VISHAY INTERTECHNOLOGY, INC.

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Reference Design | White Paper

48 V_{DC} / 12 V_{DC}, 200 A Bidirectional eFuse

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1. eFuse OVERVIEW

The Vishay eFuse is constructed using a standard double-sided, four-layer PCB (FR4), which utilizes 70 µm copper for each layer. The overall dimensions are 125 mm x 60 mm. The unit can be enabled / disabled using either the push buttons on the PCB or by an external controller. The current limit is manually adjustable within a range of approximately 1 A to 200 A, either with a potentiometer on the PCB or with the external controller. It is also possible to enable / disable the unit using an external key switch, for example, via an additional port.

The external controller is either connected via a ribbon cable or plugged directly into a header on the top of the PCB. The eFuse can then be controlled and monitored via a web interface.

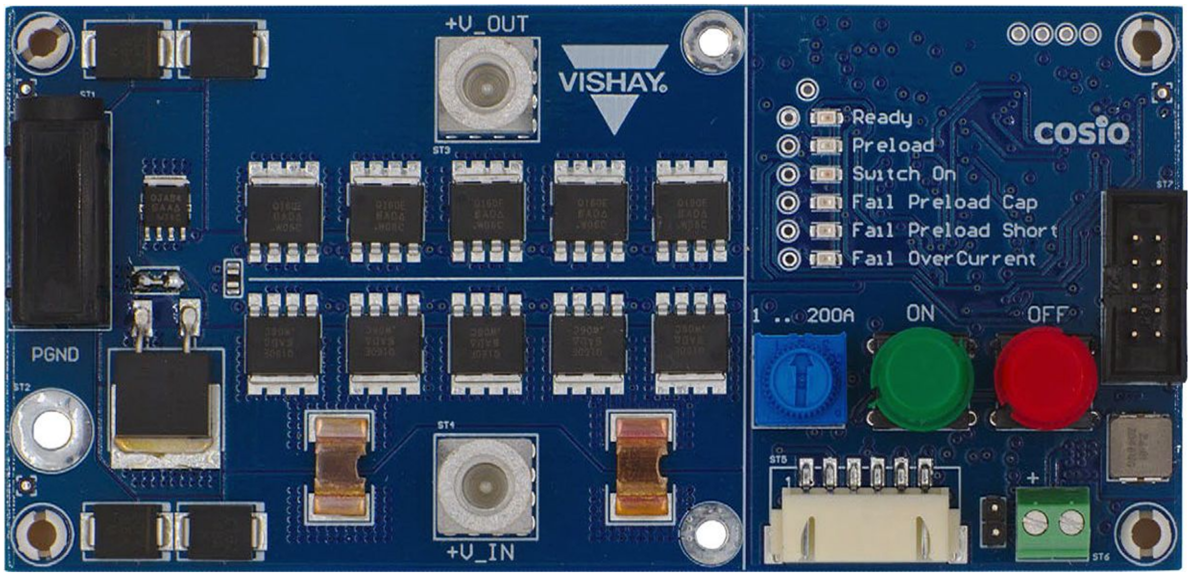

Fig. 1 - Vishay eFuse 48 V_{DC} / 12 V_{DC}, 200 A (Front Side)

