Evaluation board enabling Capacitive Load Charging with the Power PROFET™ + family

B-BTS50010-1LUA-1
Z8F80536551

About this document

Scope and purpose

This document shows how to use an external circuit with the Power PROFET™ + that requires *capacitive load switching (CLS)*. The circuitry can be used for 12 V, 24 V and 48 V applications by replacing the high-side switch with a Power PROFET™ + device that has the correct voltage range.

Intended audience

Engineers, hobbyists and students who want to use powerful, protected high-side switches in heating or power distribution projects.

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1 Concept

1.1 The challenge of Capacitive Load Charging

Applications and loads are separated into resistors, capacitors and inductors. For example, a valve or a relay can be separated as a serial resistor and an inductor. Other examples are *direct current (DC)* motors, which can be separated as a serial resistor, a capacitor and a generator. The Power PROFET™ + family has been designed to drive high-load currents in DC mode. For example, the inrush current of the capacitive load could be too high, and trigger the overcurrent protection of the Power PROFET™ + device.

1.2 The solution: Capacitive Load Charging evaluation board

The target behavior of the capacitive load charging circuitry is to ensure that the evaluation board limits the load inrush current. To limit the inrush current, one of the solutions is to add a pre-charge circuitry in parallel. The pre-charge circuitry requires a P-channel MOSFET and a serial power resistor.

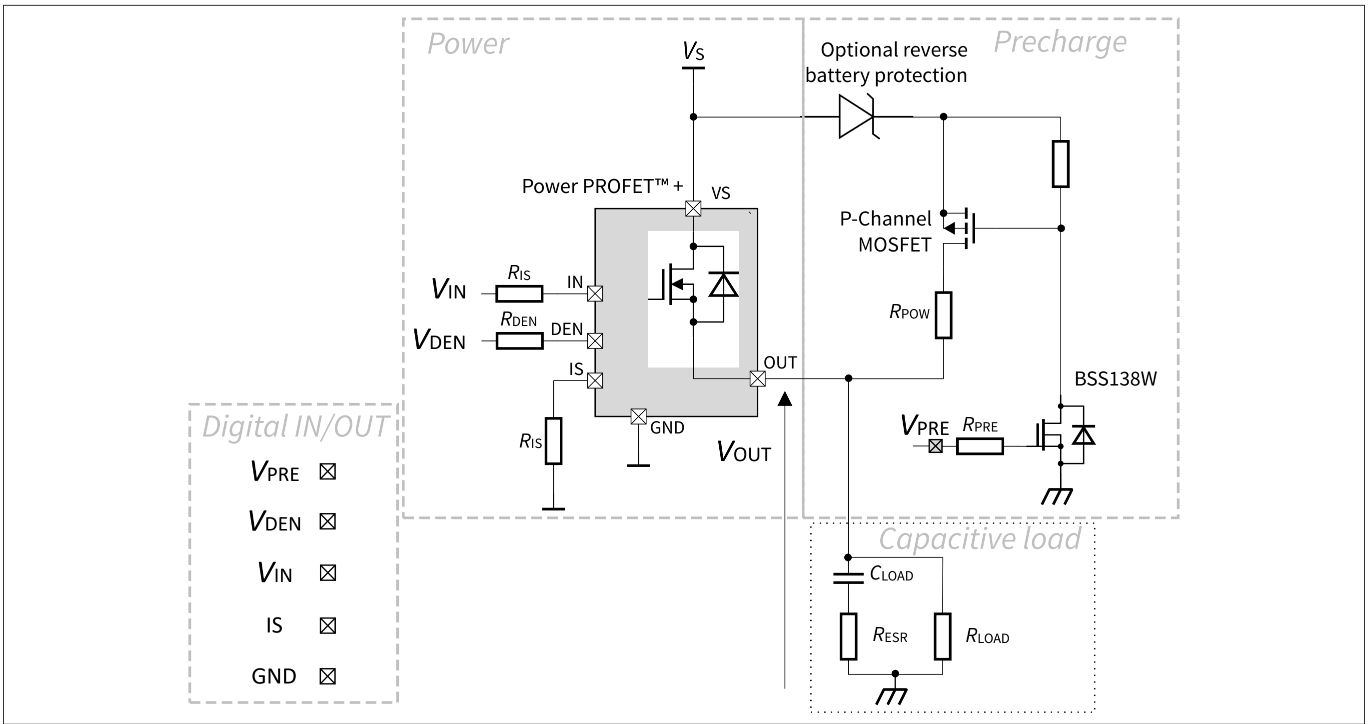

Figure 1 **Block diagram of the circuitry (comparator outputs are open-collector outputs)**

Figure 1 shows the diagram of the circuitry:

- The power area includes the BTS50010-1LUA from the Power PROFET™ + 12V family
- The pre-charge area includes the P-channel MOSFET and the components to drive it
- The Digital IN/OUT what provides the digital signals

