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AND8116/D

Integrated Relay/Inductive Load Drivers for Industrial and Automotive Applications

Abstract

Most PC board mounted relays are driven by microprocessors or other sensitive electronic devices. A successful coil drive circuit requires isolation between the relay and the microprocessor circuitry. Effective drive circuits must account for drive current and voltage requirements as well as effective suppression of L di/dt transients which can destroy microprocessor circuits. While it is easy to over-design an effective drive circuit, today's designs must be cost competitive. Integrating a monolithic IC driver device into the relay will provide significant value to the system designer.

This paper describes the operation of ON Semiconductor's integrated relay driver products to interface sensitive electronic devices with mechanical relays to accomplish different control/power functions. Important benefits such as PC board space savings and components count reduction are also explained.

Introduction

Although the advances in the electronics industry are increasing day by day, mechanical relays are still extensively used in industrial and automotive applications to control high current loads. Their low cost and excellent fault tolerance make relays to be an useful and reliable solution in industrial and automotive applications environments. The integrated relay driver devices NUD3105, NUD3112 and NUD3124 offered by ON Semiconductor are considered to be the ideal device solution to control mechanical relays used in industrial and automotive applications. Their integrated design allows significant simplification and cost reductions when replacing traditional discrete solutions such as bipolar transistors plus free-wheeling diodes.

Industrial and Automotive Application Requirements

The device requirements for industrial and automotive applications are different and must be addressed in different manner. While the requirements for automotive applications are the most difficult to comply with, industrial requirements traditionally allow more latitudes. Relay coil currents vary considerably depending on the applications. The largest class of industrial and automotive relays have coils with current consumption between 50 and 150 mA.

Selection of a suitable relay driver requires many constraints to be evaluated. For automotive applications, it is necessary to put special attention in the following requirements:

- Load Dump (80 V, 300 ms)
- Dual Voltage Jump Start (24 V or More)
- Reverse Battery (−14 V, 1 Minute or More)
- ESD Immunity (according AEC−Q100 Specification)
- Operating Ambient Temperature (−40°C to 85°C)

Meeting these automotive requirements usually results in specifying an oversized and non-cost effective relay driver, or one requiring many protection components.

Industrial applications on the other hand do not have many requirements different than the standard ones such as ESD immunity (usually 2.0 kV HBM), and a given range of operating ambient temperature (usually between 0°C to 85°C). However, some applications also call for protection devices against transient voltage conditions, which creates the need for extra protection components too.

STANDARD DISCRETE RELAY DRIVERS

For both type of applications industrial and automotive, the most traditional and popular relay drivers are the ones formed discretely with a bipolar transistor, two bias resistors and a free-wheeling diode. In some cases, it is required to add extra components such as MOVs (metal oxide varistors) and extra diodes to ensure proper protection. Figure 1 shows a typical discrete relay driver with the extra protection devices. Diode D1 provides reverse supply protection and diode D2 provides a clamp function to suppress the voltage spike generated by the relay's coil during the turn-off interactions ($V = Ldi/dt$). A power MOV device is used to limit positive transients to within the bipolar transistor's breakdown voltage. The saturation voltage of the bipolar transistor (typically over 1.0 V) causes high power dissipation which in some cases eliminates the option to use inexpensive surface mount package devices such as SOT−23 or smaller, therefore the need for bigger packages such as TO220 is always present. The resulting discrete circuit is expensive because it takes several components and a big space in the PC board.
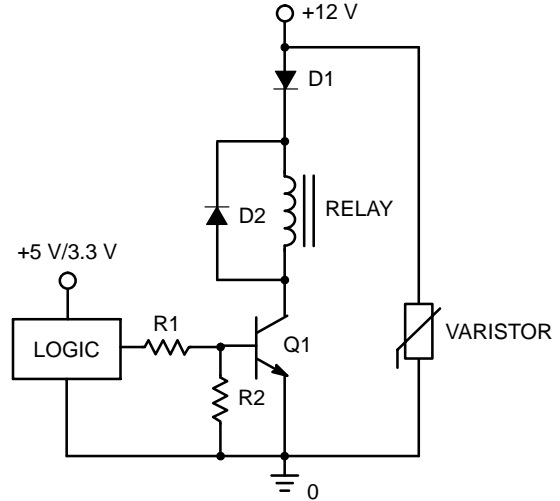