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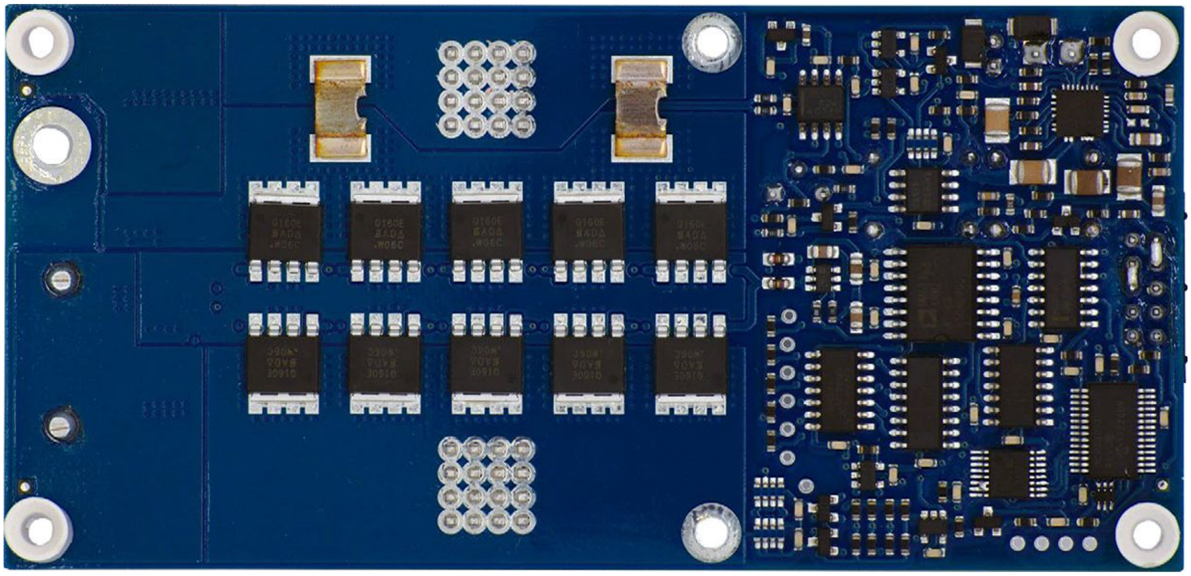

Fig. 2 - Vishay eFuse 48 V_{DC} / 12 V_{DC}, 200 A (Back Side)

2. POWER SUPPLY

The power supply for the control section of the PCB can be supplied with power from different sources. If the jumper JP1 is connected, power is supplied from the (V_{IN}) side. It is also possible to supply an external voltage (9 V to 60 V) to the ST6 port, which is also protected against a reverse polarity connection. If voltage is present at both sources and JP1 is connected, the supply with the higher voltage will be utilized.

2.1. SiC464 DC/DC Converter (Internal)

The power supply consists of a Vishay SiC464 DC/DC converter, which receives its power from either of the two sources described above and is decoupled by two diodes so that the higher voltage provides the power. All of the control circuity on the PCB receives its power from this supply.

The internal power dissipation of the eFuse under a no-load condition is 53 mA at 12 V. With a load energized, the current consumption increases to approximately 95 mA and is primarily due to the AduM5230 dual gate drive. If the web interface is supplied with 5 V from the SiC464, both the power consumption and the efficiency will increase even further.

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3. TEST POINTS

There are various test points on the PCB to observe the performance of the eFuse:

TABLE 1 - TEST POINTS ON THE PCB

TEST POINT	NAME	FUNCTION
TP1	+5.0 V	Internal power supply +5.0 V
TP2	E_PreLoad	High = preload MOSFET powered on
TP3	E_Switch_ON	High = main MOSFETs powered on
TP4	E_Fail_Pre_Cap	Error: high = capacity at the load side too high, preload cancelled after 130 ms
TP5	E_Fail_Pre_Short	Error: high = short to ground at the load side, preload cancelled after 13 ms
TP6	E_Fail_OC	Error: high = current was higher than the limit for 100 µs
TP7	GND	Ground reference for all test points
TP8	Meas_V_Out	The output voltage U_{OUT} can be calculated from the voltage at TP8 U_{TP8} using the formula $U_{OUT} = 21 \times U_{TP8}$ The limits are: U_{TP8} = 0 V⇔ U_{OUT} = 0 V U_{TP8} = 3.3 V⇔ U_{OUT} = 69.3 V
TP9	Meas_V_In	The input voltage U_{IN} can be calculated from the voltage at TP9 U_{TP9} using the formula $U_{IN} = 21 \times U_{TP9}$ The limits are: U_{TP9} = 0 V⇔ U_{IN} = 0 V U_{TP9} = 3.3 V⇔ U_{IN} = 69.3 V
TP10	Meas_NTC	Temperature measurement, at 25 °C the voltage is $Meas_{NTC}$ = 1.650 V
TP11	Meas_Current	The current can be calculated from the voltage at TP11 using the formula I = [U_{TP11} (V) - 1.650 V] x 200 A / 1.5 V The limits are: U_{TP11} = 0.15 V⇔ U_{IN} = -200 V U_{TP11} = 1.65 V⇔ U_{IN} = 0 V U_{TP11} = 3.15 V⇔ U_{IN} = 200 V

Notes

- The “Name” in Table 1 refers to the labels used in the schematics
- The eFuse can sense and switch bidirectional load currents
- Positive current flows from “Meas_V_In” to “Meas_V_Out”, negative current flows from “Meas_V_Out” to “Meas_V_In”
- The ground reference is the test point TP7; all voltages should be measured against this point; “GND” is equal to “PGND” on the power side

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4. EXPANSION PLUG

Via the 6-pin expansion connector ST5, the PCB can be controlled with external control elements such as the Vishay web interface “MessWEB”.