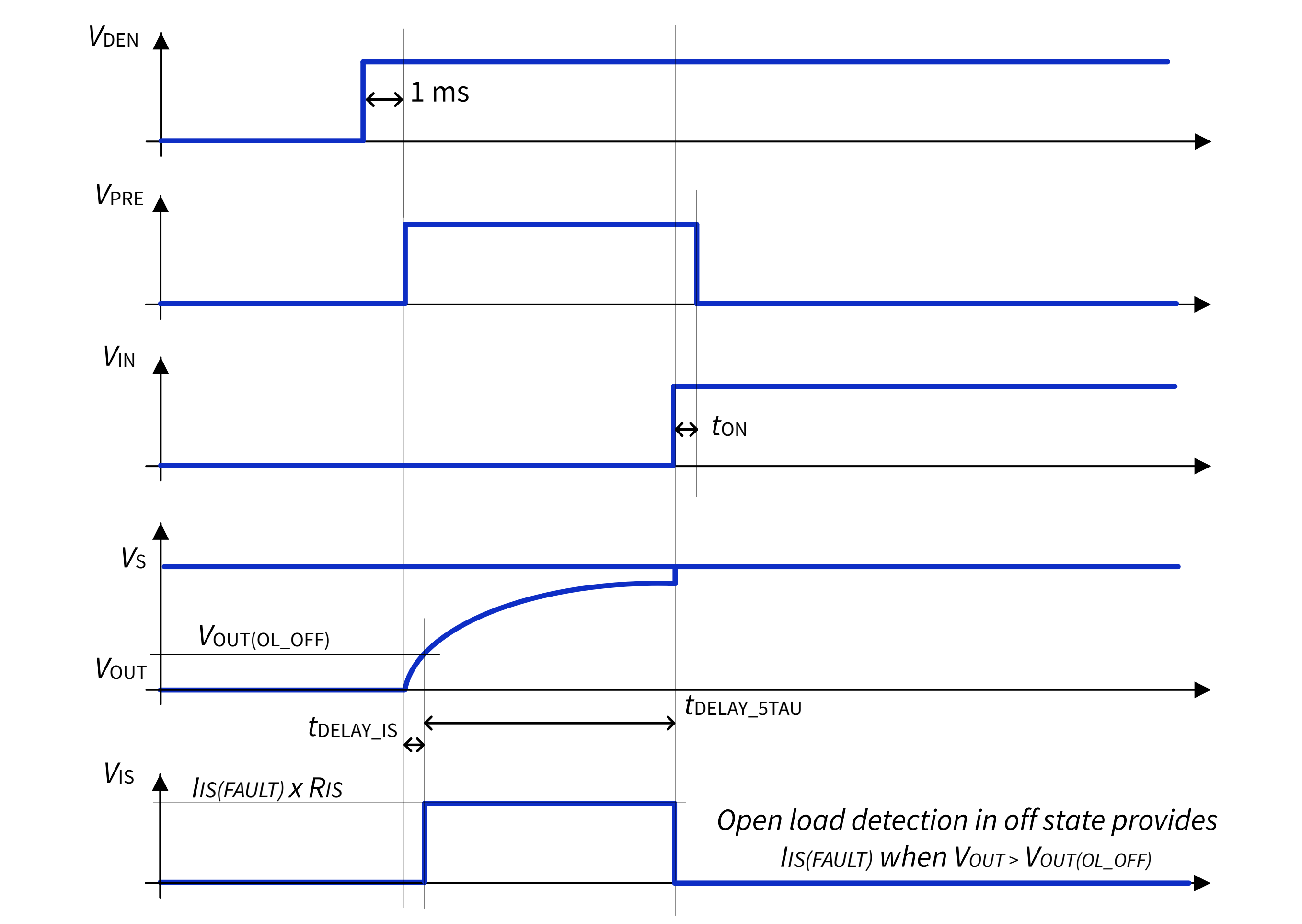

Figure 2 **Timing diagram of the circuitry in normal mode**

Figure 2 describes the timing diagram of the circuitry, below are the explanations step by step:

Step 1: V_S (battery voltage) is high, V_{DEN}, V_{PRE} and V_{IN} are low.

Step 2: V_{DEN} is set high. At this time, $V_{OUT} < V_{OUT(OL\_OFF)}$ so V_{IS} is low.

Step 3: After 1 ms, V_{PRE} is set high. The capacitive load is starting to be pre-charged.

Step 4: After t_{DELAY_IS}, the output voltage reached $V_{OUT(OL\_OFF)}$, V_{IS} is high. BTS50010-1LUA detects an open load, so IS pin is providing $I_{IS(FAULT)}$. If V_{IS} is still low after t_{DELAY_IS}, there is a short-circuit and the microcontroller must set V_{DEN} and V_{PRE} to low.

