

Introduction

This application note describes some common problems caused by operating inductive loads. An inductor is passive two-terminal electrical component that stores electrical energy in a magnetic field when electric current flows through it. Any device that has coils of wire as an integral part of its design can be classified as inductive. Some common examples are motors, relays, solenoids, electromagnets, etc. Operating such loads without circuit protection can greatly shorten the switch service life. This application note is devoted to solve such a problem.

Design Description

In this application note, we will describe how to use Dialog’s GreenFET load switch SLG59M1638V to operate inductive loads. For an inductive load, we will use a 0.8 W solenoid. The SLG59M1638V is a dual-channel, 45 mΩ PMOS load switch that is capable of switching 1.5 to 5.5 V power rails up to 2 A in each channel. A typical schematic of using Silego’s SLG59M1638V as a switch for inductive load is illustrated in Figure 1.

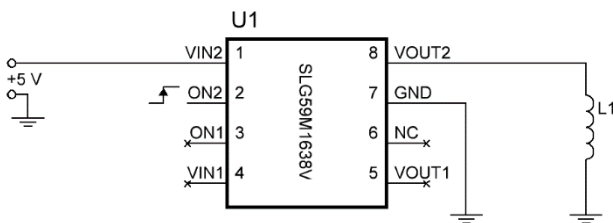


Figure 1. Application diagram of operating a load switch with an inductive load

Inductive Loads Operation

When an inductive load is connected to a power supply and the switch is closed, the current flows through the coil and generates a magnetic field. Since the rise time of the SLG59M1638V is fixed, due to internal turn on ramp control circuit, it prevents some inductive effects while switching on an inductive load. A typical Turn On behavior for SLG59M1638V and a 0.8 W solenoid is illustrated in Figure 2.

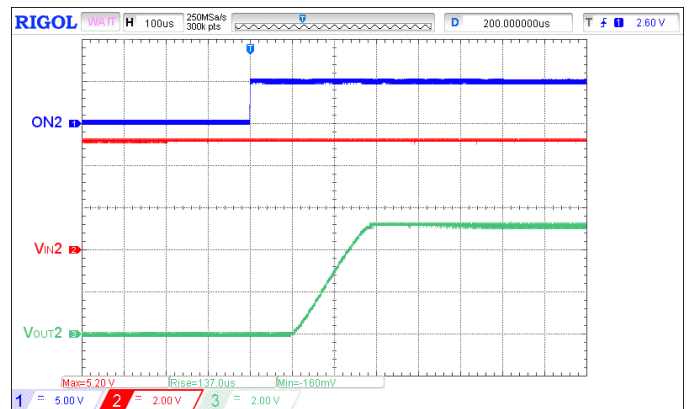


Figure 2. Turn On waveform for $V_{IN} = 5\text{ V}$ and a 0.8 W solenoid.

When the switch is opened, the current is interrupted and the magnetic field changes in strength and collapses. This induces current flow in the opposite direction, according to Lenz’s Law. A negative potential is created where there was once a positive potential, and vice versa. This is commonly known as fly-back behavior. The coil now acts like a new power source, but with a much greater potential difference (measured in volts) between the positive and negative than the original power source. It can be significantly higher the nominal circuit voltage. This high voltage spike, shown visually on Figure 3, is governed by the equation:

$$V = L \frac{di}{dt}$$

where V is the voltage across the inductive load, L is the inductance of the load, and (di/dt) is the rate of current change with respect to time. The more quickly the current is changed in the load, the higher the voltage. This can severely damage the switch and greatly shorten any product's service life.