On the eFuse PCB, a JST socket S6B-XH-SM4 with a 2.5 mm pitch is used, which will accept an XHP-6 mating connector.

TABLE 2 - PIN ASSIGNMENT FOR THE EXPANSION PLUG

PIN	NAME	DESCRIPTION
1	GND	
2	/Tast_ON_EXT	Switch-on button / switch to GND
3	/Tast_OFF_EXT	Switch-off button / switch to GND
4	+5 V via 1 kΩ	LED indicating eFuse ready
5	E_Switch_ON via 1 kΩ	LED indicating eFuse switched on
6	E_Fail via 1 kΩ	LED indicating eFuse failure

<E_Fail> is a sum signal and the output goes high whenever one of the three possible errors occur: <E_Fail_Pre_Cap>, <E_Fail_Pre_Short>, or <E_Fail_OC>. The indicators should be standard LEDs with their cathode connected to GND; a series resistor is already integrated on the PCB. The ON / OFF switches can be implemented with either a push button or a standard switch since only the rising edge of the signal is recognized. If both push buttons are pressed, the OFF switch has priority. If an error occurs (E_Fail active), it must be acknowledged using the </Tast_OFF_Ext>.

5. WEB BROWSER INTERFACE

The web browser interface “Vishay MessWEB” can be used to connect the eFuse to a computer. With the “MessWEB”, the current status of the eFuse can be displayed on a computer, and all the parameters can be set:

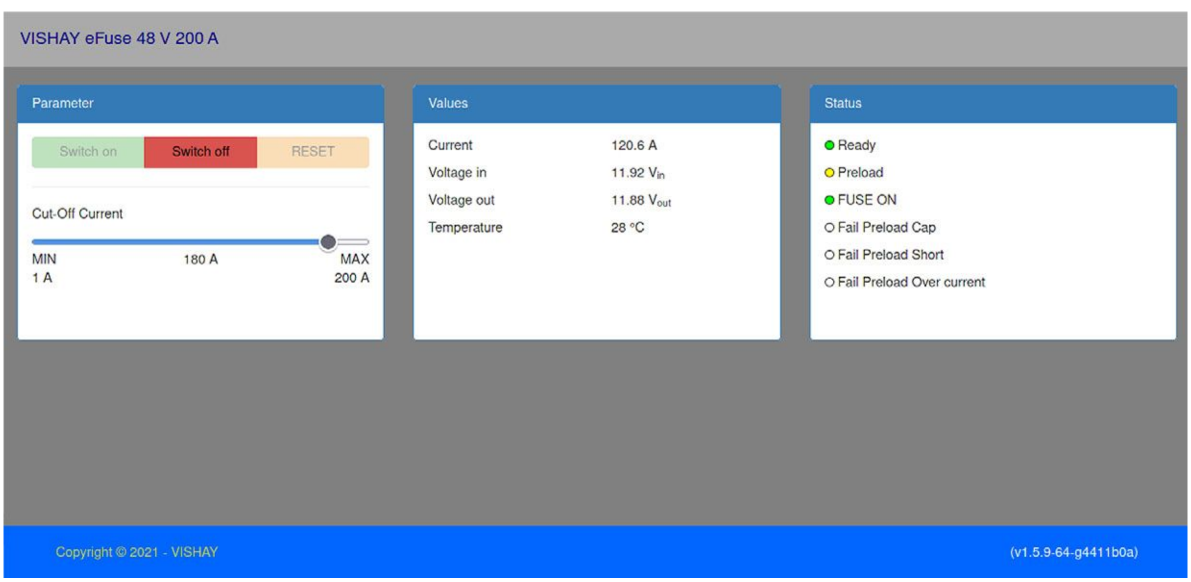

Fig. 3 - Overview of the Interface of the MessWEB

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The web interface is divided into three sections. In the left column the eFuse can be switched on and off, errors can be acknowledged, and the maximum current can be set. In the middle column the currently measured values of the eFuse are displayed: input voltage, output voltage, load current, and ambient temperature. The right column displays the same status indicators as the LEDs on the PCB.

