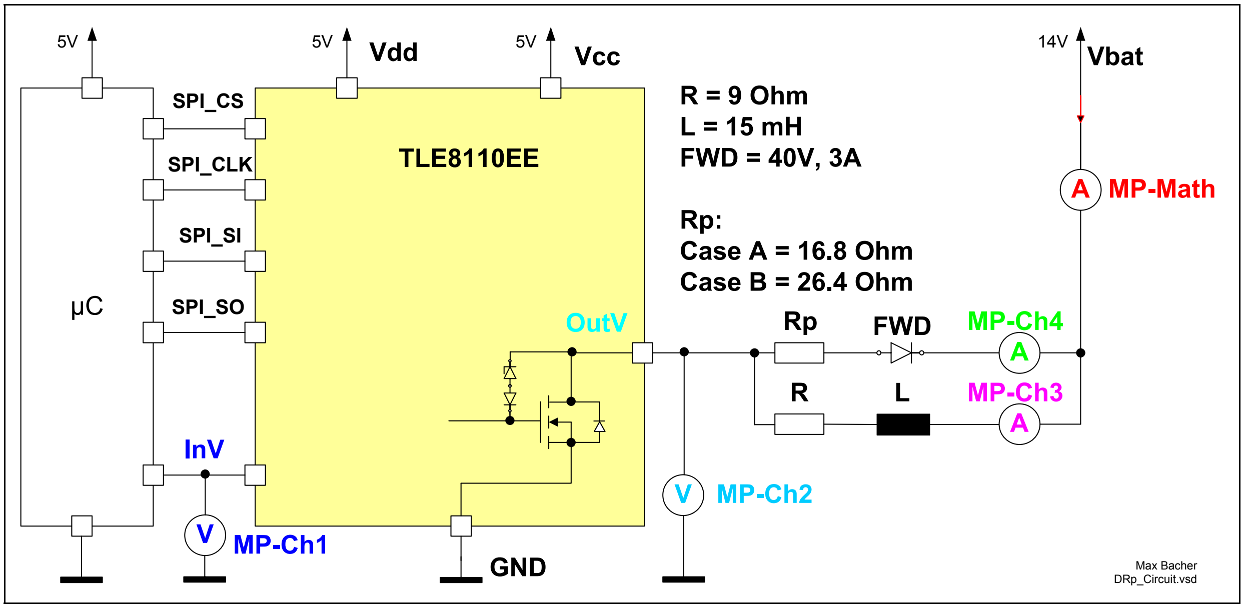

Figure 28 TLE8110EE with FWD and parallel resistor (Rp) for external clamping

6.2 Measurements

Figure 29 to Figure 31 show the clamping behavior with parallel resistor of 16.8 Ohm and FWD at 25°C. This is the temperature for the TLE8110EE and also for the Rp and the FWD. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

The “Math Channel” (the red one) describes the current “MP-Math” in Figure 28and is calculated as channel 3 (MP-Ch3 – the load current) plus channel 4 (MP-Ch4 – the FWD-Rp current).

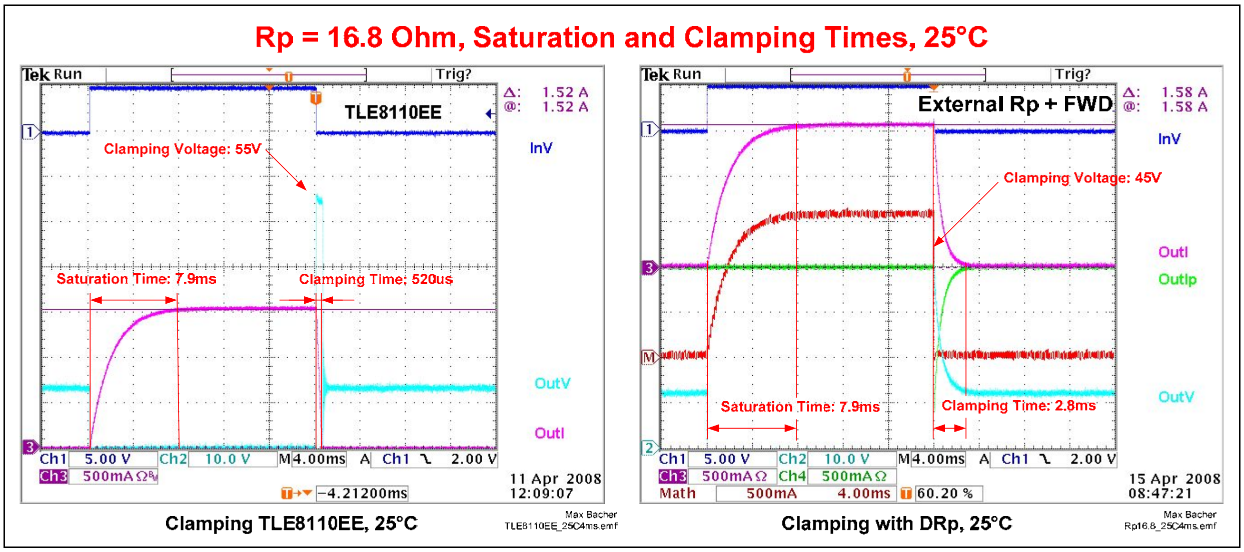

Figure 29 Comparing the clamping time for internal and external clamping with FWD and Rp=16.8Ohm