Figure 1. Typical Discrete Relay Driver

ON SEMICONDUCTOR'S RELAY DRIVERS

The ON Semiconductor's relay drivers portfolio is divided in two main categories:

- Industrial Version (Devices NUD3105, NUD3112)
- Automotive Version (Device NUD3124)

Industrial Version

Figure 2 describes the industrial relay driver version (devices NUD3105, NUD3112). This device integrates several discrete components in a single SOT−23 three leaded surface mount package to achieve a simpler and more efficient solution than the conventional discrete relay drivers. The characteristics of the integrated devices are listed below:

- N-Channel FET 40 V, 500 mA
- ESD Protection Zener Diodes (7.0 V)
- Bias Resistors (1.0 kΩ in the Gate and 300 kΩ between Gate and Source)
- Clamping Protection Zener Diodes (7.0 V for 5.0 V Relay's Coils, and 14 V for 12 V Coils)
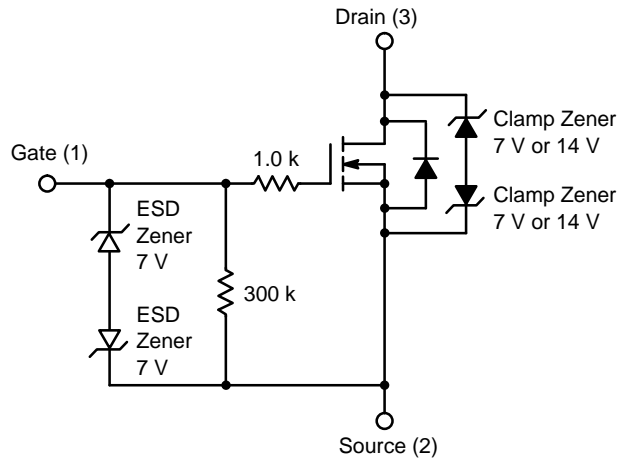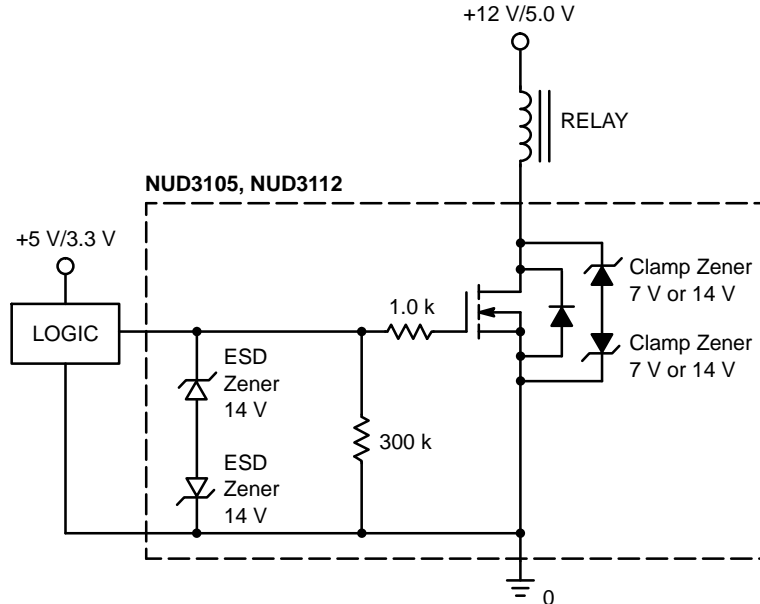

