

Design Considerations for the DRV411

ABSTRACT

The DRV411 is a signal-conditioning integrated circuit for use in closed-loop, magnetic, current-sensor modules. The DRV411 is designed to interface with symmetrical indium antimonide (InSb) and gallium arsenide (GaAs) type Hall sensors. Symmetrical Hall elements have their input and output impedances closely matched. The DRV411 contains excitation and conditioning circuitry that significantly reduces the offset and offset drift over temperature that Hall elements suffer from. This application note presents key considerations for designing with the DRV411.

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1 Introduction

The DRV411 is designed to interface with symmetrical indium antimonide (InSb) and gallium arsenide (GaAs) type Hall sensors. Closed-loop current transducers measure currents over wide frequency ranges, including dc currents. These types of closed-loop modules offer a contact-free, current-sensing method, as well as excellent galvanic isolation combined with high resolution, accuracy, and reliability.

At dc and in low-frequency ranges, the magnetic field induced from the current in the primary winding (I_{PRIM}) is compensated by a current driven through a secondary compensation coil wound on a ferro-magnetic core that functions as a field concentrator. A magnetic field probe (Hall sensor) located within a gap in the magnetic core detects the magnetic flux created by current flowing through the primary winding. This probe delivers a signal to the signal-conditioning circuitry block, which in turn drives a current (I_{SEC}) through the compensation coil. The secondary current creates a flux equal in magnitude but in the opposite direction to the flux created by the primary, bringing the magnetic flux back to zero. At higher frequencies, the compensation winding functions as the secondary winding in a current transformer, whereas the H-bridge compensation driver is rolled off and provides low output impedance.

The compensation current is also passed through a shunt resistor (R_{SHUNT}), creating a voltage drop that is passed to a differential amplifier. The differential amplifier provides a gain of 4 V/V that is delivered to the DRV411 output stage. The resulting output voltage is proportional to the current flowing through the primary winding, as shown in the transfer function defined in Equation 1.

$$V_{OUT} = I_{PRIM} * \left(\frac{N_P}{N_S} \right) * R_{SHUNT} * Gain \quad (1)$$

Figure 1 shows the principle of a closed-loop current sensor using the DRV411.