To use the web interface, the eFuse must first be connected to a power supply at 9 V to 60 V (see section 2). Then plug the MessWEB into the 10-pin header (ST7) on the PCB. And finally, connect the MessWEB to the computer using a LAN cable. The web interface can be initialized using the computer's web browser with the address "http://192.168.0.1".

Even with the web interface in use, the eFuse can still be turned on or off at any time using the <ON / OFF> buttons on the PCB.

If an error occurs during operation and causes the eFuse to turn off, it must first be acknowledged using the <RESET> button on the web interface before it can be turned on again:

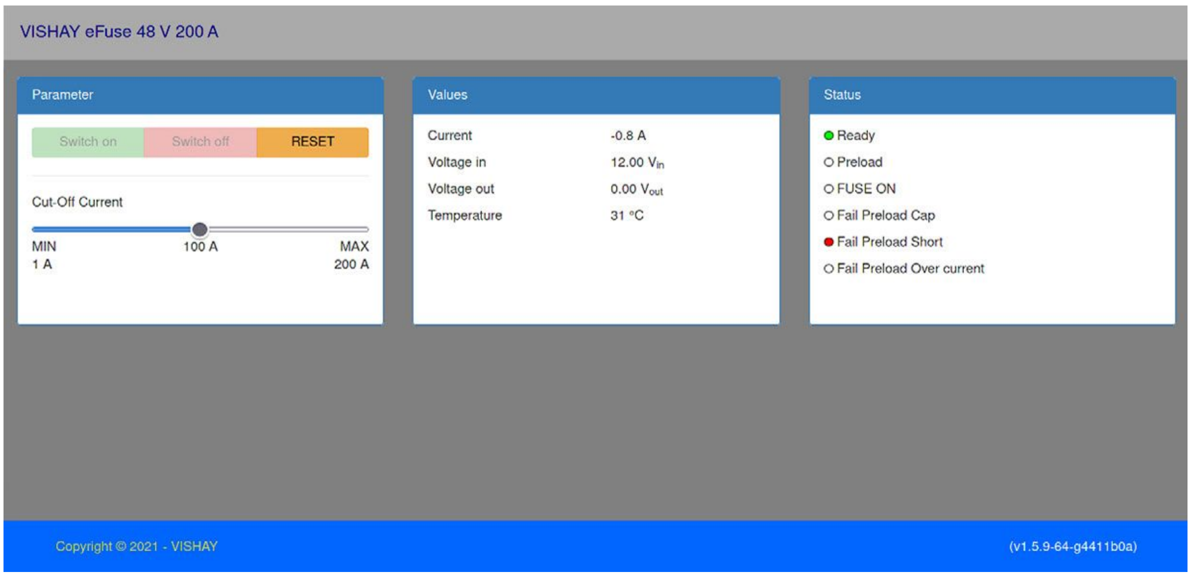

Fig. 4 - Web Interface After an Error Occurred

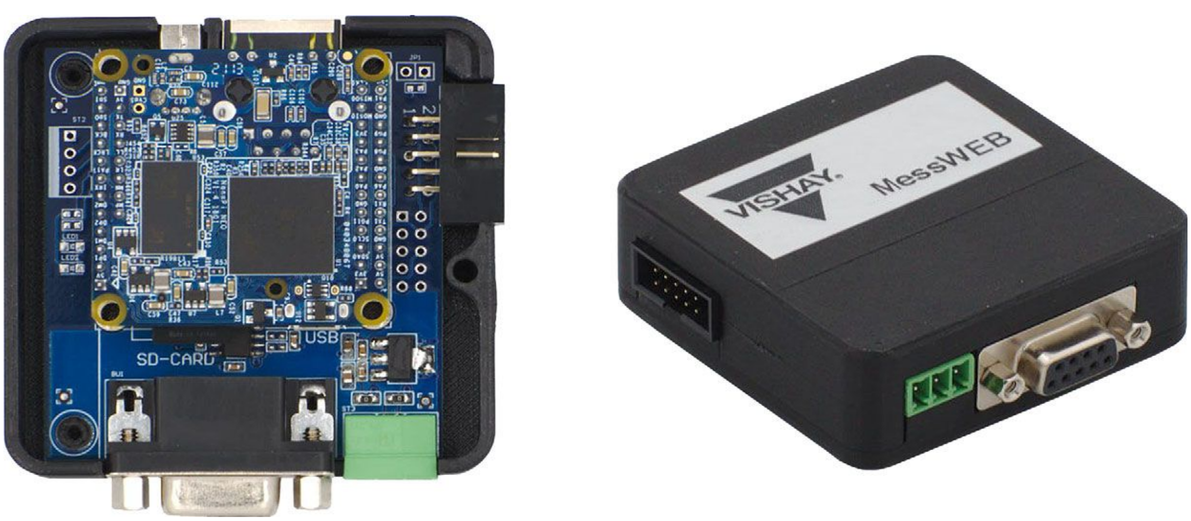

Fig. 5 - MessWEB Hardware

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6. OPERATING PRINCIPLE

6.1. Power-Up Reset

The circuit should first go into a defined <OFF> state after the input voltage is applied. If the output voltage reaches 85 % of the input voltage during power-up, a <Fail_Preload> will be generated and has to be cleared with the <OFF> button. An RC-circuit on the PCB with 100 kΩ and 100 nF should prevent this condition during power-up.