Figure 2. Industrial Relay Driver Description (NUD3105 and NUD3112 Devices)

The 40 V N-channel FET is designed to switch the relay's coil for currents up to 500 mA. The clamping protection Zener diodes (14 V) provides a clamp function to suppress the voltage spike generated by the relay's coil during the turn−off interactions (V = Ldi/dt). The ESD protection Zener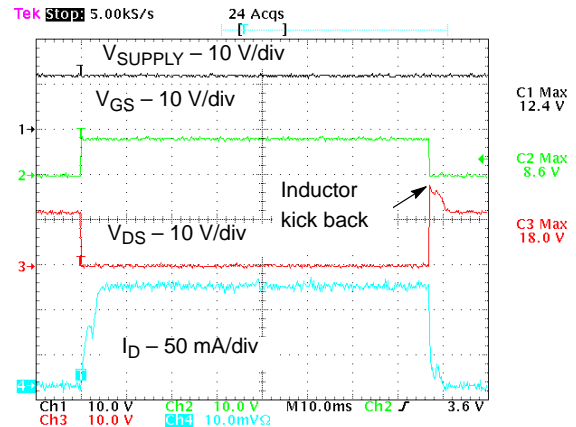 diodes protects the gate-source silicon junction against ESD conditions possibly induced by persons during the handling or assembly of the device. And the bias resistor provides the drive control signals to the FET.

Figure 3 illustrates the typical connection diagram of the NUD3105/NUD3112 devices:

**Figure 3. Typical Connection Diagram
(NUD3105 5.0 V Relay's Coils and NUD3112 for 12 V)**

When positive logic voltage is applied to the gate of the device (5.0 V/3.3 V), the FET is turned-on which activates the relay. When the FET is turned-off, the relay's coil is deactivated which causes it to kickback and generates a high voltage spike, this voltage spike is suppressed by the clamp Zener diodes placed across the FET. This operation sequence is repeated for all the on and off operations of the relay driver. Figure 4 shows the voltage and current waveforms generated across the NUD3112 relay driver when it is controlling an OMRON relay (G8TB−1A−64). This relay has the following coil characteristics: L = 46 mH, Rdc = 100 Ω. The current that the relay takes for 12 V of supply voltage is 120 mA. The integrated FET has a typical on-resistance of 1.0 Ω, therefore the power dissipation generated in the FET is around 15 mW ($P = I^2R$) at 25°C of ambient temperature. It results in an on-voltage drop of only 125 mV at 120 mA of current.

**Figure 4. Traces Generated Across NUD3112 Device
when Driving OMRON Relay G8TB−1A−64**

Based on the relay coil specifications, the energy that is transferred to the driver by the relay's coils can be theoretically calculated by using the formula $E = \frac{1}{2} L I2$, which results in 0.331 mJ. The avalanche energy capability of the NUD3105 and NUD3112 devices is 50 mJ, so the 0.331 mJ transferred by the OMRON relay only represents a 0.65% of their energy capability. The same theoretical principle ($E = \frac{1}{2} L I2$) can be used to find out the type of relay's coils that the NUD3105 and NUD3112 devices can drive. For these purposes, one needs to know the inductance and current characteristics of the relay's coil to calculate the energy that will be transferred. The resulting energy should not exceed the 50 mJ at which the devices are rated.

Automotive Version

Figure 5 describes the automotive relay driver version (device NUD3124).