Step 5: After t_{DELAY_5TAU}, the capacitive load is fully loaded. V_{IN} is set high to turn on the BTS50010-1LUA, and V_{PRE} is set low to turn off the P-channel MOSFET after the turn on time of the BTS50010-1LUA. The sequence is now finished.

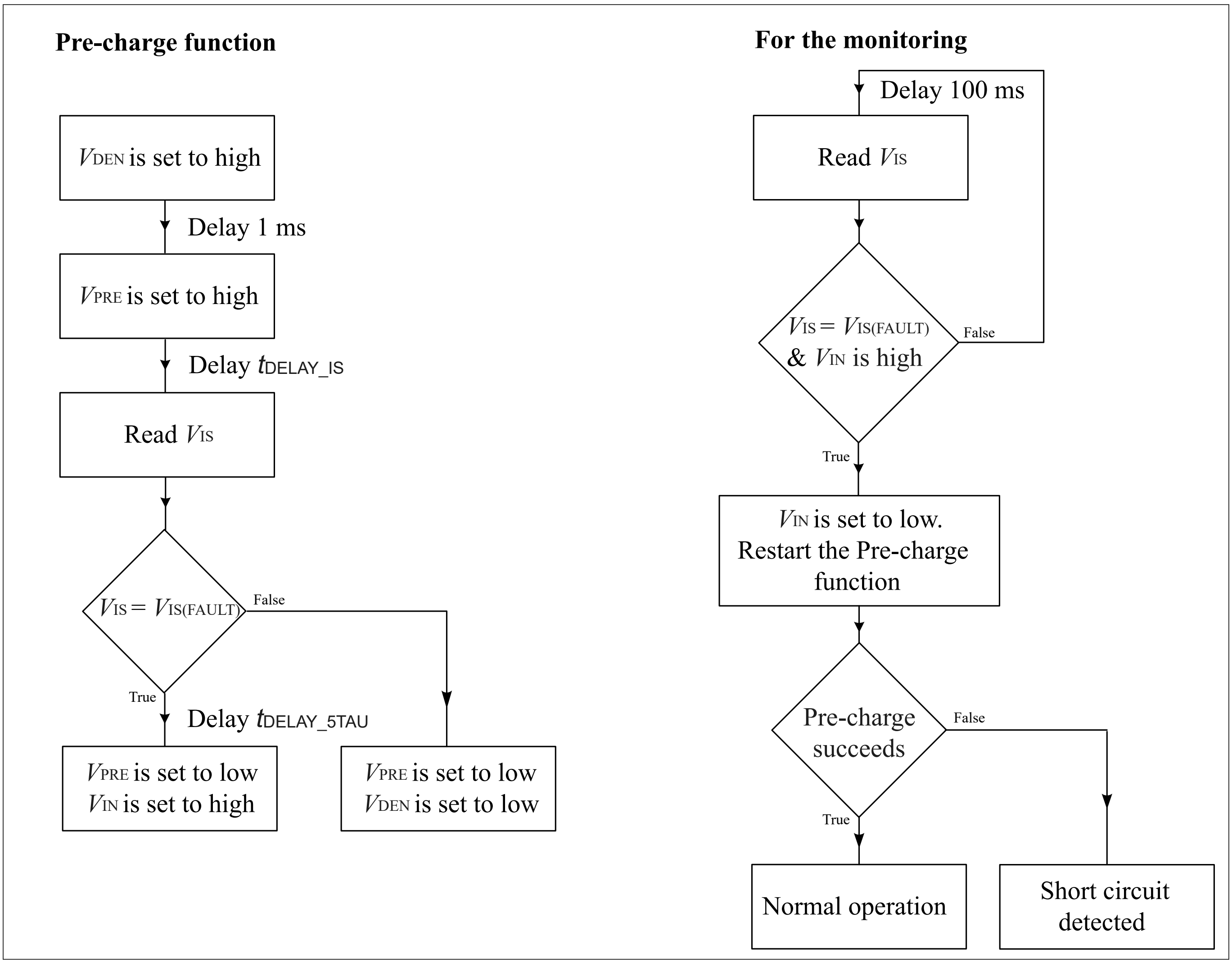

Figure 3 **Flowchart of the pre-charge function to implement in the microcontroller**

Figure 3 shows the flowchart to implement inside the microcontroller to satisfy the timing diagram in Figure 2. After setting V_{PRE} to high, users must wait for a given delay t_{DELAY_IS} defined by the load. This delay is the time to reach $V_{OUT} > V_{OUT(OL\_OFF)}$ and is calculated with V_S, C_{LOAD} and R_{POW}. The delay t_{DELAY_IS} to wait before measuring IS voltage is calculated by applying the equation below (users must take margin with this timing):

$$t_{DELAY\_IS} = -R_{POW} \times C_{LOAD} \times In\left(\frac{V_S - V_{OUT(OL\_OFF)}}{V_S}\right) \tag{1}$$

