

# Application Note

## Applying the GreenFET Load Switches in Bidirectional Applications

AN-CM-268

### Abstract

*This application note describes how to use the unidirectional GreenFET™ load switches in bidirectional applications while keep operating all protection features including Current Limiting, Short Circuit Protection, Thermal Shutdown Protection and Inrush Current Control. Corresponding oscilloscope captures of operational behavior are included.*

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## Applying the GreenFET Load Switches in Bidirectional Applications

### 1 Terms and Definitions

ACL	Active Current Limit
BLS	Bidirectional Load Switch

### 2 References

- [1] SLG59M1558V, Datasheet
- [2] SLG59M1709V, Datasheet
- [3] AN-1068, GreenFET and High Voltage GreenFET Load Switch Basics, Application Note

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### 3 Introduction

Portable devices constitute the fastest growing segment of modern electronics in number and type. When portable devices are charging, current flows INTO the battery. When the charging adapter is removed and the portable device is powered up, current flows FROM the battery to power the device. It follows that such a system needs an active component which can conduct current in both directions. Furthermore, this component should have an ability to block positive and negative voltages to prevent battery discharge when the device is turned off. There are, in general, two ways to deal with this system-level issue. The first one is to use dedicated bidirectional load switches available on the market, but at a hefty price. Another way is to construct such an active component using discrete or integrated MOSFETs, at lower cost. This is the approach we will describe.

MOSFETs have a body diode, so it blocks voltage only in one direction. To block voltages in both directions, an additional series diode of opposite polarity can be used, but in this case, current flow is unidirectional. To achieve bidirectional current flow with ability to block voltages in both directions, a second MOSFET is needed. Thus, a bidirectional load switch (BLS) is a four-quadrant switch that can block positive and negative voltages in the OFF state and allows load currents in either direction in the ON state.

Figure 1 shows common configurations which can be used for BLS realization using MOSFETs: a) - common drain N-channel MOSFETs; b) - common source N-channel MOSFETs; c) - common drain P-channel MOSFETs and d) - common source P-channel MOSFETs.

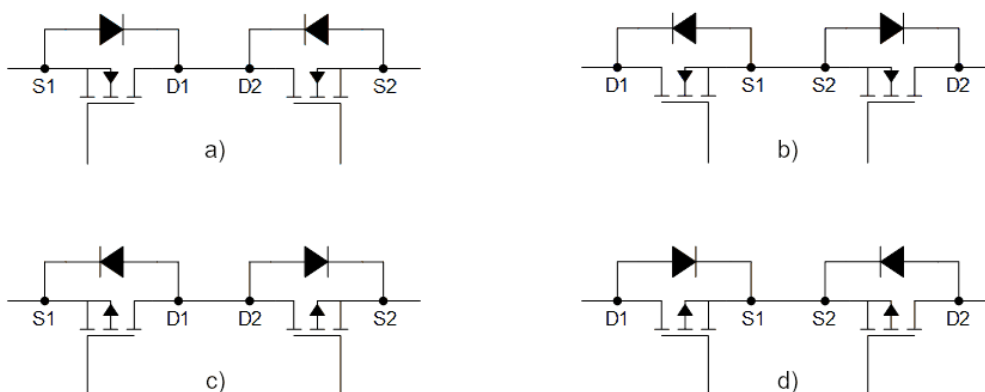


Figure 1. Common Configurations for BLS Realization

This application note will describe BLSs constructed with common-drain connected pairs of unidirectional GreenFET load switches, both P and N-channel. In these circuits, the GreenFET load switches' source terminals are respectively connected to power supply and load.

### 4 A Very Low-Power, Bidirectional Load Switch Using Two SLG59M1558Vs

The SLG59M1558V is a 28.5 m $\Omega$ , 1.0 A rated P-channel MOSFET controlled by a single ON pin and is packaged in an ultra-small 1.0 x 1.0 mm package. Serially connecting these two GreenFET load switches in the way shown in Figure 2, a simple and very small bidirectional load switch can be obtained.