This device also integrates several discrete components in a single SOT−23 three leaded surface mount package to achieve a simpler and even more robust solution than the conventional discrete relay drivers. The characteristics of the integrated devices are listed below:

- N-Channel FET 40 V, 150 mA
- ESD Protection Zener Diodes (14 V)
- Bias Resistors (10 kΩ in the Gate and 100 kΩ between Gate and Source)
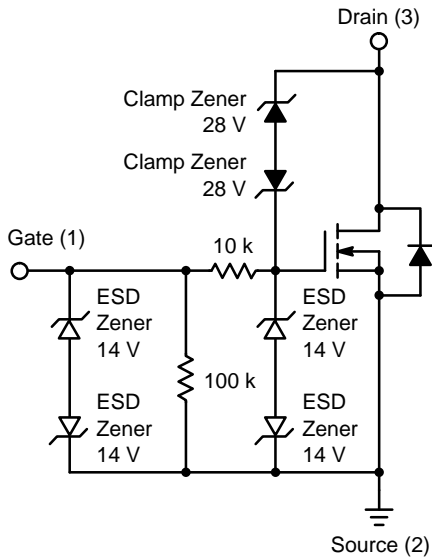- Clamping Protection Zener Diodes (28 V) to Perform as an Active Clamp Function

Figure 5. Automotive Relay Driver Description (NUD3124 Device)

The 40 V N-channel FET is designed to switch on and off the relay's coil for currents up to 200 mA. The clamping protection Zener diodes (28 V) provides an active clamp function to drain to ground the voltage spikes generated by the relay's coils during the turn-off interactions (V = Ldi/dt). This function is achieved by partially activating the FET through the clamp Zener diodes anytime the voltage across them reaches their breakdown voltage level (28 V). The ESD protection Zener diodes protects the gate-source silicon junction against ESD conditions possibly induced by persons during the handling or assembly of the device. And the bias resistor provides the drive control signals to the FET.

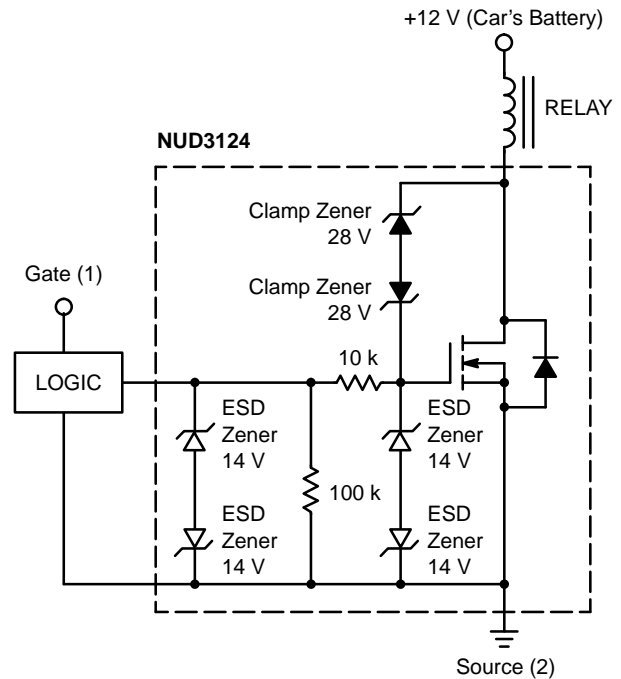Figure 6 illustrates the typical connection diagram of the NUD3124 device.

Figure 6. Typical Connection Diagram for Automotive Relay Driver (NUD3124 Device)

When positive logic voltage is applied to the gate of the device (5.0 V/3.3 V), the FET is turned-on which activates the relay. When the FET is turned-off, the relay's coil is deactivated which causes it to kickback and generates a high voltage spike. This voltage spike causes the clamp Zener diodes (28 V) to breakdown which partially activates the FET to drain this condition to ground. This operation sequence is repeated for all the on and off operations of the relay driver.