If the V_{IS} voltage is not rising after this delay, the BTS50010-1LUA has detected a short circuit situation. The microcontroller must set low by itself V_{PRE}. If IS pin is providing $I_{IS(FAULT)}$, there is no short circuit, and users must wait until 5 Tau to turn the BTS50010-1LUA on. The delay t_{DELAY_5TAU} to wait before turning the BTS50010-1LUA on is calculated by applying the equation below (users must take margin with this timing):

$$t_{DELAY\_5TAU} = 5 \times R_{POW} \times C_{LOAD} - t_{DELAY\_IS} \tag{2}$$

The microcontroller must consider negative and positive VS voltage drops. To do so, the microcontroller must sense the IS voltage and look for a fault signal (if $I_{IS(FAULT)}$ is provided by the IS pin). If the BTS50010-1LUA is in on state (IN pin is high) and there is a fault signal (IS pin is high), the microcontroller must retry the pre-charge algorithm. If there is still a fault signal, a short circuit is detected, if not, the system has restarted correctly.

2 Schematic

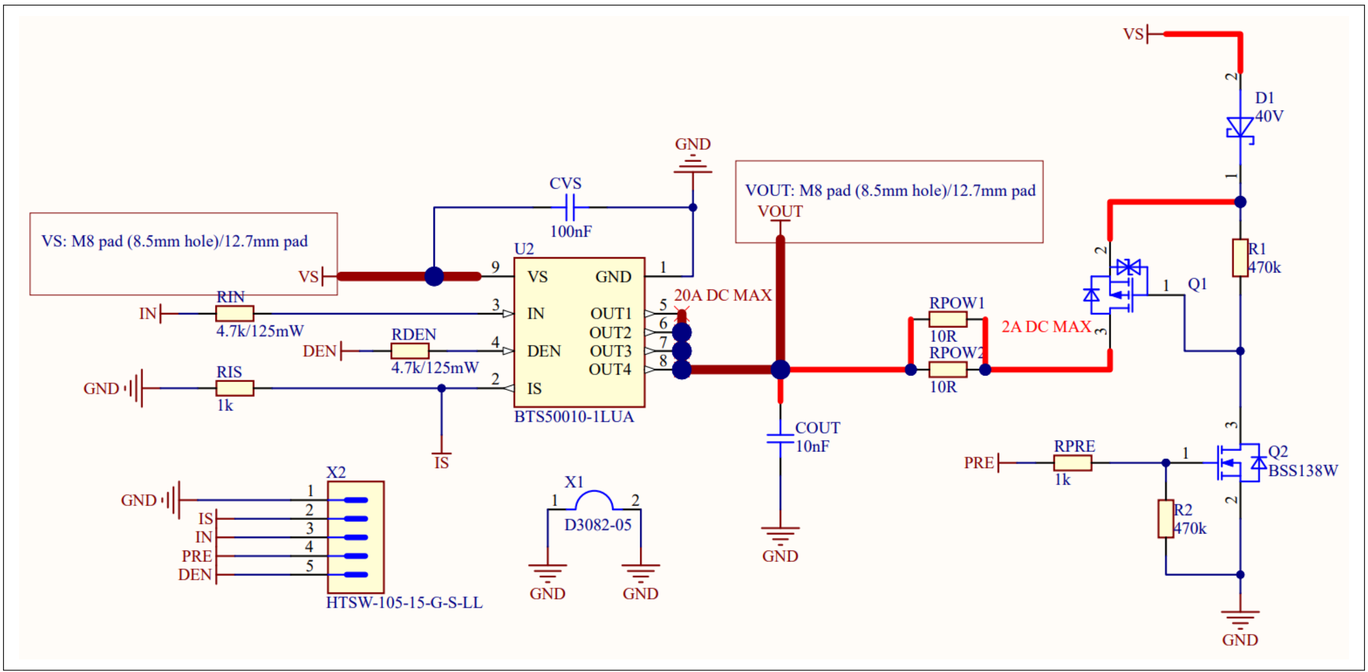

Figure 4 **Schematic of the circuitry**

Figure 4 describes the circuitry and conditions to add to the pre-charge capacitors.