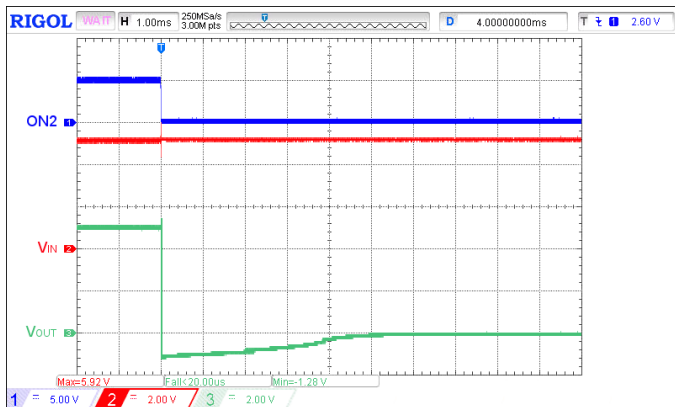


Figure 3. Turn Off waveform for $V_{IN} = 5\text{ V}$ and a 0.8 W solenoid.

Also there is an influence on the input inducing some small voltage spikes which are illustrated in Figure 4.

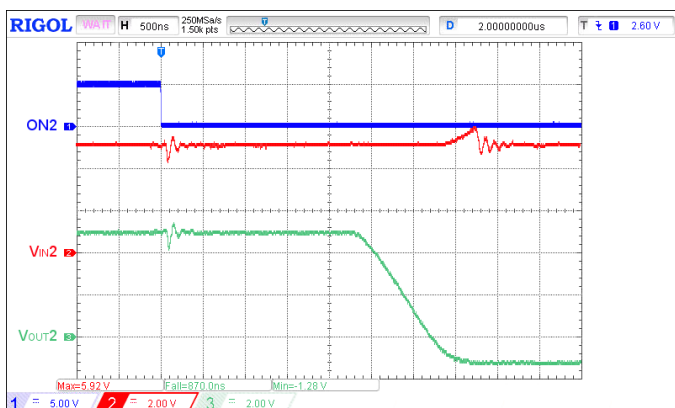


Figure 4. Turn Off waveform (extended view) for $V_{IN} = 5\text{ V}$ and a 0.8 W solenoid

To minimize or eliminate voltage spikes altogether, a $10\text{ }\mu\text{F}$ input capacitor can be

added as shown in Figure 5. A corresponding operation waveform is illustrated in Figure 6.

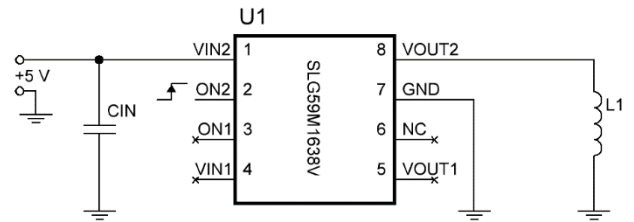


Figure 5. Application diagram of operating an inductive load with an input capacitor

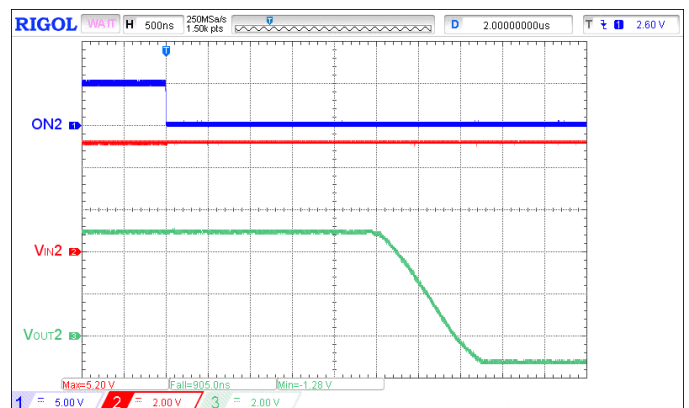


Figure 6. Turn Off waveform (extended view) for $V_{IN} = 5\text{ V}$, $C_{IN} = 10\text{ }\mu\text{F}$, and a 0.8 W solenoid.

Protection Recommendations

The best way to suppress unwanted fly-back voltage is to add a diode placed in parallel with the inductive load.

A diode is a simple semiconductor device which allows current to flow only in one direction. Figure 7 shows a circuit with an inductive load and a diode placed in parallel.