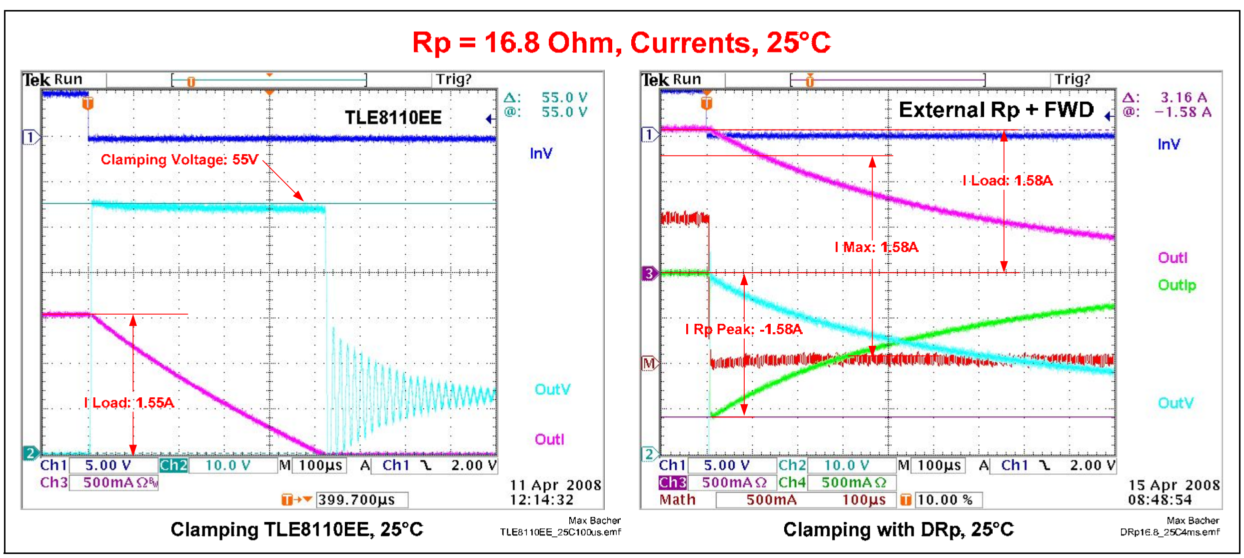

Figure 30 Comparing the currents for internal and external clamping with FWD and Rp=16.8Ohm

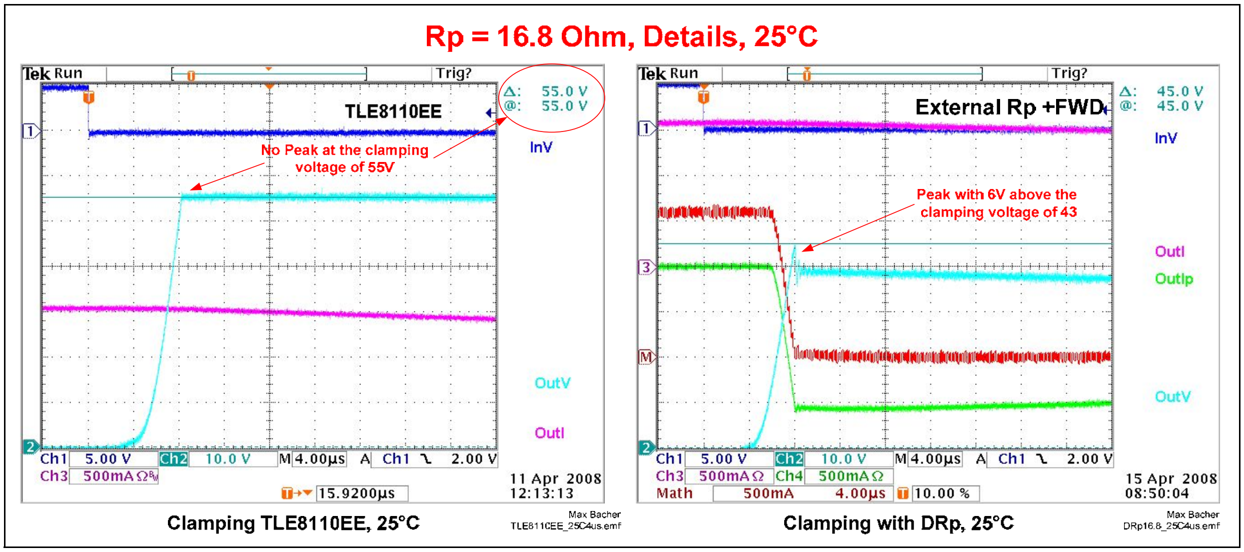

Figure 31 Comparing the voltage peak for internal and external clamping with FWD and Rp=16.8Ohm