3 Description of the PCB

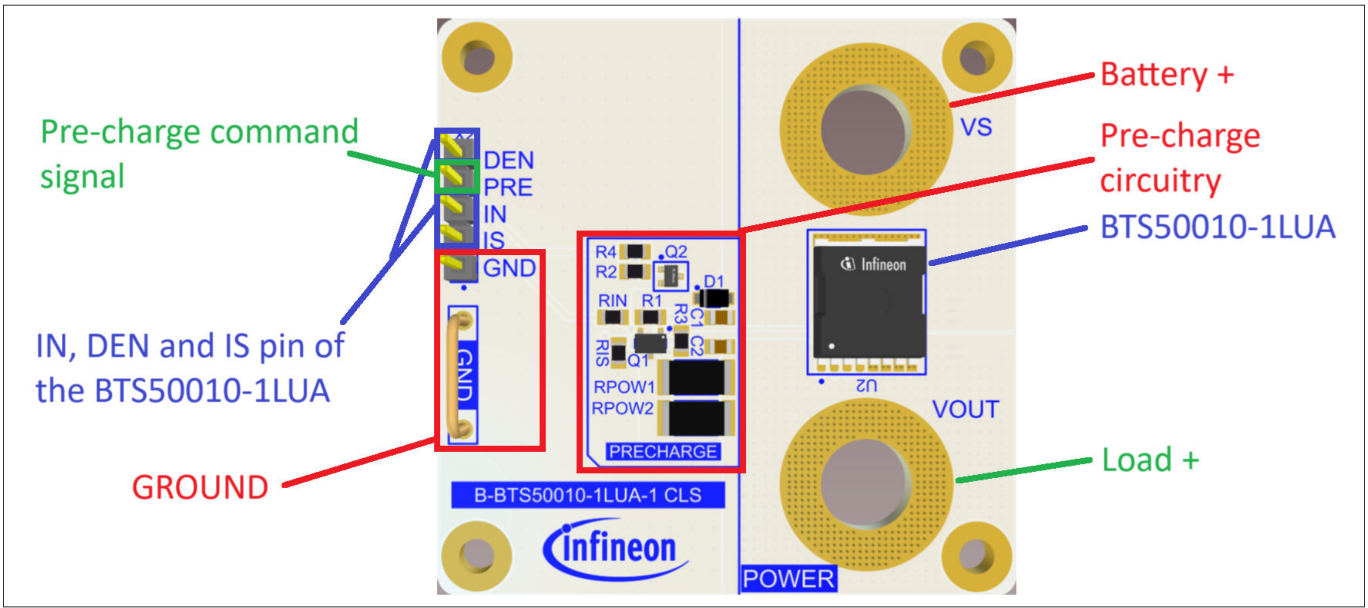

Figure 5 **Description of the PCB**

The evaluation board featuring the Power PROFET™ + 12V BTS50010-1LUA, provides a range of input and output connections:

- **Input and output connections:** GND hook, IS pin of the Power PROFET™ + 12V, DEN pin to turn the diagnosis enable on and off, IN pin to turn the input on and off, and PRE pin to drive the P-channel MOSFET
- **Power path:** VS and VOUT connections are available for the power path

To operate the system:

- **Turn on:** Set V_{DEN} to high. Apply a minimum of 3 V and a maximum of 5.5 V between V_{PRE} and *ground (GND)*. Then set V_{PRE} to low and apply the same voltage between V_{IN} and GND
- **Turn off:** Pull down V_{IN}, V_{DEN} and V_{PRE} to GND
- **Short circuit detection:** If V_{DEN} and V_{PRE} signals are high, V_{IN} is low and V_{IS} is still low t_{DELAY_IS} after V_{PRE} has been set high, there is a short circuit. The microcontroller must turn off V_{PRE} and V_{DEN} in this case
- **Maximum rating:** The BTS50010-1LUA is soldered, so V_{S_MAX} = 27 V and I_{OUT_MAX} = 30 A DC and 90 A AC. $t_{DELAY\_IS} + t_{DELAY\_5TAU}$ must be down to 100 ms

The board features three distinct areas:

- **PRECHARGE area:** This area features two power resistors RPOW1 and RPOW2 for the pre-charge path, as well as a P-channel MOSFET Q1 and a N-channel MOSFET Q2 to turn it on. The surrounding capacitors and resistors drive the MOSFETs. User can modify the power resistors to adapt the pre-charging timing. Diode D1 provides reverse battery protection
- **POWER area:** The main power path with the BTS50010-1LUA included
- **DIGITAL IN/OUT area:** The interface with the microcontroller with GND, IS, IN, DEN and PRE pin

4 Simulation results

4.1 Introduction

This section shows an applicative simulation result and how the evaluation board reacts versus casual use cases. For example, nominal pre-charge operation and short circuit type 1 situation have been simulation on the Evaluation board schematic. Short circuit type 2 scenario is not necessary to simulate because it only concerns the BTS50010-1LUA, in this case the P-channel MOSFET is in an off state.