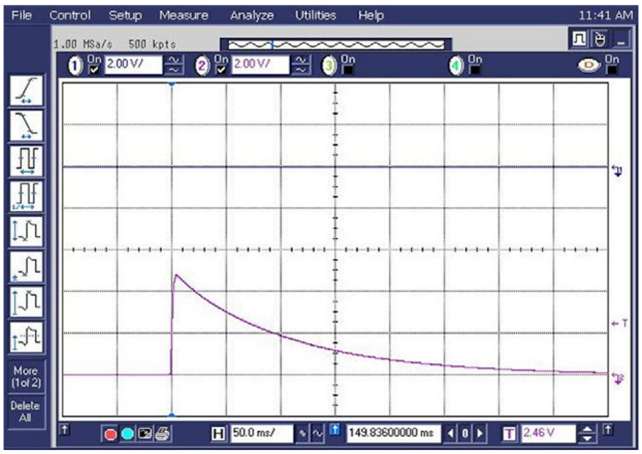

Fig. 6 - Glitch Signal at Power-Up

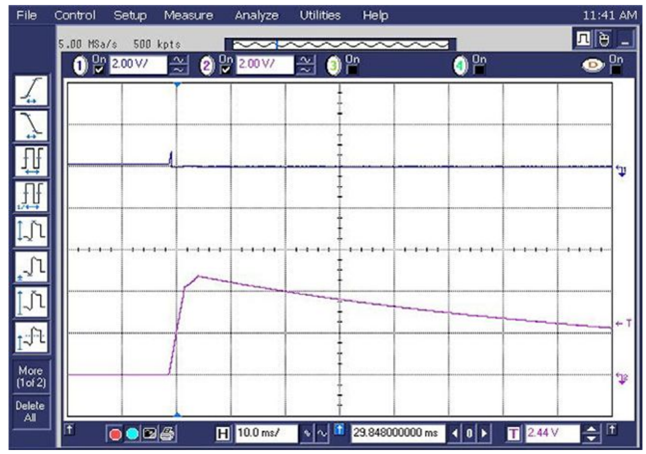

Fig. 7 - Switch-On Voltage Inside the RC-Circuit

6.2. Two-Stage Preload

When the eFuse is first switched on, a large pulse current could flow to the connected loads, as any input bus capacitors would have to be charged up to the input voltage level. As a result, two conditions must be satisfied during start-up:

1. A quick short-circuit test
2. A sufficiently long preload to charge all the capacitors on the load side to most of their final value

Therefore, a two-stage preload has been implemented on the PCB. The first stage switches in a series resistor (10 Ω / 20 W) between V_{IN} and V_{OUT}. After 13 ms the output voltage is measured to see if it has risen above 10 % of the input voltage. If the output voltage remains close to 0 V, a short circuit condition exists in the load, the preload stage is terminated (see Fig. 8), and the error LED <Fail_Preload_Short> is turned on. At 48 V, a current of 4.8 A flows for 13 ms, resulting in a power dissipation of approximately 250 W.