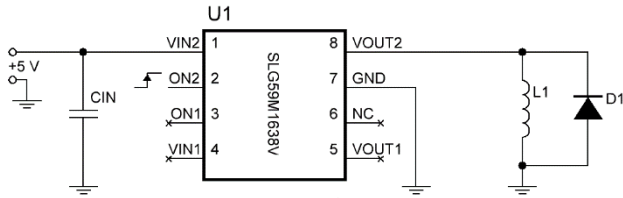


Figure 7. Application diagram of operating an inductive load with an input capacitor and a fly-back diode

The induced current is re-routed down an alternative path back through the coil. In this way, the coil draws a current from itself (hence the name 'fly-back') in a continuous loop until the energy is dissipated harmlessly through losses in the wire and across the diode (Figure 8). The diode needs to be placed correctly in the circuit so that during normal operation it is not activated, but, during the fly-back operation, it becomes active and conducts current away from the rest of the circuit and back through the inductor. It should be placed as close to the inductive load as possible.

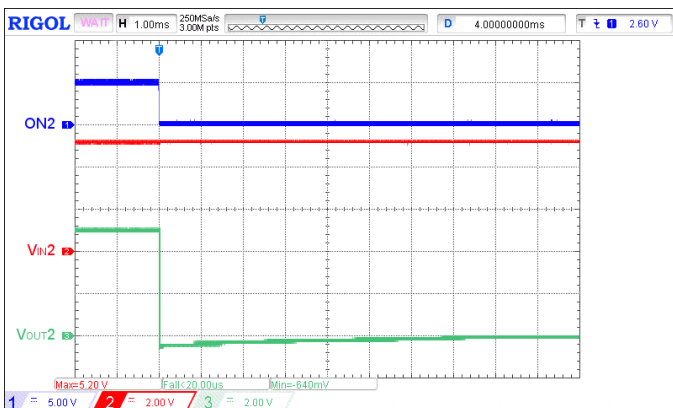


Figure 8. Turn Off waveform for $V_{IN} = 5\text{ V}$, $C_{IN} = 10\ \mu\text{F}$, a 0.8 W solenoid, and a fly-back diode

To further reduce a negative voltage spike, an output capacitor can be added as shown in Figure 9. In this case, circuit fall time increases. The dependence of fall time with respect to output capacitance is illustrated in Figures 10-12.

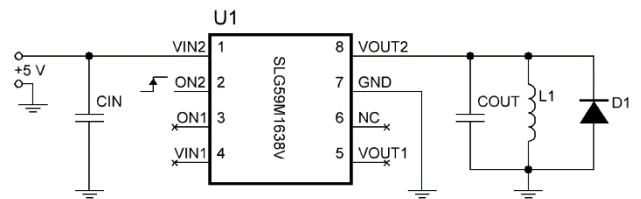


Figure 9. Application diagram of operating an inductive load with input and output capacitors and a fly-back diode

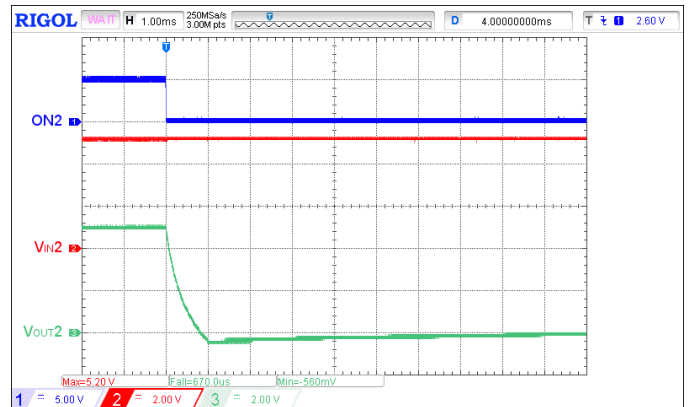


Figure 10. Turn Off waveform for $V_{IN} = 5\text{ V}$, $C_{IN} = 10\ \mu\text{F}$, $C_{OUT} = 10\ \mu\text{F}$, a 0.8 W solenoid, and a fly-back diode