Figure 32 to Figure 34 show the clamping behavior with parallel resistor of 26.4 Ohm and FWD at 25°C. This is the temperature for the TLE8110EE and also for the Rp and the FWD. The figures show always the comparisons with the original TLE8110EE clamping. The setup and the load are always the basic setup shown in chapter 2.1.

The "Math Channel" (the red one) describes the current "MP-Math" in Figure 28and is calculated as channel 3 (MP-Ch3 – the load current) plus channel 4 (MP-Ch4 – the FWD-Rp current).

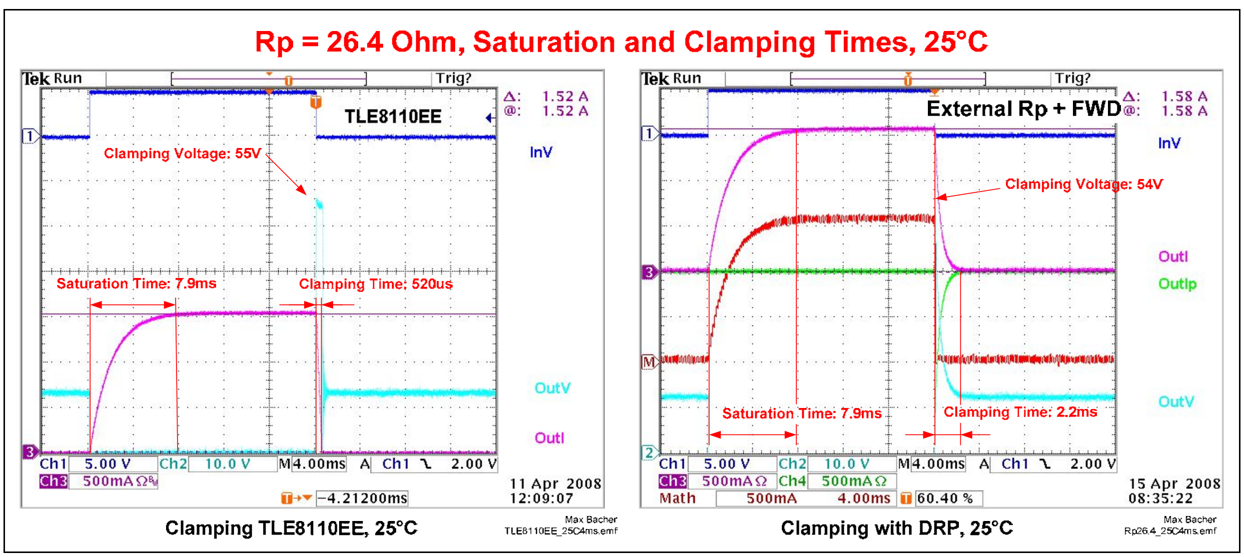

Figure 32 Comparing the clamping time for internal and external clamping with FWD and Rp=26.4Ohm