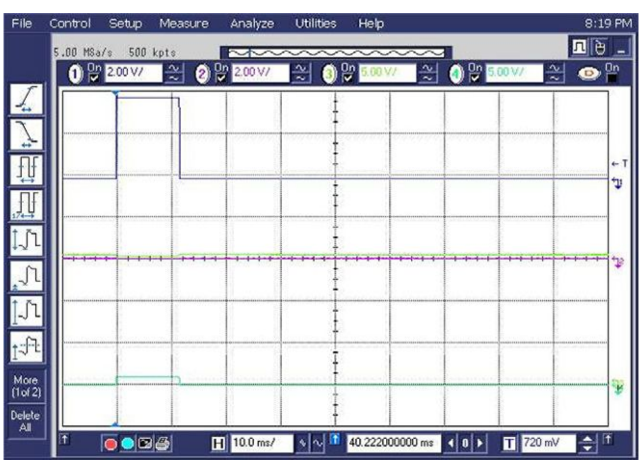

Fig. 8 - Preload (Dark Blue) and Input Voltage (Green)

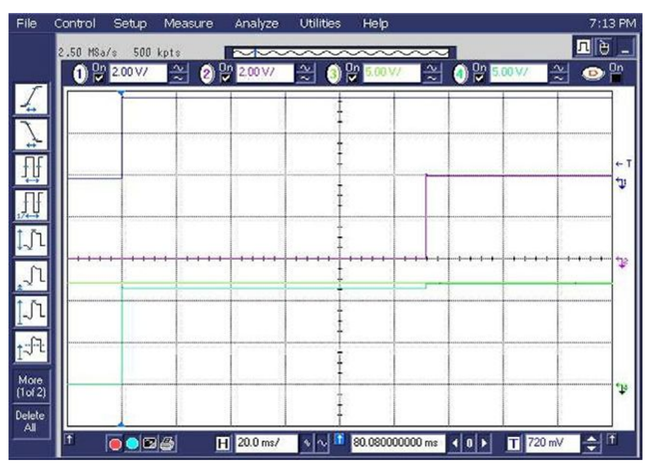

Fig. 9 - Switch On (Purple) and Output Voltage (Bright Blue)

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If the output voltage has risen to more than 10 % of the input voltage after 13 ms, the preload stage is extended. After 130 ms the output voltage is measured again to see if it has risen to at least 85 % of the input voltage. In this case, the main MOSFETs are switched on.

Fig. 9 displays the normal process during switch-on without any load on the output. Only a capacitive load on the output is charged during the preload. If the total capacitance value is too large, the preload is cancelled after 130 ms and the error LED <Fail Preload Cap> is turned on.

The threshold of the maximum preload capacitance allowed is approximately 5000 µF (Fig. 11 with 1400 µF if the load starts successfully, but Fig. 10 with 6800 µF if the load leads to an error condition). If an error occurs, it must first be acknowledged with the <OFF> button before the eFuse can be restarted.

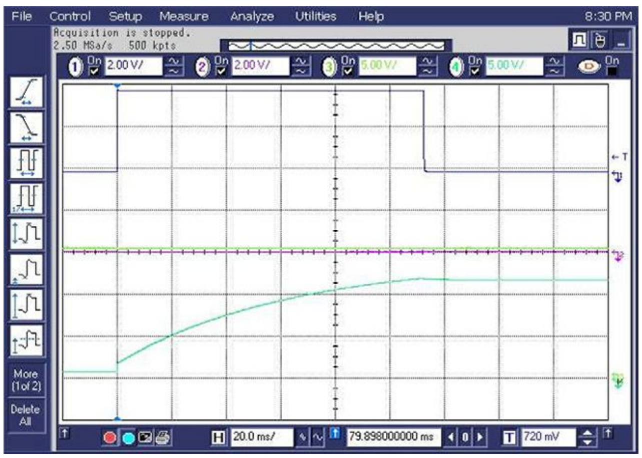

Fig. 10 - Preload (Dark Blue) and Input Voltage (Green)

