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.

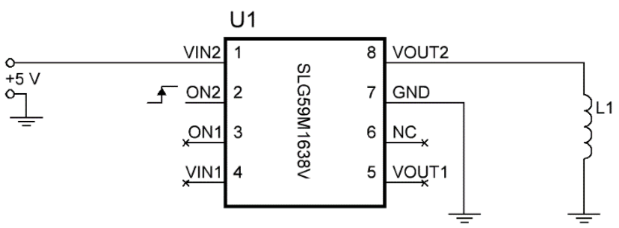

Figure 1. Application diagram of operating a load switch with an inductive load

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.

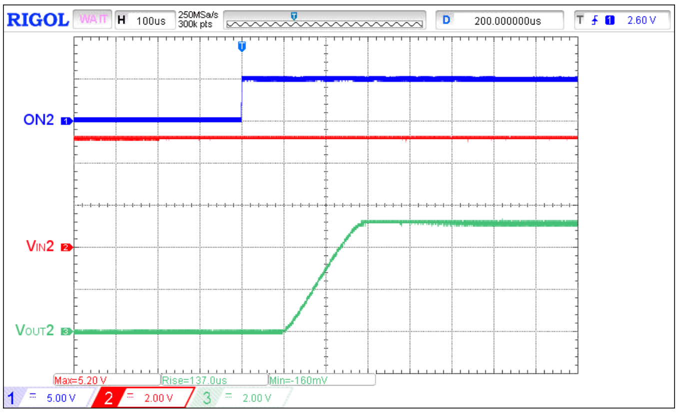

Figure 2. Turn On waveform for V_{IN} = 5 V and a 0.8 W solenoid.

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.

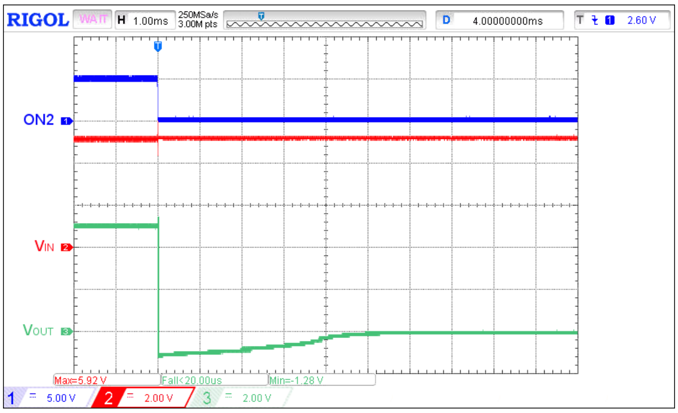

Figure 3. Turn Off waveform for V_{IN} = 5 V and a 0.8 W solenoid.

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

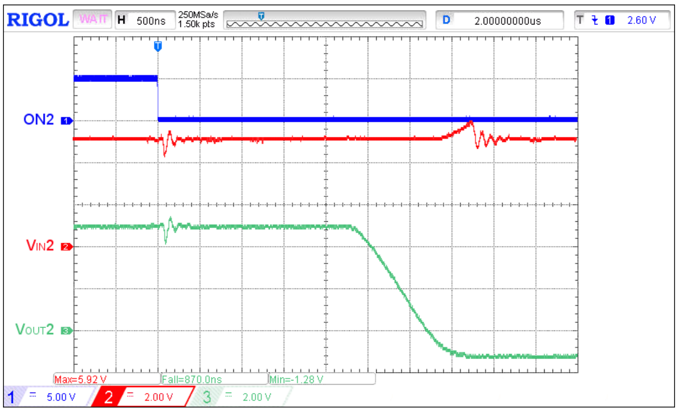

Figure 4. Turn Off waveform (extended view) for V_{IN} = 5 V and a 0.8 W solenoid

To minimize or eliminate voltage spikes altogether, a 10 µF input capacitor can be added as shown in Figure 5. A corresponding operation waveform is illustarted in Figure 6.

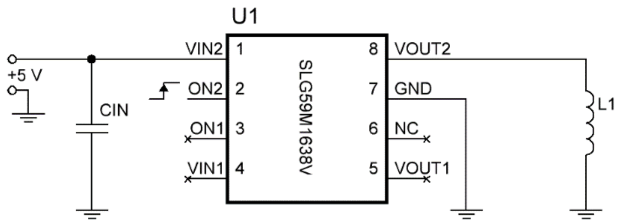

Figure 5. Application diagram of operating an inductive load with an input capacitor

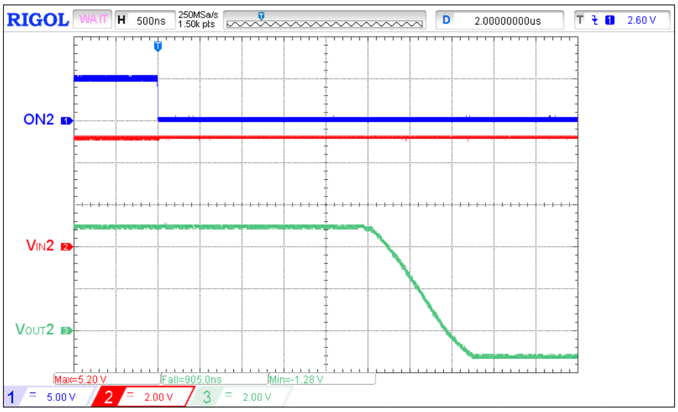

Figure 6. Turn Off waveform (extended view) for V_{IN} = 5 V, C_{IN} = 10 µF, and a 0.8 W solenoid.

Protection Recommendations

The best way to supress 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.