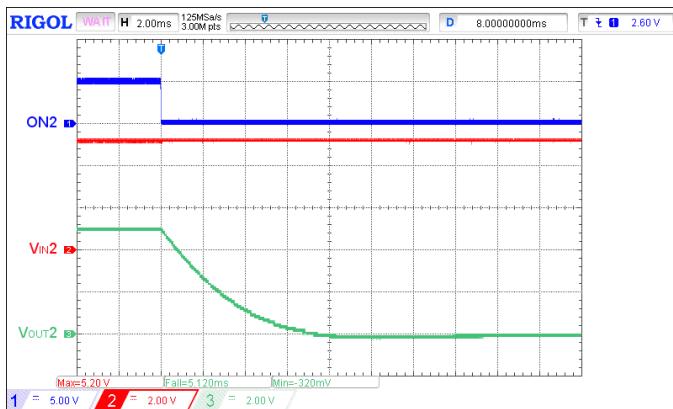


Figure 11. Turn Off waveform for $V_{IN} = 5\text{ V}$, $C_{IN} = 10\ \mu\text{F}$, $C_{OUT} = 100\ \mu\text{F}$, a 0.8 W solenoid, and a fly-back diode

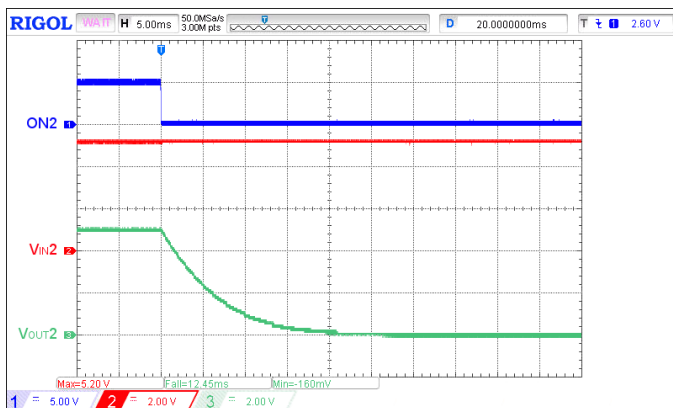


Figure 12. Turn Off operation waveform for $V_{IN} = 5\text{ V}$, $C_{IN} = 10\ \mu\text{F}$, $C_{OUT} = 200\ \mu\text{F}$, a 0.8 W solenoid, and a fly-back diode

Conclusions

Operating inductive loads without protection can severely damage switches and greatly shorten any product’s service life. To avoid this, a diode – to prevent unwanted fly-back operation – placed in parallel with the inductive load is recommended. An additional output capacitor can be added, but, in this case, circuit fall time increases.

IMPORTANT NOTICE AND DISCLAIMER

RENESAS ELECTRONICS CORPORATION AND ITS SUBSIDIARIES (“RENESAS”) PROVIDES TECHNICAL SPECIFICATIONS AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for developers skilled in the art designing with Renesas products. You are solely responsible for (1) selecting the appropriate products for your application, (2) designing, validating, and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. Renesas grants you permission to use these resources only for development of an application that uses Renesas products. Other reproduction or use of these resources is strictly prohibited. No license is granted to any other Renesas intellectual property or to any third party intellectual property. Renesas disclaims responsibility for, and you will fully indemnify Renesas and its representatives against, any claims, damages, costs, losses, or liabilities arising out of your use of these resources. Renesas' products are provided only subject to Renesas' Terms and Conditions of Sale or other applicable terms agreed to in writing. No use of any Renesas resources expands or otherwise alters any applicable warranties or warranty disclaimers for these products.

(Rev.1.0 Mar 2020)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:
www.renesas.com/contact/

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.