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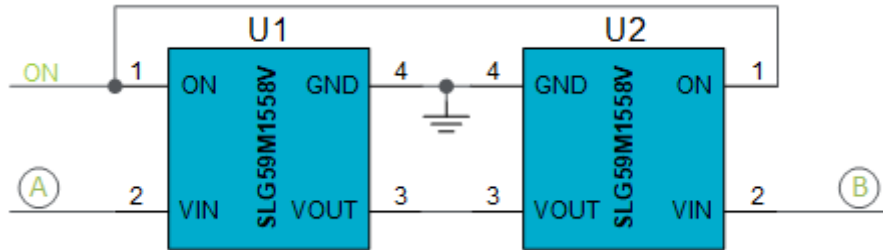


Figure 2. A Very Small and Very Low Power Bidirectional Load Switch Realization Using a Pair of SLG59M1558V GreenFET Load Switches

Let's assume that terminal "A" is the input terminal of the BLS and the ON pin is asserted LOW. The "B" terminal has a 20 Ω load resistor and 10 μF load capacitor. When 5 V is applied at terminal "A" this voltage is blocked from U2-3 because the ON pin is asserted LOW. When the ON pin becomes asserted HIGH, U1 and U2 close simultaneously and the voltage appears at terminal "B". This power-up operation is illustrated in Figure 3.

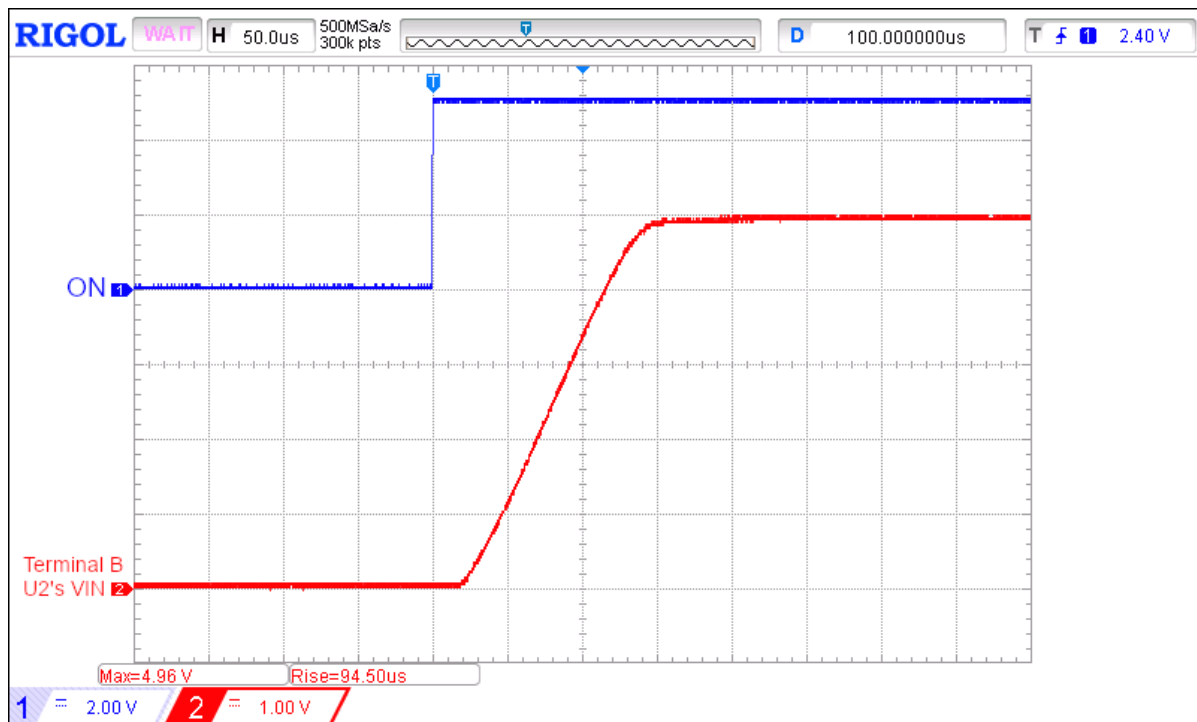


Figure 3. BLS Turn-ON Operation for Two, Series-Connected SLG59M1558V GreenFET Load Switches for  $V_{IN(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ ,  $C_{LOAD} = 10\ \mu\text{F}$

BLS turn off operation waveforms with and without capacitive loads are presented in Figure 4 and Figure 5, respectively.