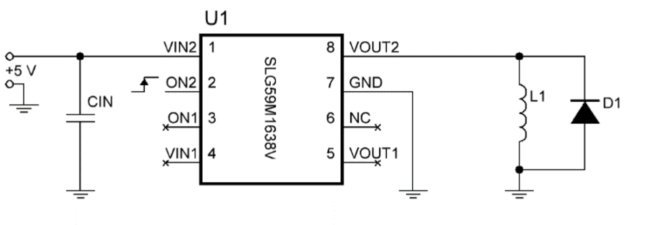

Figure 7. Application diagram of operating an inductive load with an input capacitor and a fly-back diode

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.

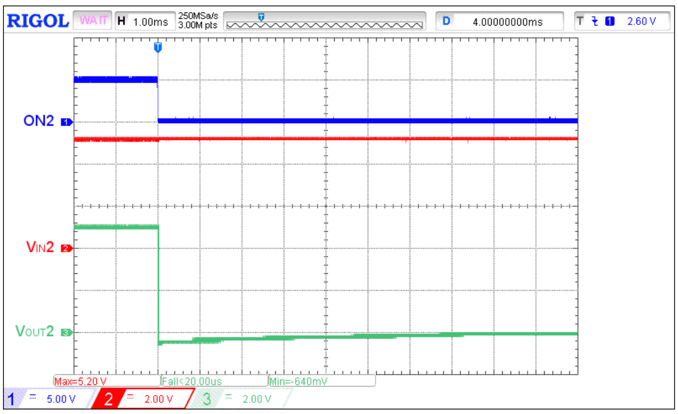

Figure 8. Turn Off waveform for V_{IN} = 5 V, C_{IN} = 10 µF, a 0.8 W solenoid, and a fly-back diode

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 dependance of fall time with respect to output capacitance is illustrated in Figures 10-12.

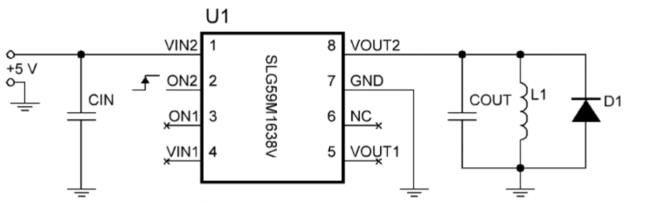

Figure 9. Application diagram of operating an inductive load with input and output capacitors and a fly-back diode

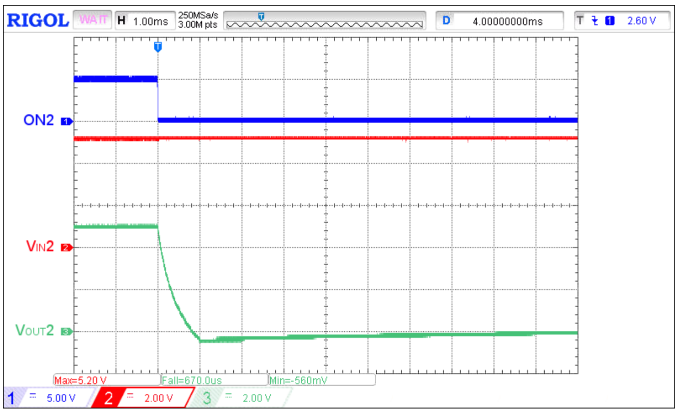

Figure 10. Turn Off waveform for V_{IN} = 5 V, C_{IN} = 10 µF, C_{OUT} = 10 µF, a 0.8 W solenoid, and a fly-back diode

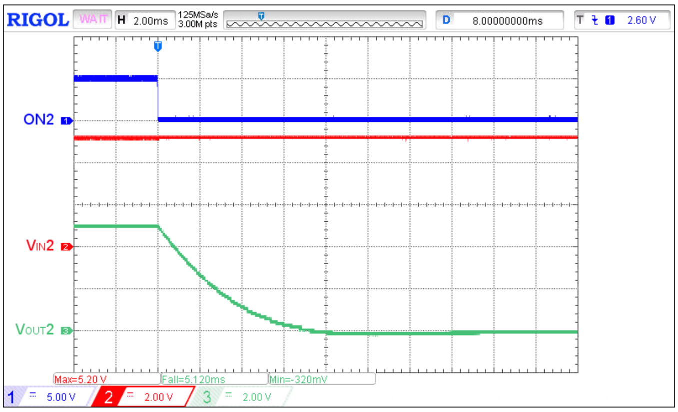

Figure 11. Turn Off waveform for V_{IN} = 5 V, C_{IN} = 10 µF, C_{OUT} = 100 µF, a 0.8 W solenoid, and a fly-back diode

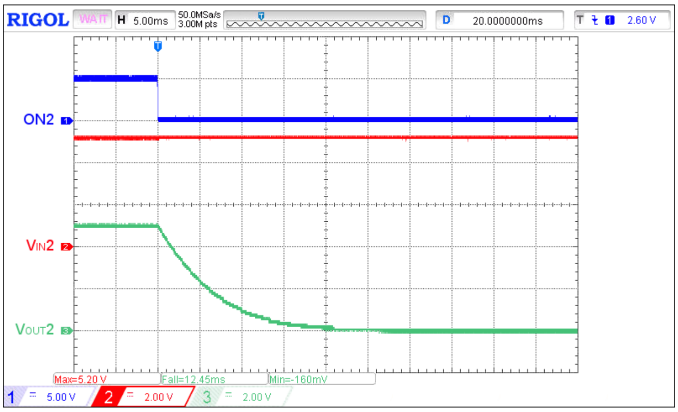

Figure 12. Turn Off operation waveform for V_{IN} = 5 V, C_{IN} = 10 µF, C_{OUT} = 200 µF, a 0.8 W solenoid, and a fly-back diode

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.

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