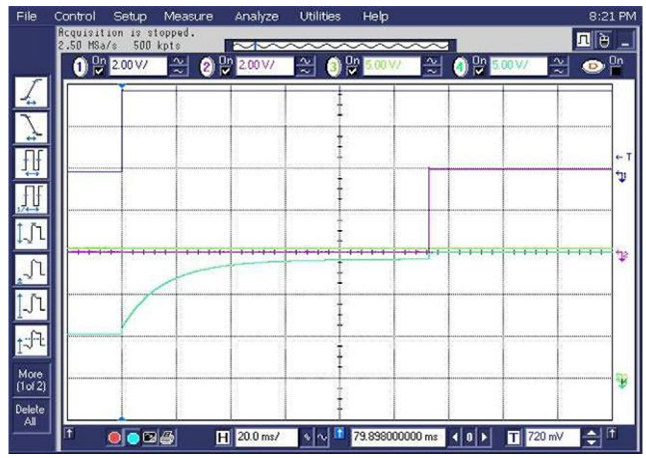

Fig. 11 - Switch On (Purple) and Output Voltage (Bright Blue)

6.3. Switch-On Procedure

The 20 SQJQ160E MOSFETs (10 on the front, 10 on the back side of the PCB) are driven by a MOSFET driver to keep the switching times (approximately 1 µs) as low as possible. The maximum total current into the 20 gate terminals is +4 A (measured 4 V over 1 Ω, as shown in Fig. 12). This limit is defined by the gate driver and is specified at ± 4 A.

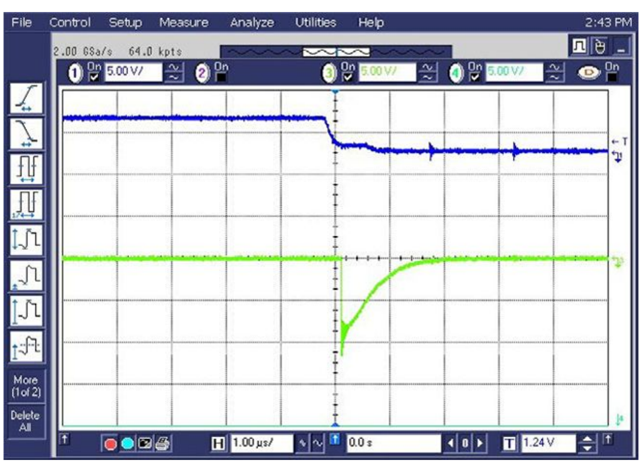

Fig. 12 - Switch On (Dark Blue) and Current Through the 1 Ω Gate Resistor (Green)

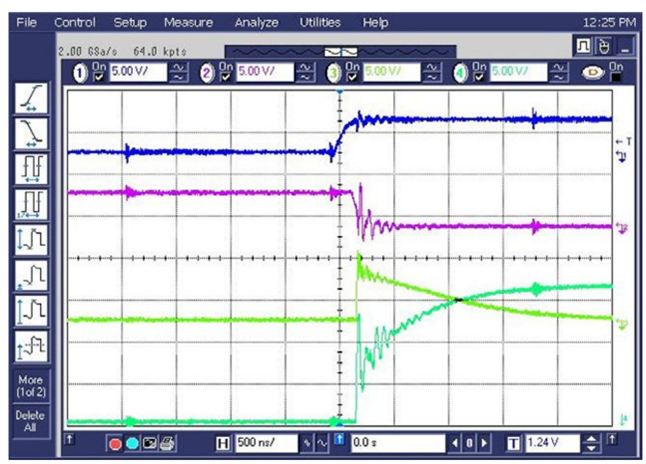

Fig. 13 - Preload (Purple) and Voltage at the Gate (Bright Blue)

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6.4. Switch-Off Procedure

It is also important to ensure that the 20 SQJQ160E MOSFETs are turned off as quickly as possible when the load is commanded to be de-energized. The turn-off time is even more important than the turn-on time since it could potentially be under a full load or short circuit condition.

6.5. Power Dissipation

The total resistance of the eFuse during continuous operation is composed of several components:

- The on-resistance of the MOSFETs (2x 0.85 mΩ/10 =170 µΩ)
- The current measurement resistors (300 µΩ/4 =75 µΩ)
- The resistance of the copper traces and terminals (55 µΩ)

Therefore, the total resistance is approximately 300 µΩ.

The MOSFETs, as well as the copper traces and terminals, have a positive temperature coefficient, which results in an increase in the resistance as the temperature increases.