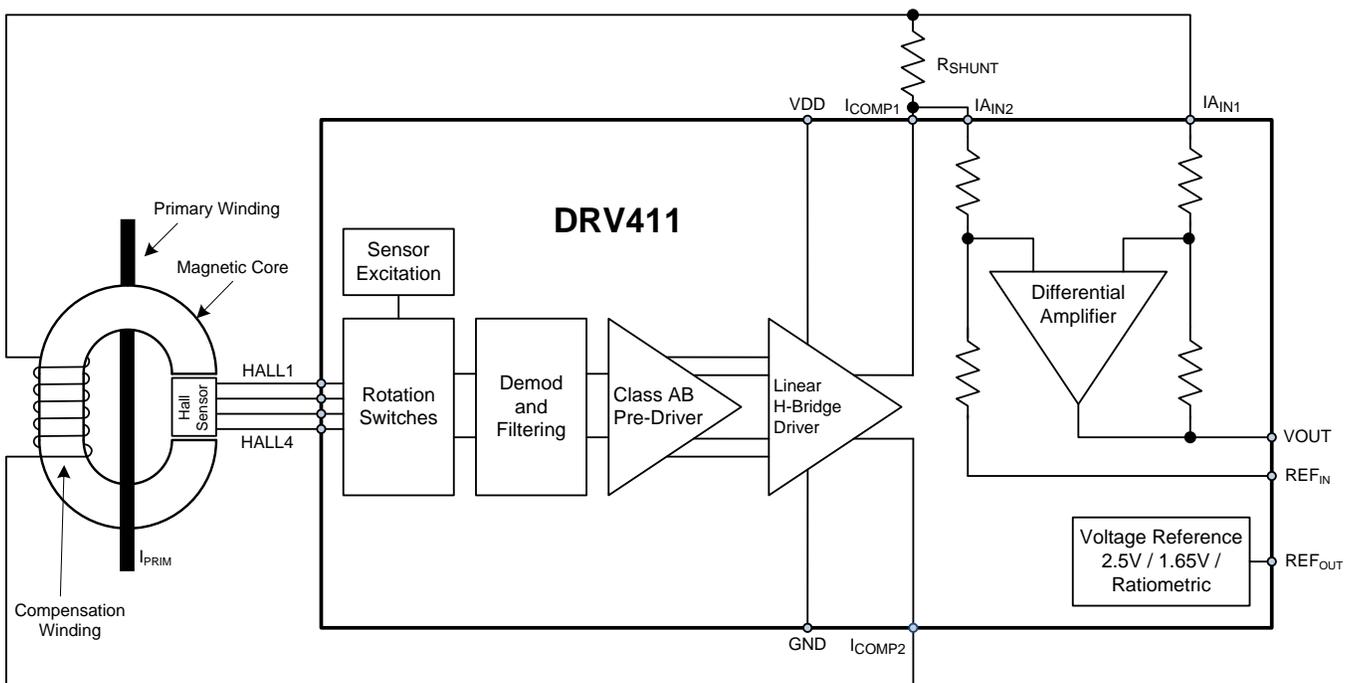


Figure 1. Typical Closed-Loop Current Sensor

2 Core and Hall Sensor Considerations

Although the details on the physical construction of the core are outside the scope of this application note, note that there are many different materials available to create magnetic concentrator cores. The selection is determined according to criteria such as material performance, the current measurement range requirements, and the desired mechanical shape and cost.

High-quality, four-lead linear or symmetric Hall elements are normally used in current transducers. From an electrical standpoint, the Hall element can be modeled as a resistance bridge formed by four resistors (R1 to R4). The DRV411 incorporates dynamic offset cancellation circuitry that helps eliminate offset drift and 1/f noise of the Hall sensor, increasing the overall accuracy of the current transducer. The excitation current is spun through the Hall sensor in orthogonal directions using rotation multiplexer switches, as shown in Figure 2a to Figure 2d. The excitation source ensures a constant current during each spin cycle but keeps the sensitivity of the Hall sensor independent by varying the current across temperature. The corresponding Hall output is averaged across the four orthogonal directions to effectively cancel the Hall offset.