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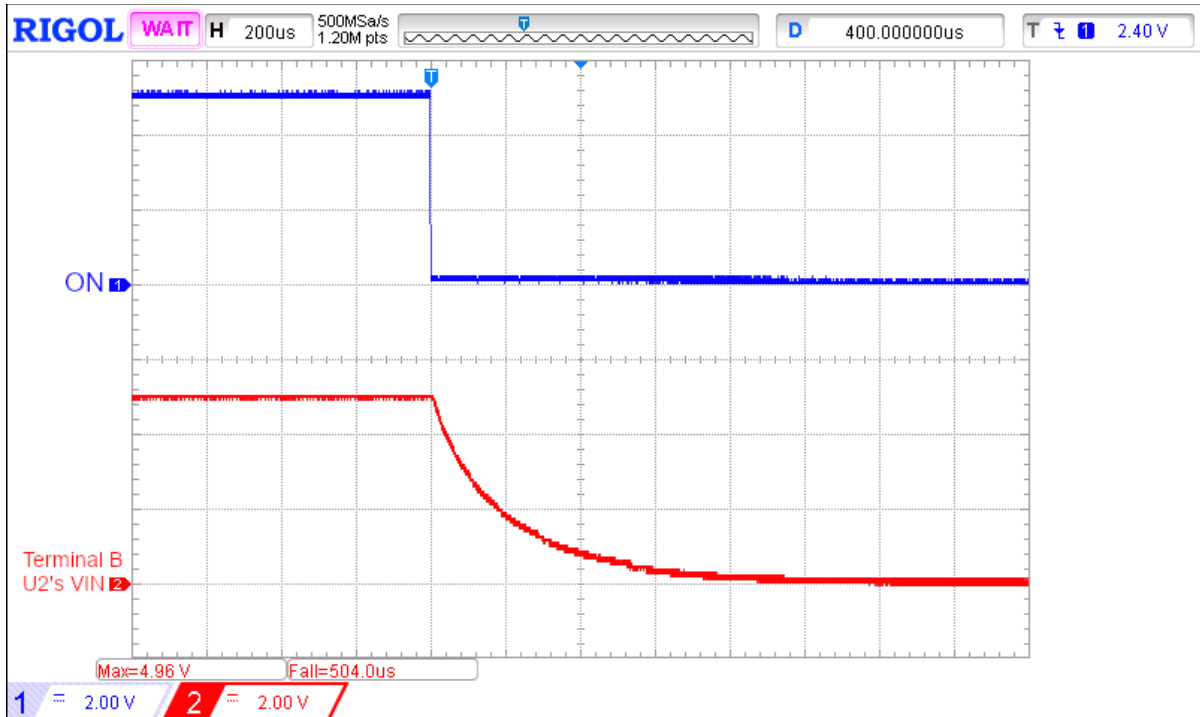


Figure 4. BLS Turn-OFF Operation for Two, Series-Connected SLG59M1558V GreenFET Load Switches for  $V_{IN(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ ,  $C_{LOAD} = 10\ \mu\text{F}$