4.2 Pre-charge operation

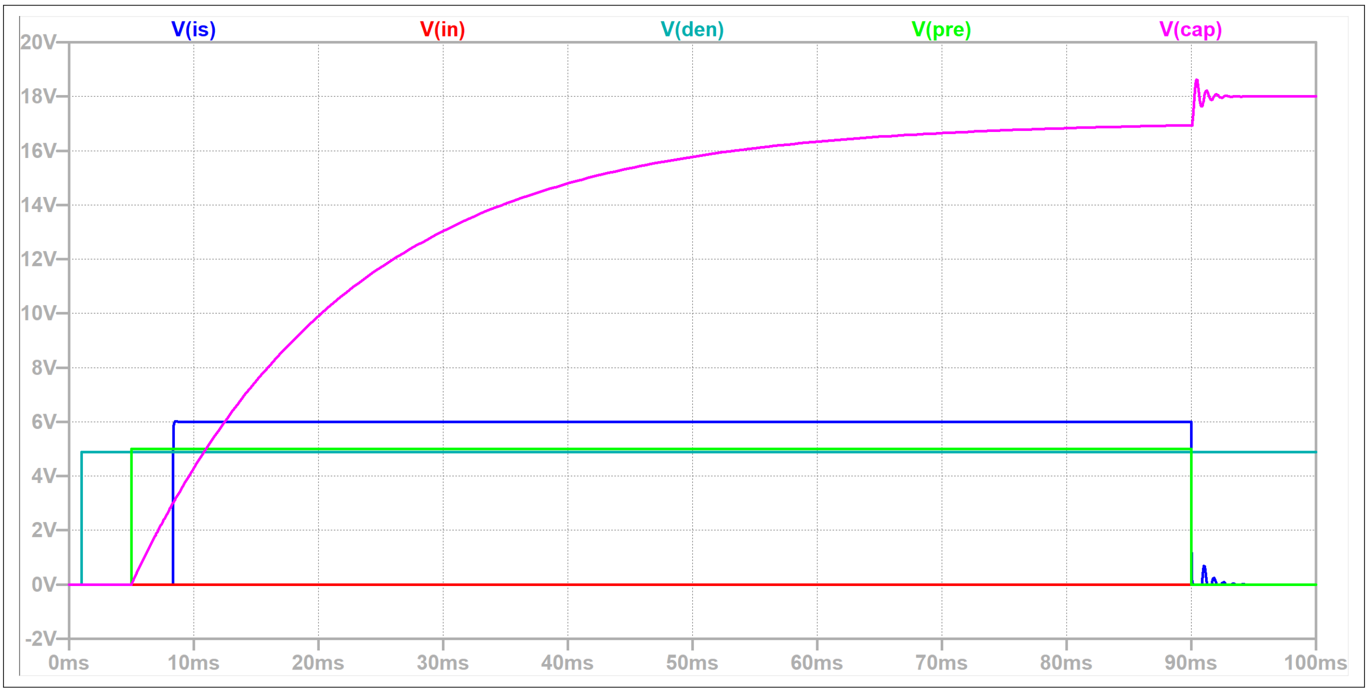

Figure 6 **Result with the BTS50010-1LUA**

Figure 6 shows the behavior of the Evaluation board in normal operation with a capacitive load C_{LOAD} = 5 mF, a battery voltage V_S = 18 V, T_J = 25°C and R_{POW} = 5 Ω:

1. V_{DEN} is set high by the microcontroller
2. After 1 ms, V_{PRE} is set high to turn the P-channel MOSFET on, the pre-charge begins
3. After reaching $V_{OUT(OL\_OFF)}$, $I_{IS(FAULT)}$ is provided by the IS pin. The BTS50010-1LUA detects an output voltage, there is no short circuit situation detected, pre-charge is on-going
4. Then, after reaching t_{DELAY_5TAU} the delay to pre-charge the capacitive load, V_{PRE} is set low to turn the P-channel MOSFET off and V_{IN} is set high to turn the BTS50010-1LUA on

No fault has been seen from the BTS50010-1LUA because the inrush load current is low enough to avoid the over-current protection to latch the device. In this simulation, after t_{DELAY_5TAU}, the capacitive load is fully loaded and the BTS50010-1LUA is in on state.