The following ten pictures display the increase in heat / temperature of the power components at various load conditions:

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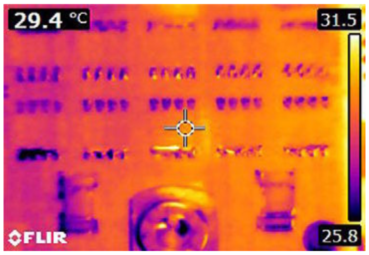

Fig. 14 - FLIR#20 / 20 A

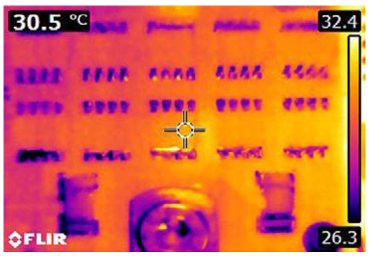

Fig. 15 - FLIR#21 / 40 A

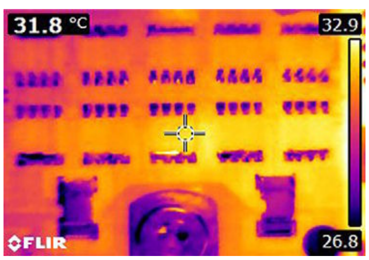

Fig. 16 - FLIR#22 / 60 A

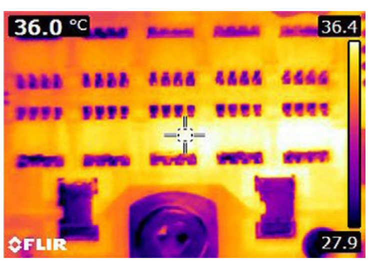

Fig. 17 - FLIR#23 / 80 A

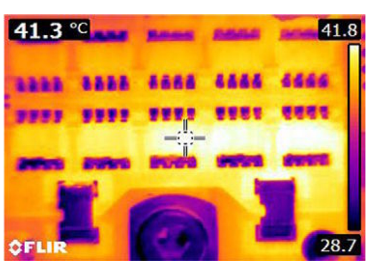

Fig. 18 - FLIR#24 / 100 A

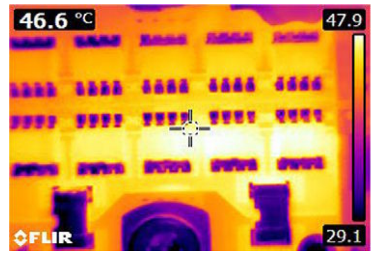

Fig. 19 - FLIR#25 / 120 A

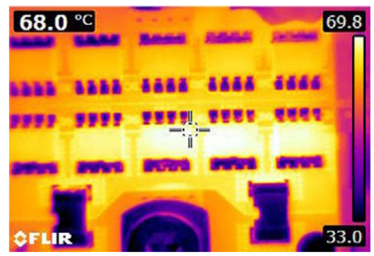

Fig. 20 - FLIR#26 / 140 A

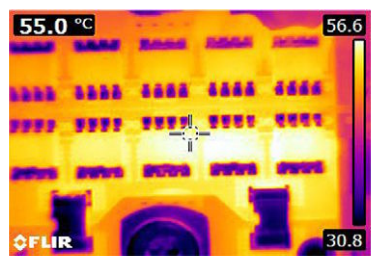

Fig. 21 - FLIR#27 / 160 A

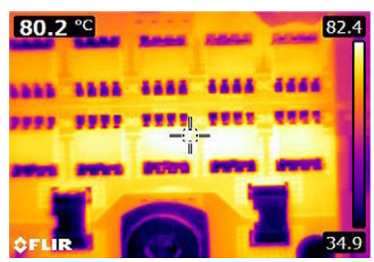

Fig. 22 - FLIR#27 / 180 A

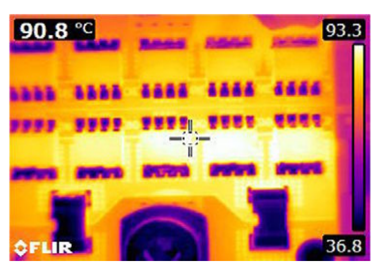

Fig. 23 - FLIR#28 / 200 A

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7. CONCLUSION

The power dissipation of the eFuse during continuous operation is very low at only 14 W under a 200 A load condition, which results in an approximately 65 °C temperature rise over the ambient temperature.

Therefore, the PCB does not require any active cooling. Since the MOSFETs are specified up to a maximum operating junction temperature of 175 °C, there is still enough headroom available to operate at full load up to ambient temperatures of approximately 100 °C. If operation at higher ambient temperatures is required, or more headroom is needed, some type of heatsinking or active cooling could be implemented.