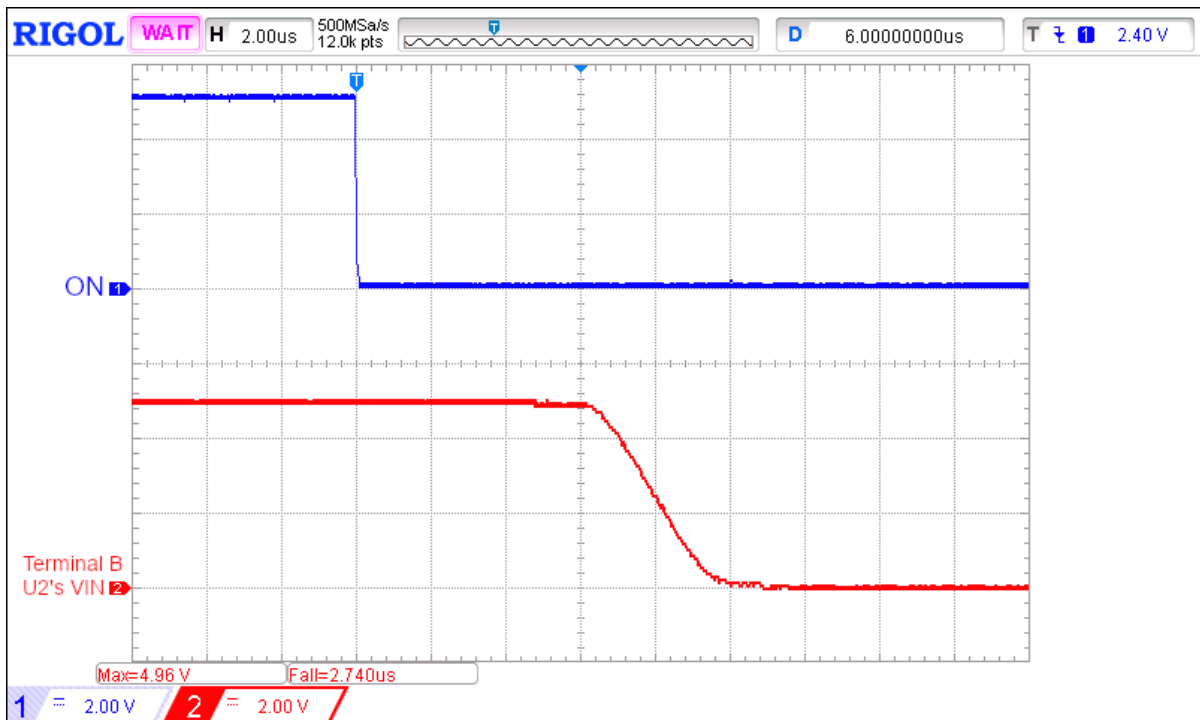


Figure 5. BLS Turn-OFF Operation for Two, Series-Connected SLG59M1558V GreenFET Load Switches for  $V_{IN(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ , no  $C_{LOAD}$

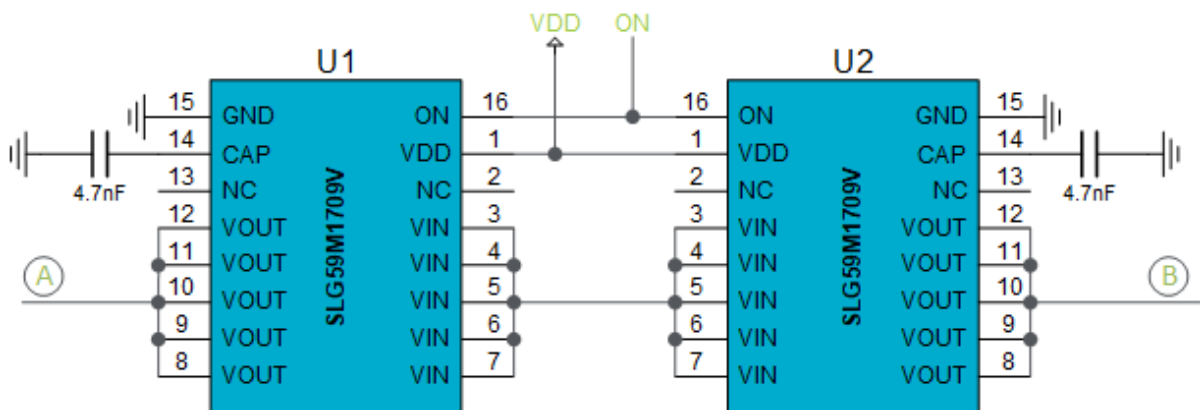
BLS behavior for reverse load-current operation is the same.

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### 5 A Feature-Rich, High-Performance Bidirectional Load Switch Using Two SLG59M1709Vs

Operating from a 2.5 V to 5.5 V power supply and fully specified over the -40 °C to 85 °C temperature range, the SLG59M1709V is a high-performance 4 mΩ, 4 A single-channel nFET load switch with adjustable inrush current control which is achieved by adjusting the  $V_{OUT}$  slew rate with an external capacitor. Using a proprietary MOSFET design, the SLG59M1709V achieves a stable 4 mΩ  $R_{DS(ON)}$  across a wide input/supply voltage range. Incorporating two-stage current protection as well as thermal protection, the SLG59M1709V is designed for all 0.8 V to 5.5 V power rail applications.

For this type of GreenFET load switches, a common drain connection is selected as was shown in Figure 1a. The resulting design of this BLS is shown in Figure 6.



**Figure 6: A High-Performance, Bidirectional Load Switch Using a Pair of SLG59M1709V GreenFET Load Switches**

ON and VDD pins of U1 and U2 are connected in parallel, respectively, so both ICs can be turned on and off simultaneously. The BLS's output voltage follows a linear ramp set by a capacitor connected to each CAP pin. A larger capacitor value at the CAP pin produces a slower ramp, reducing inrush current from capacitive loads.

By applying 5 V at terminal "A", which corresponds to the U1's VOUT pins (U1-[8:12]), imparts a voltage at the node common to U1 and U2. This takes place because of the U1's body diode, which in this case is forward biased. Since there is a voltage drop across this diode, the voltage at the node common to both ICs (U1-[3:7] and U2-[3:7]) is approximately 4.4 V. This voltage is blocked by U2 because its ON pin asserted LOW. When the ON pin is asserted HIGH, both GreenFET load switches power up and the voltage now appears at terminal "B". During power up, a small transition, illustrated in Figure 7, can be observed. It is caused by internal linear ramp control circuit operation.