4.3 Short circuit type 1 situation

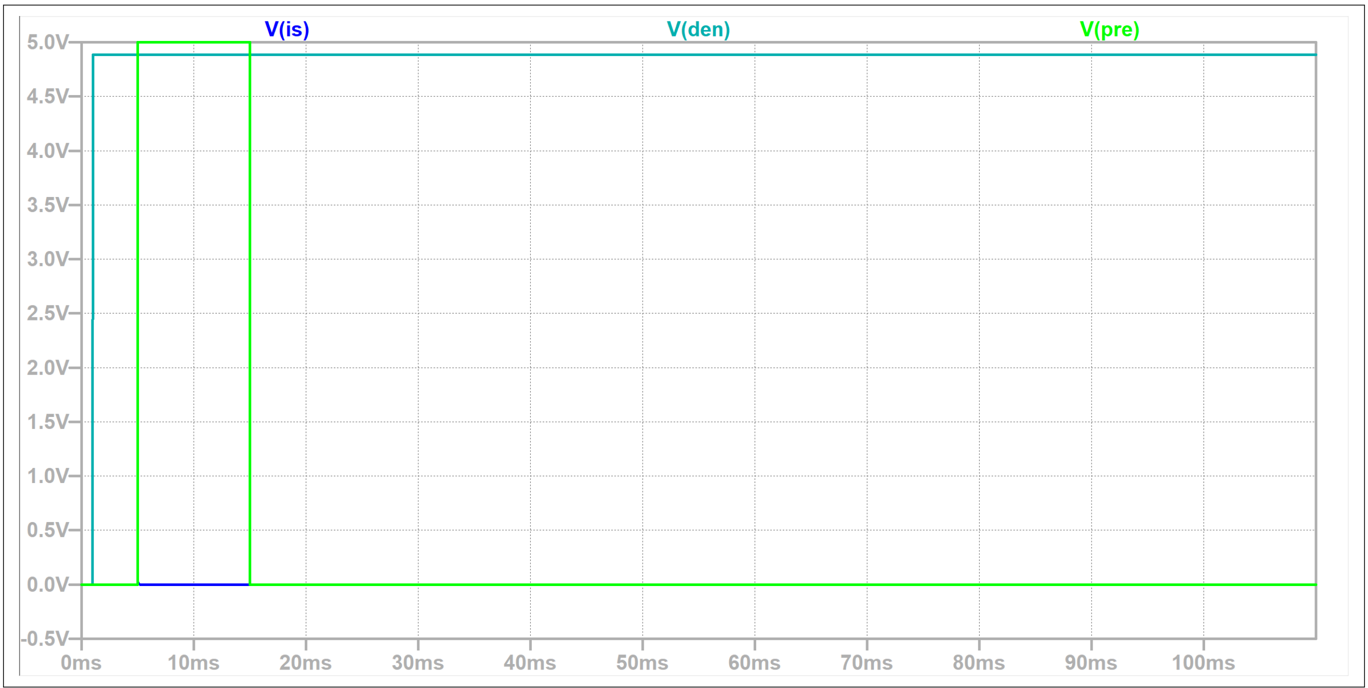

Figure 7 Result of applying a short circuit type 1 between the output and GND

Figure 7 shows the behavior of the Evaluation board when a short circuit type 1 is directly applied between the output and the *GND*:

1. VS is high, V_{DEN} is set high
2. After 1 ms, V_{PRE} is set high. The P-channel MOSFET of the pre-charge circuitry is in on state
3. Due to the short circuit OUT to GND condition, V_{OUT} voltage is close to GND, V_{OUT} is never reaching $V_{OUT(OL\_OFF)}$. So IS pin is never providing $I_{IS(FAULT)}$, then IS voltage is still low
4. V_{IS} is not rising after t_{DELAY_IS}, that means the Evaluation board is in short circuit condition, the microcontroller must turn off V_{PRE} and V_{DEN}