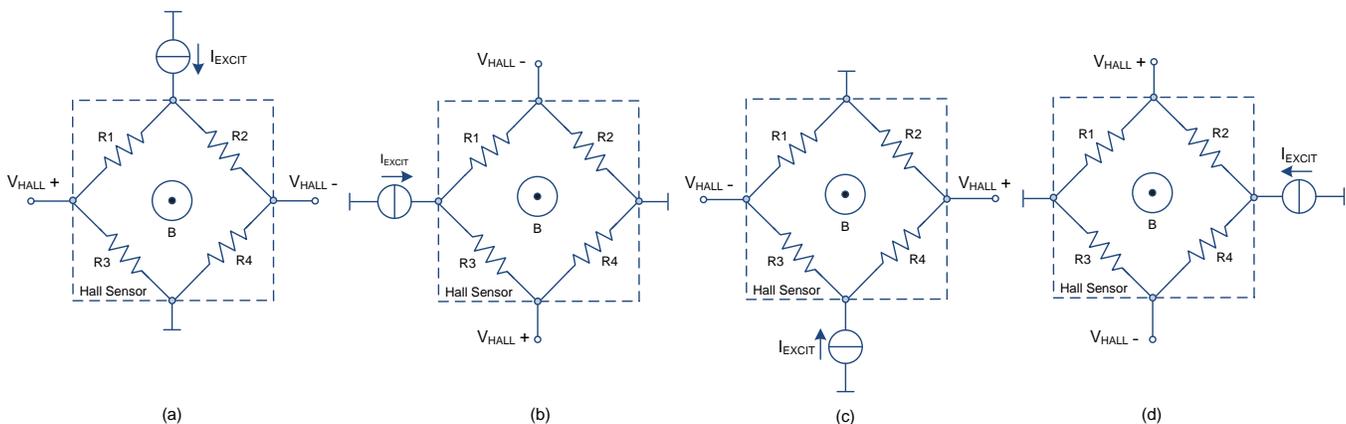


Figure 2. Hall Element Current Spinning

The core material in combination with the selected Hall element drives the gain and frequency compensation requirements of the transducer. The DRV411 has two gain select pins (GSEL1 and GSEL2) that can accommodate a wide variety of core materials and Hall elements. Table 1 provides the details on the available settings.

Table 1. Gain Setting and Frequency Compensation

MODE	GSEL1	GSEL2	DESCRIPTION
Gain 1	0	0	G = 250 V/V. Compensation frequency is set to 3.8 kHz.
Gain 2	0	1	G = 250 V/V. Compensation frequency is set to 7.2 kHz.
Gain 3	1	0	G = 1000 V/V. Compensation frequency is set to 3.8 kHz.

The size and inductance of the compensation coil is the main factor in determining what gain is best suited to the particular application. Start with gain 3 (GSELx = [1:0]) during the initial debug and adjust as necessary to obtain the required response from the transducer.

3 Reference Options and Common-Mode Voltage

The compensation coil driver H-bridge has a fixed common-mode output voltage of $V_{DD} / 2$. The internal reference voltage selections are applied to the output driver stage in order to maintain the same common-mode voltage on the output of the DRV411 differential amplifier.

The DRV411 features three different settings for the reference voltage options: fixed 1.65 V for use in 3.3-V applications, fixed 2.5 V for use in 5.0-V applications, and a ratiometric $V_{DD} / 2$ mode when the operating voltage varies from 2.7 V to 5.5 V. The reference output voltage is controlled by the REFSEL1 and REFSEL2 input pins in accordance with the settings described in [Table 2](#).

Table 2. Reference Output Selection

MODE	REFSEL1	REFSEL2	DESCRIPTION
REF = 2.5 V	0	0	Used with a sensor supply of 5 V.
REF = 1.65 V	1	0	Used with a sensor supply of 3.3 V.
Ratiometric output	1	1	Used with a variable sensor supply from 2.7 V to 5.5 V. Provides an output centered at $V_{DD} / 2$.

3.1 Ratiometric Mode

In applications where the supply voltage can vary, care must be taken to ensure the common-mode voltage levels at the H-bridge coil driver and the difference amplifier output stages are the same. The supply rail determines the common-mode voltage at the H-bridge and the reference defines the common-mode level of the output difference amplifier. The ratiometric reference mode is intended for applications where the supply voltage can vary between 2.7 V and 5.5 V. The reference in this mode is derived from a precision resistor divider internal to the DRV411 that divides the supply voltage by two. Because the output common-mode voltage of the coil driver stage is fixed at $V_{DD} / 2$, using the ratiometric reference option provides a matching common-mode voltage at the differential amplifier output stage. If an external reference is used, care must be taken to keep the output common-mode voltage at or near $V_{DD} / 2$ to avoid unwanted offset and gain errors.

3.2 Differences in V_{REF} and V_{CM}

In applications where the reference voltage of the DRV411 is not equal to $V_{DD} / 2$, there can be offset errors and non-symmetrical current measurements ranges. The circuit of Figure 3 depicts the DRV411 configured with a 5-V supply with the internal reference fixed at 1.65 V. In this condition, the common-mode output of the signal conditioning and H-bridge stage is 2.5 V. The difference in V_{CM} versus V_{REF} causes current to flow through the 10-k Ω and 40-k Ω resistors found internal to the DRV411 as well as the compensation coil and shunt resistor. The difference in voltage across the shunt causes an offset in V_{OUT} . Positive current can be measured to the level of V_{REF} plus the level of V_{CM} , providing 4.15 V on V_{OUT} . In the negative direction, V_{OUT} is V_{REF} minus V_{CM} . The DRV411 cannot provide negative output voltage and begins clipping at approximately 300 mV.