Turn-off operation waveforms with and without capacitive loads are presented in Figure 8 and Figure 9, respectively.

The reverse operational behavior of the BLS from terminal "B" to terminal "A" remains the same as in the forward direction.

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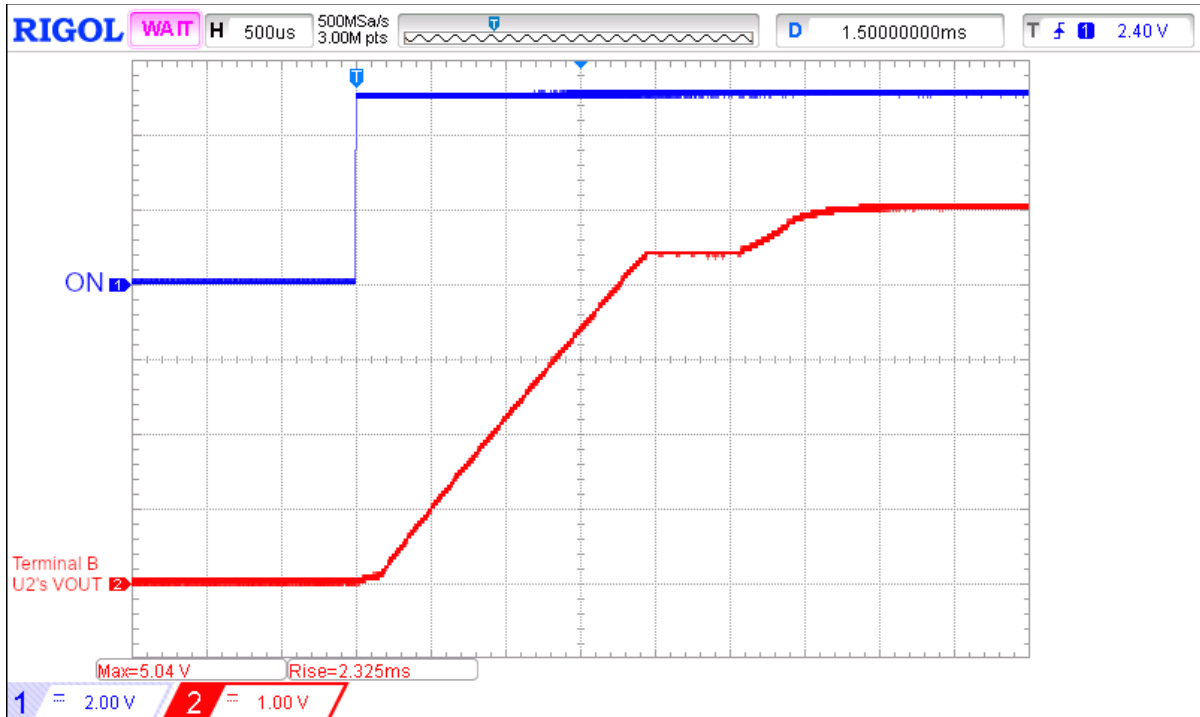


Figure 7. BLS Turn-ON Operation Using a Pair of Series-Connected SLG59M1709V GreenFET Load Switches for  $V_{OUT(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ ,  $C_{LOAD} = 10\ \mu\text{F}$