4.4 Capacitive load abilities versus the power resistor value used

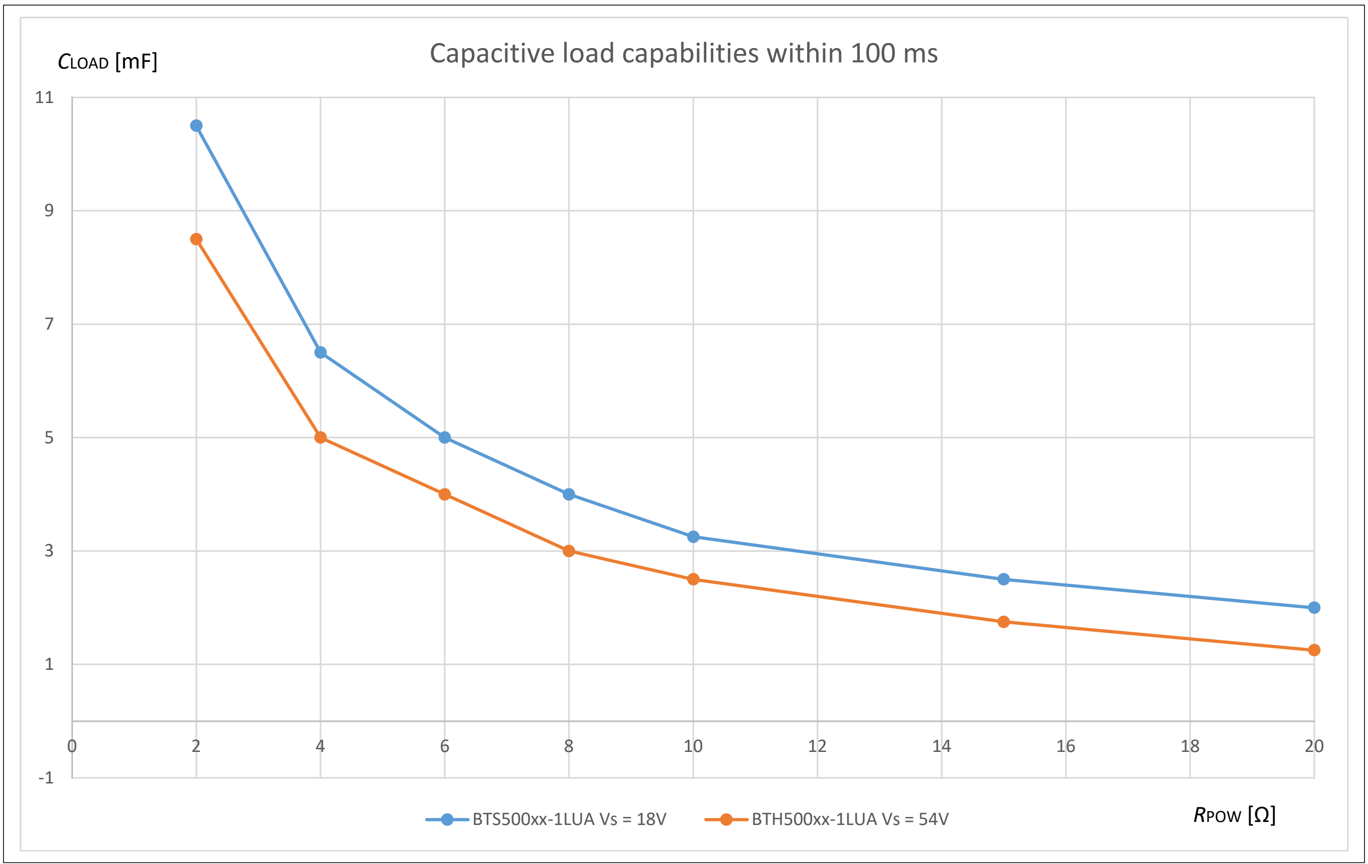

Figure 8 **Time to pre-charge versus capacitor value with the default setting of the circuitry**

Figure 8 shows the capabilities of the Evaluation board to pre-charge capacitive loads within 100 ms. The 100 ms requirement is used in this case to avoid self-heating of the power resistor.

Blue curve is the simulation results for Power PROFET™ + 12V at 18 V and orange curve is for Power PROFET™ + 24/48V at 54 V. Both curves show the maximum capacitance value loadable versus the power resistor value used. Going upper the curve means the Power PROFET™ + can latch in over-current protection.

5 Bill of material, size and price estimation

Table 1 Bill of material of the circuitry

Item	Qty	Ref	Value	Package
1	1	U2	BTS50010-1LUA	PG-HSOF-8
2	1	Q1	SQ2337CES	SOT-23
3	1	Q2	BSS138W	SOT-23
4	1	X1	D3082-05	
5	1	X2	HTSW-105-15-G-S-LL	
6	1	D1	RB162MM-40TFTR	SOD-123
7	2	RPOW1, RPOW2	CRCW251210R0FK	SR2512
8	2	RIS, RPRE	1kR	CMS-0805
9	2	RIN, RDEN	4.7kR	CMS-0805
10	3	R1, R2	470kR	CMS-0805
11	1	COUT	10nF	CMS-0805
12	1	CVS	100nF	CMS-0805

Component	Quantity in schematic	Cost / piece	Package	Area placed (mm²)
Resistors + capacitors	3	0.0020	CMS 0805	8
BSS138W	1	0.0070	SOT-23	8
SQ2337CES	1	0.0070	SOT-23	8
RB162MM-40TF	1	0.0240	SOD-123	17
CRCW251210R0FKEG	1	0.0550	CMS 2512	28

Price	**€**	**0.10**
PCB area needed	**mm²**	**68**

Figure 9 Price and size estimation of the external circuitry

6 Conclusion

By using a parallel resistive path and the IS pin to have feedback, this evaluation board provides a solution for handling capacitive load for Power PROFET™ + family. The solution can be used for 12 V, 24 V and 48 V application according to the Power PROFET™ + used. Users can adapt the power resistor to meet their requirements.

Glossary

CLS

capacitive load switching (CLS)

DC

direct current (DC)

One-directional flow of electric charge. An electrochemical cell is a prime example of DC power. Direct current may flow through a conductor such as a wire, but can also flow through semiconductors, insulators, or even through a vacuum as in electron or ion beams. The electric current flows in a constant direction, distinguishing it from alternating current (AC).

GND

ground (GND)

Revision history

Document version	Date of release	Description of changes
Rev. 2.0	2025-06-30	• BoM, cost and size on PCB reduction • System explanation revised and updated
Rev. 1.00	2025-04-16	• Initial document release