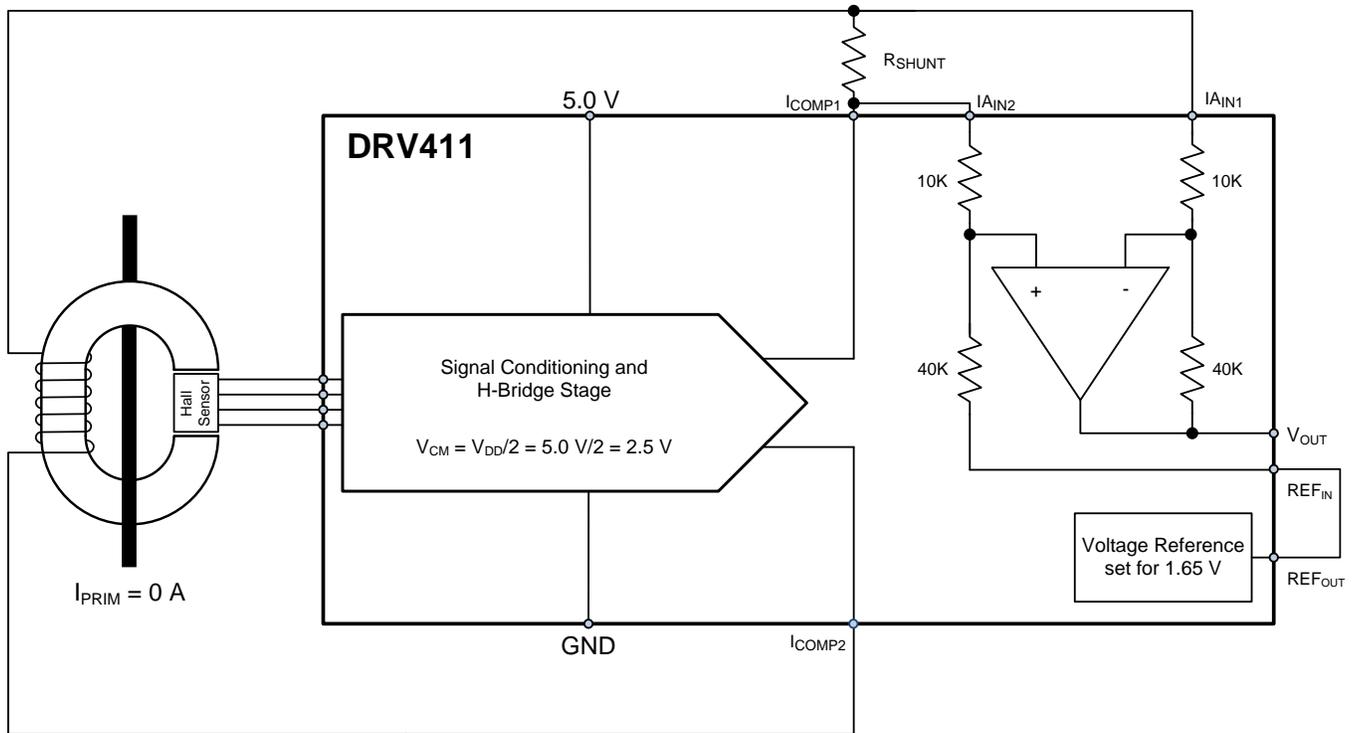


Figure 3. Uncommon V_{REF} and V_{CM}

4 Power-Supply Considerations

4.1 Single-Supply Operation

The typical application circuit of the DRV411 uses a single supply in the range of 3.3 V to 5.0 V. The circuit of [Figure 4](#) uses a 50-A passive sensor module. The module provides galvanic isolation and contains a toroidal ferrite core with an InSb Hall element mounted into an air gap in the core. The compensation coil has 1000 turns and a resistance of approximately 11 Ω at 25°C. With a single 50-A turn through the primary, a 1:1000 reduction (or 50 mA) is developed in the compensation coil, as defined by [Equation 2](#).