Figure 7 shows the voltage and current waveforms generated across the NUD3124 relay driver when it is controlling an OMRON relay (G8TB−1A−64). This relay has the following coil characteristics: L = 46 mH, Rdc = 100 Ω. The current that the OMRON relay takes for 12 V of supply voltage is 120 mA. The integrated FET has a typical on-resistance of 1.0 Ω, therefore the power dissipation generated in the FET is around 15 mW ($P = I^2R$) at 25°C of ambient temperature. It results in an on−voltage drop of only 125 mV at 120 mA of current.
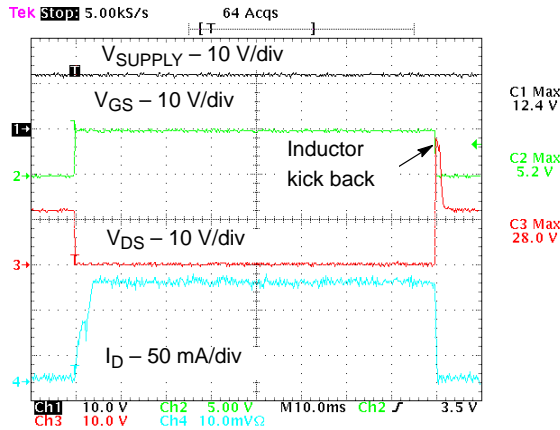

Figure 7. Waveforms Generated Across the NUD3124 when Driving OMRON Relay G8TB−1A−64

Unlike the NUD3105 and NUD3112 devices (industrial version), the unique design of the NUD3124 device (automotive version) provides the active clamp feature that allows higher reverse avalanche energy capability by activating the FET anytime transient voltage conditions exceed the breakdown voltage of the clamp Zener diodes (28 V). The energy capability of the NUD3124 device is 350 mJ typically. Figure 8 shows an oscilloscope picture of a surge test applied to the device when it was characterized to find its maximum reverse avalanche energy capability.

The high reverse avalanche energy capability of this device (350 mJ) allows to control most of the relays used in automotive applications since they usually have coils between 50 mA and 150 mA with inductance values lower than 1 Henry. These type of coils do not transfer high levels of energy to the NUD3124 device ($E = \frac{1}{2} L I^2$), and therefore each of them can be controlled with the same device (NUD3124). Big advantages are obtained when a common relay driver product is used to control the majority of the relays used in a particular application circuit. PC board space is saved and the circuit design is optimized. In addition, components count purchasing operations are also simplified.

The active clamp characteristic of the NUD3124 device also allows it to comply with automotive requirements of load dump and other voltage transients required by the automotive specifications. Load dump transients are generated by the vehicle's alternator when the battery connection fails during heavy charging. These type of transients could occur when the relay is on or off. Although automotive requirements for load dump vary between suppliers, it has been learned that most of the load dump requirements can be covered by devices which can sustain a load dump transient of 60 V with 350 ms of duration. Figure 9 shows a load dump transient of 60 V and 350 ms of duration.
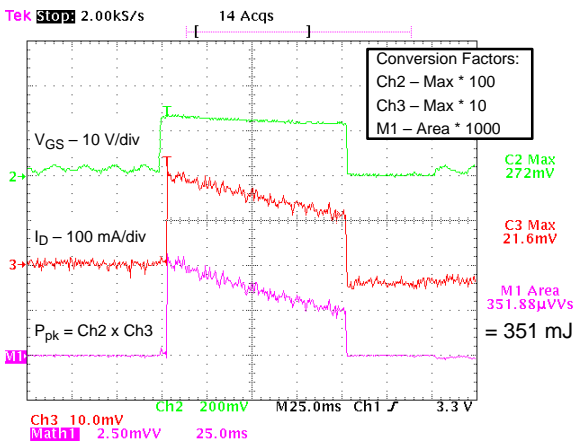

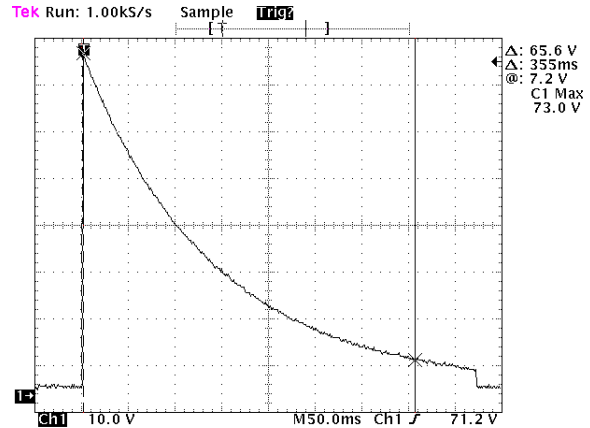**Figure 8. Waveforms Generated Across the NUD3124 Device During Surge Test**

Figure 9. Load Dump Transient Waveform (60 V, 350 ms).