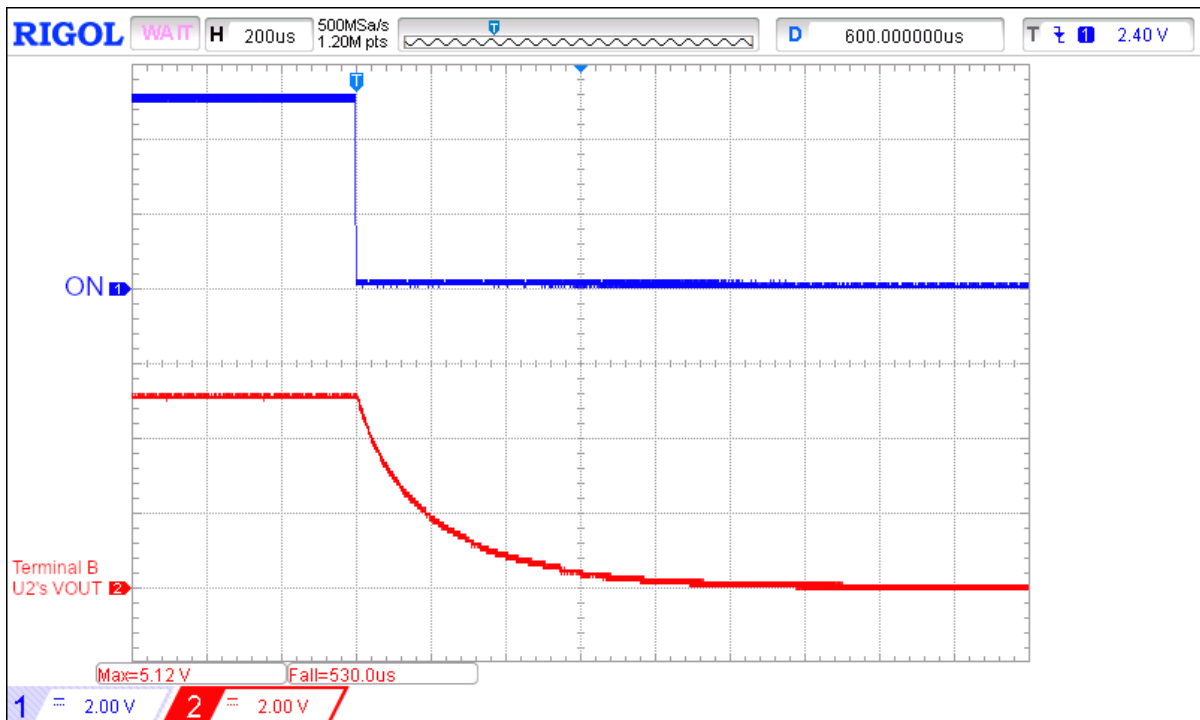
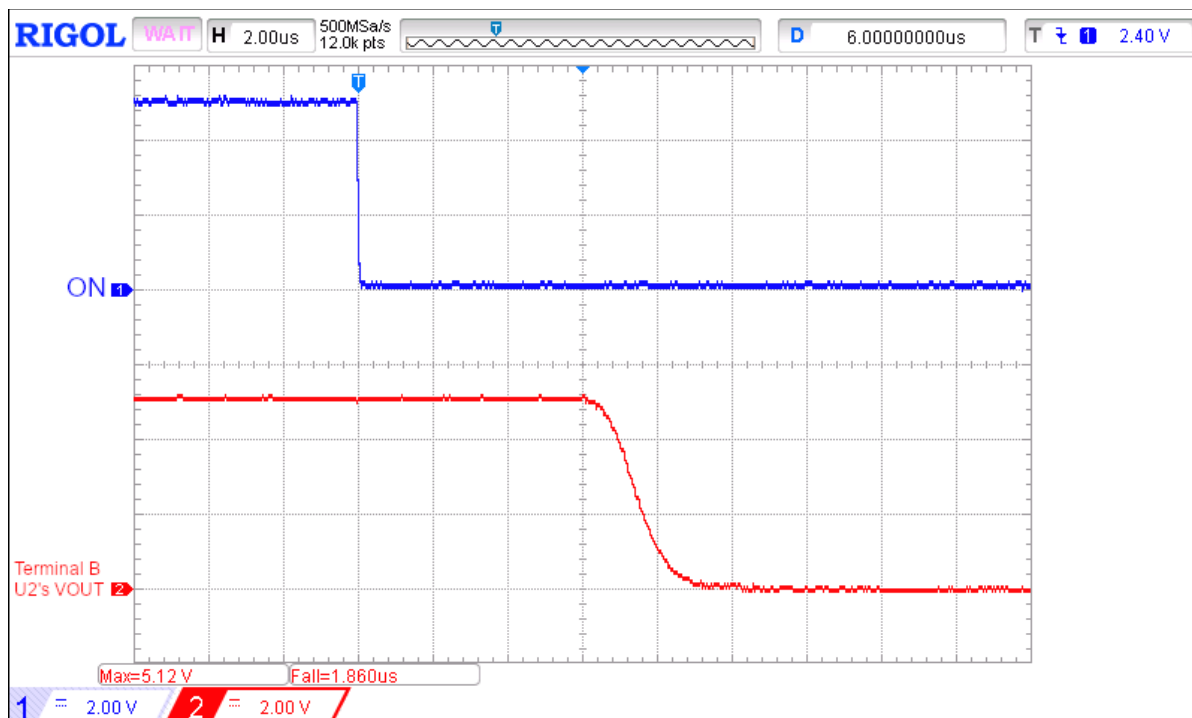