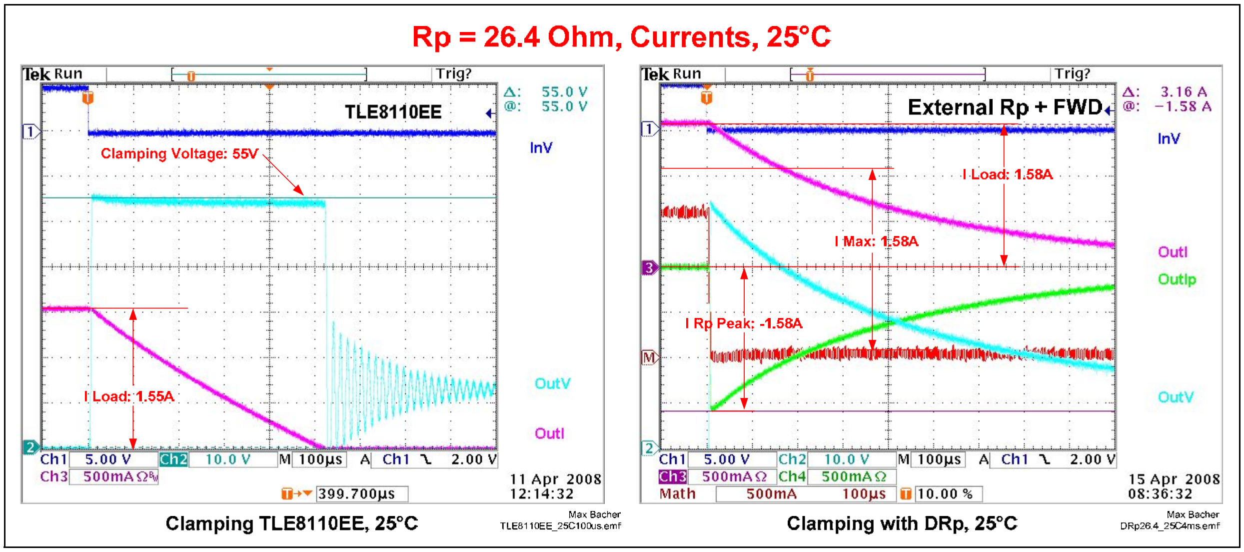

Figure 33 Comparing the currents for internal and external clamping with FWD and Rp=26.4Ohm

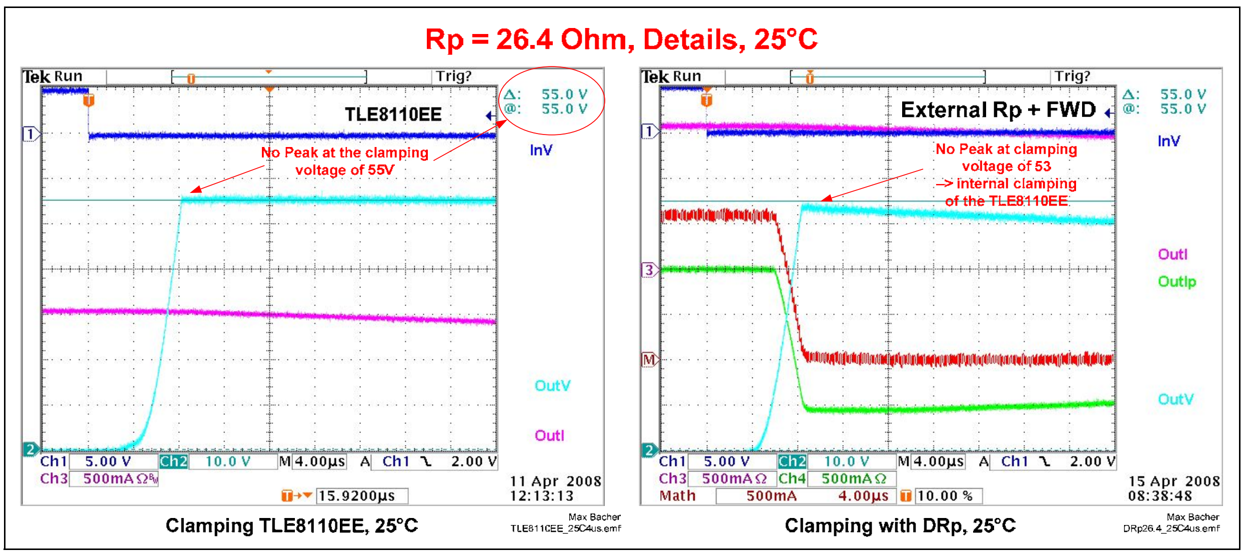

Figure 34 Comparing the voltage peak for internal and external clamping with FWD and Rp=26.4Ohm

6.3 Conclusion

The expected behavior with the parallel resistor and the FWD was observed. The big advantage against the external Rp clamping without FWD is that there is now no additional current when the output is switched on. The other effect (longer clamping time) is still apparent. To observe the effects resulting from the presence of different amounts of parallel resistance, the behavior with two different parallel resistors was measured.

The values of the resistors are chosen:

C.) to be under the minimum clamping voltage of the TLE8110EE. Rp=16.8Ohm, which causes a clamping voltage of 43V.

D.) to be under the typical clamping voltage of the TLE8110EE. Rp=26.4Ohm, which causes a clamping voltage of 53V.

Case A (Rp=16.8Ohm)**:**

The clamping time has significantly increased (5.5 times, to be more exact) compared to TLE8110EE. A voltage peak for 1µs with near 5V overvoltage when the clamping with the parallel resistor starts, was observed.

Case B (Rp=24.4Ohm)**:**

The clamping time has significantly increased (4 times, to be more exact) compared to TLE8110EE. No voltage peak was observed in this case because above 55V the internal clamping from the TLE8110EE is activated.

7 Appendix

7.1 Table of Figures

7.2 Revision History Table Example

Previous Version:	none
Page	Subjects (major changes since last revision)

Edition 2006-02-01

Published by
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