The 73 V waveform shown in the oscilloscope picture (Figure 9) resulted from the 60 V load dump transient plus the vehicle's battery voltage (13 V). In the application field, the relay driver (NUD3124) is always connected to relays, therefore if a load dump condition occurs, the current is limited by the relay's coil resistance which reduces the amount of energy that the relay driver (NUD3124) needs to drain to ground. Figure 10 shows an oscilloscope picture with the waveforms generated across the NUD3124 device when it is subjected to a load dump transient. For this case, the device is controlling an OMRON relay (G8TB–1A–64)

The most stressful and aggressive requirement for automotive transients is load dump. Therefore if a device is able to comply with this requirement, it is assured that it will sustain all the other less aggressive transients such as 240 V (10 Ω source impedance), 350 μs time-duration type.

In addition to complying with the load dump transient requirements and all the other smaller automotive transients, the NUD3124 device also complies with other automotive requirements such as reverse battery (−14 V, 1 minute or more) and dual voltage jump start (24 V ±10%).

If a reverse battery condition occurs, it will cause the body diode of the FET to be forward biased and hence conduct. During this condition, the current will be limited by the relay's coil resistance to a safe level causing the relay be energized. With the traditional discrete approach, damage can occur to the control logic circuitry due to a possible current path from a reverse connected battery through the driver to the logic's output. This possibility is eliminated when the NUD3124 device is used.

If a dual voltage jump start is used (24 V or more), the NUD3124 device will remain in its off-state and therefore the relays will too. This is the ideal operation required during a dual voltage jump start condition, otherwise the relays would be activated and could create serious operation problems in the equipment or functions that they are controlling (windows, seats, etc.).

RELAY MODULE

The benefits of the ON Semiconductor's relay driver devices (NUD3105, NUD3112 and NUD3124) are even more unique and useful if they are integrated inside the relay body to create relay modules that can be driven directly from the logic circuitry. The advantages are:

- No Need for External Driver Device
- PC Board Space Reduction
- Reduction for Insertion Operations
- Optimized Design for Lower Cost

All the previous advantages will result in costs reduction for industrial and automotive applications which have the need for mechanical relays. Figure 10 describes graphically the design of the relay module. Some relay manufacturers already integrate a diode connected in parallel with the relay's coil to simplify the driver circuitry. Others are considering to develop the concept of the relay module. The major goal of the relay's manufacturers is to offer more added value to their customers for design optimization and cost reduction.
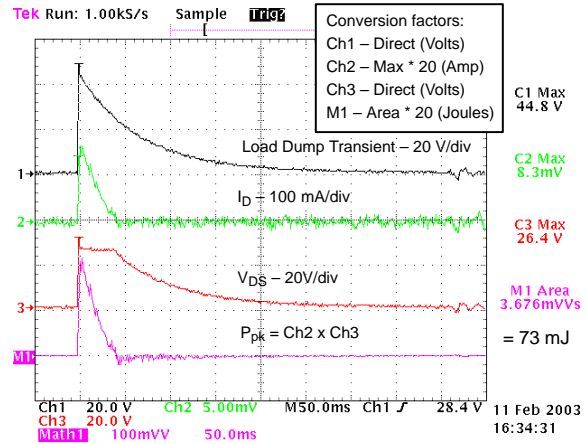