Figure 8. BLS Turn-OFF Operation Using a Pair of Series-Connected SLG59M1709V GreenFET Load Switches for  $V_{OUT(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ ,  $C_{LOAD} = 10\ \mu\text{F}$



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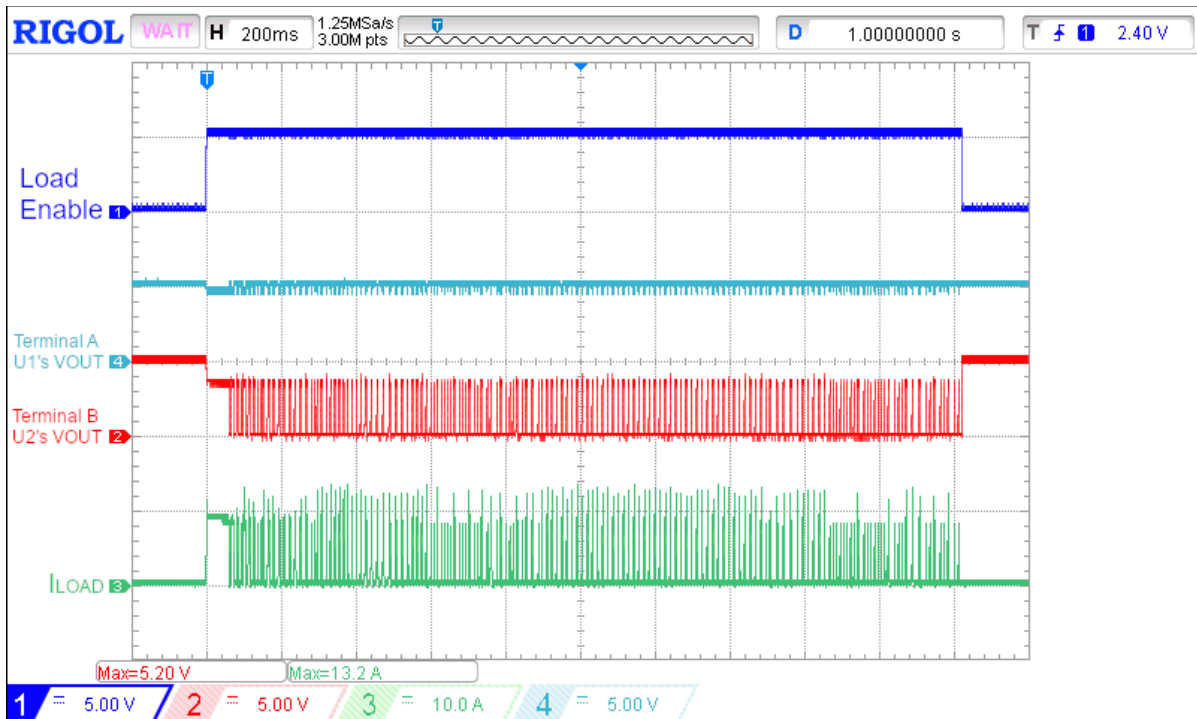


**Figure 9. BLS Turn-OFF Operation Using a Pair of Series-Connected SLG59M1709V GreenFET Load Switches for  $V_{OUT(A)} = 5\text{ V}$ ,  $R_{LOAD} = 20\ \Omega$ , no  $C_{LOAD}$**

Constructing a bidirectional load switch using the SLG59M1709V and similar GreenFET load switches retains all protection features. Thus, an GreenFET load switch's Active Current Limit, Short Circuit Protection, Thermal Shutdown Protection, and Inrush Current Control can easily protect important components upstream and downstream of the GreenFET load switch as well as the load switch itself.