Figure 10. Waveforms Generated Across the NUD3124 Device During a Load Dump Transient
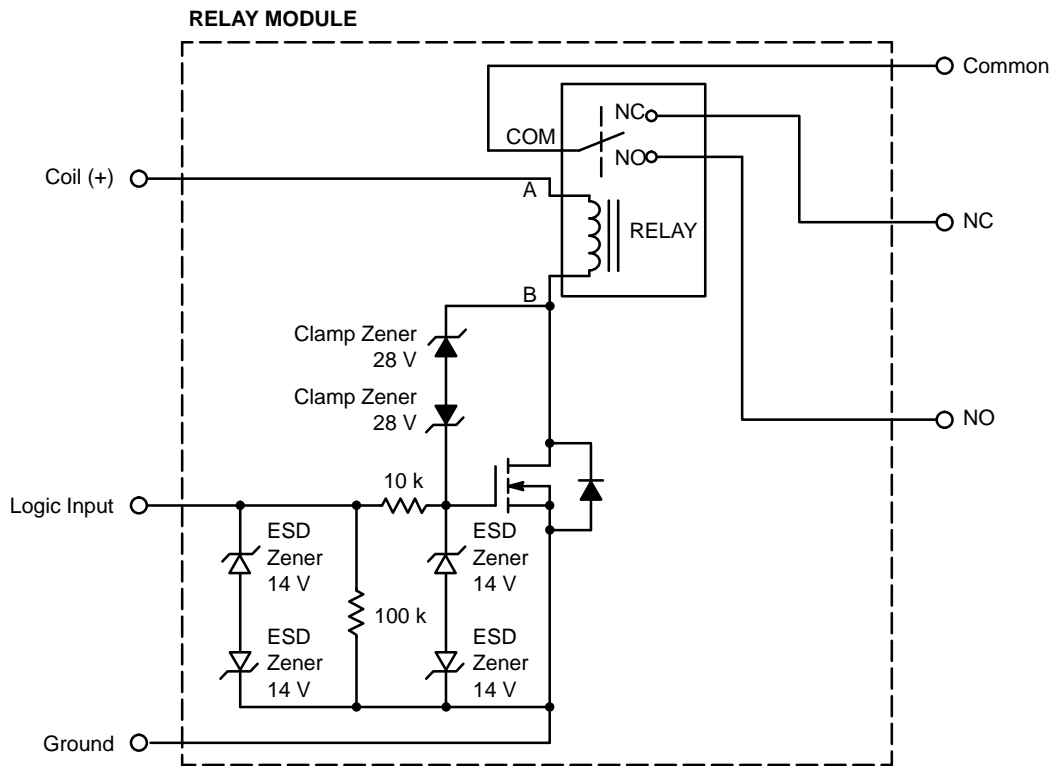
RELAY MODULE

Figure 11. Relay Module Formed by the Integration of the NUD3124 Device within the Relay Body

SUMMARY

The traditional discrete relay driver approach (bipolar transistor, bias resistors and free-wheeling diode) is expensive because it takes several components and a big space in the PC board. In some cases it requires extra protection components to achieve proper functionality in automotive and some industrial applications.

The NUD3105 and NUD3112 relay driver devices offered by ON Semiconductor replace the traditional discrete relay driver approach by integrating all the necessary components through a monolithic process. Their integrated design is packaged in a small three leaded surface mount SOT–23 package that allows optimum operation with reduced PC board space, which results in cost savings from the manufacturing and components count stand point.

The NUD3124 device is intended for automotive applications. It fully complies with major automotive requirements such as load dump, reverse battery, dual voltage jump start and ESD. Its unique active clamp design makes this device to be a robust driver for automotive applications. It is also packaged in a small three leaded surface mount SOT–23 package that allows optimum operation with reduced PC board space for cost reductions.

The relay module represents significant benefits for the industrial and automotive relay markets. It reduces PC board space and optimize the circuits design. These benefits result in a significant added value and cost reduction for customers. Advantages like these are always a premium.

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