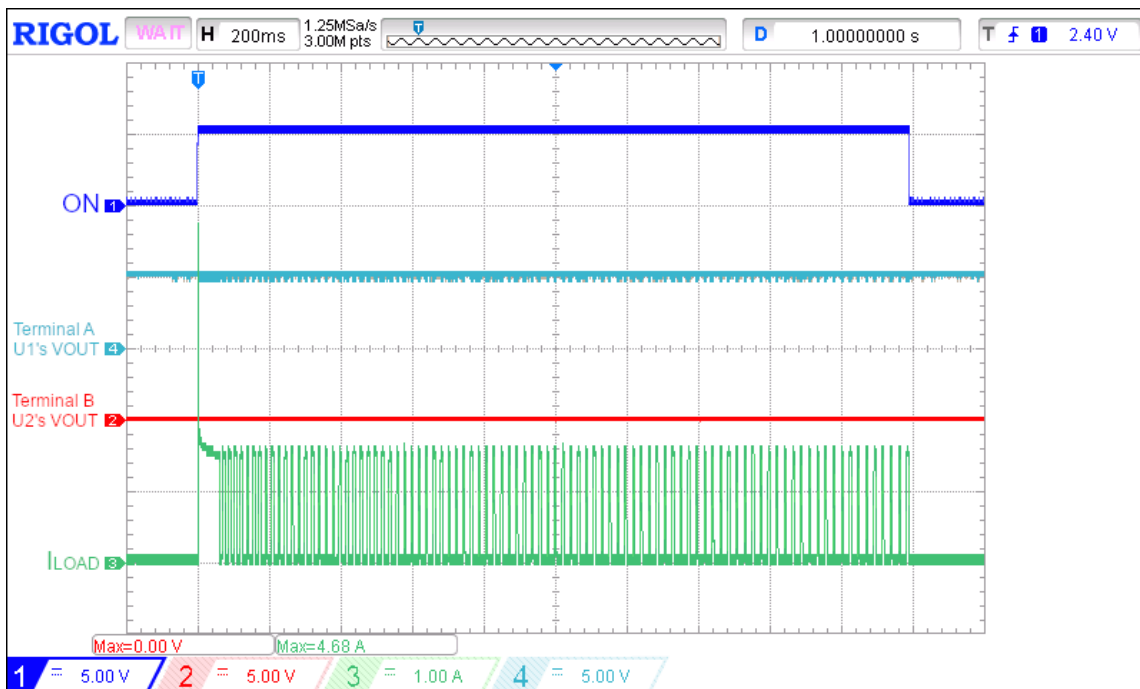
For example, when the BLS's output voltage is greater than 300 mV, output current is initially limited to U2's Active Current Limit ( $I_{ACL}$ ) threshold which is 8 A (from the SLG59M1709V's spec sheet). When a load current overload is detected, U2's ACL monitor increases U2's FET resistance to keep the current from exceeding the U2's  $I_{ACL}$  threshold. During active current-limit operation, the output voltage is also reduced by  $I_{ACL} \times R_{DS_{ON}(ACL)}$ . However, if the load-current overload condition persists where the die temperature rises because of the increased FET resistance, the U2's internal Thermal Shutdown Protection circuit will be activated. If the die temperature exceeds 125 °C, U2's FET is shut OFF completely, thereby allowing the die to cool. When U2's die cools to 100 °C, U2's FET is turned back on. This process may repeat while the output current overload condition persists. Operation of both Active Current Limit protection as well as Thermal Shutdown Protection is illustrated in [Figure 10](#).

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**Figure 10. BLS ACL and Thermal Shutdown Protection Operation Waveform Using a Pair of Series-Connected SLG59M1709V GreenFET Load Switches**

When the BLS's output voltage is less than 300 mV (a short circuit condition), the U2's internal Short-circuit Current Limit (SCL) monitor limits the FET current to approximately 500 mA (the  $I_{sc}$  threshold). Observed BLS behavior is shown in Figure 11.



**Figure 11. BLS Short Circuit Protection with Thermal Shutdown Protection Operation Using a Pair of Series-Connected SLG59M1709V GreenFET Load Switches**

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## Applying the GreenFET Load Switches in Bidirectional Applications

### 6 Conclusions

In this application note, the SLG59M1558V and SLG59M1709V GreenFET load switches were configured for bidirectional applications. Additionally, it is also possible to use other P- and N-channel GreenFET load switches provided that those load switches do not include Reverse-Current Blocking, Reverse-Voltage Blocking, and VOUT Discharge features. The GreenFET load switches featuring Active Current Limiting and Short Circuit Current Limiting Modes with Thermal Shutdown Protection, and Inrush Current Control are all excellent candidates for constructing high-performance, pcb space-efficient bidirectional load switches.

The list of GreenFET load switches which can be used for bidirectional load switching applications (at time of this writing) are listed below:

- SLG59M1442V
- SLG59M1545V
- SLG59M1556V
- SLG59M1599V
- SLG59M1657V
- SLG59M1710V
- SLG59M1721V
- SLG59M1735C

More detailed information can be found on <https://www.dialog-semiconductor.com/products/load-switches>

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