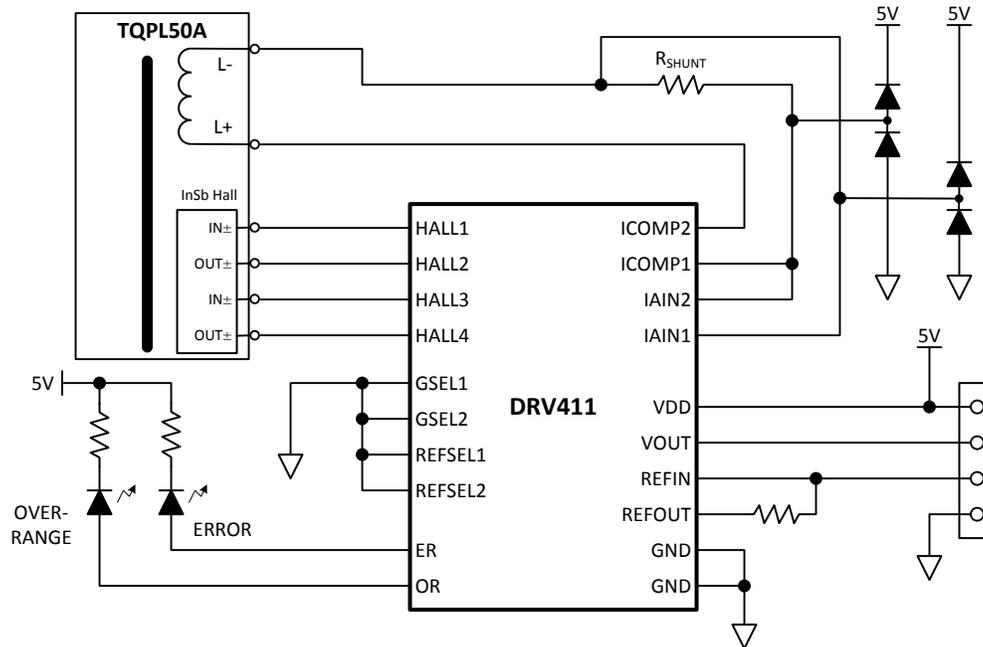


Figure 4. Typical 5-V DRV411 Application Example

$$I_{COIL} = \frac{I_{PRIM} * N_P}{N_s} = \frac{50A * 1}{1000} = 50mA \quad (2)$$

In a typical 5-V application, the output voltage swing of the DRV411 is dependent on the output load current (refer to the typical characteristic curves in the [DRV411](#)). With no load, the output can swing to within ± 85 mV of the rails or 4.83 V_{PP} with an output common-mode voltage (V_{CM}) of $V_{DD} / 2$. Using the 2.5-V internal reference, the output voltage of the sensor module is 0.085 V – 4.915 V or ± 2.415 V at a common-mode level of 2.5 V. The voltage drop across the shunt (V_{SHUNT}) can be derived from the DRV411 output voltage using [Equation 3](#).

$$V_{SHUNT} = \frac{\pm V_{OUT}}{Gain} = \frac{\pm 2.415V}{4V/V} = \pm 604mV \quad (3)$$

With V_{OUT} at ± 2.5 V, the maximum voltage across the shunt resistor is ± 604 mV. With the shunt voltage determined, the maximum shunt resistor value can be derived using [Equation 4](#).

$$R_{SHUNT} = \frac{V_{SHUNT}}{I_s} = \frac{604mV}{50mA} = 12.1\Omega \quad (4)$$

For additional details, including performance details on the circuit in [Figure 4](#), see TI Precision Design [TIPD180](#).

4.2 Bipolar Supply Operation

Using the DRV411 in a bipolar configuration requires the implementation of a 5-V power source within the sensor module. The easiest way to achieve this implementation is to provide a low-dropout, 5-V regulator referenced to the negative rail, as shown in Figure 5.

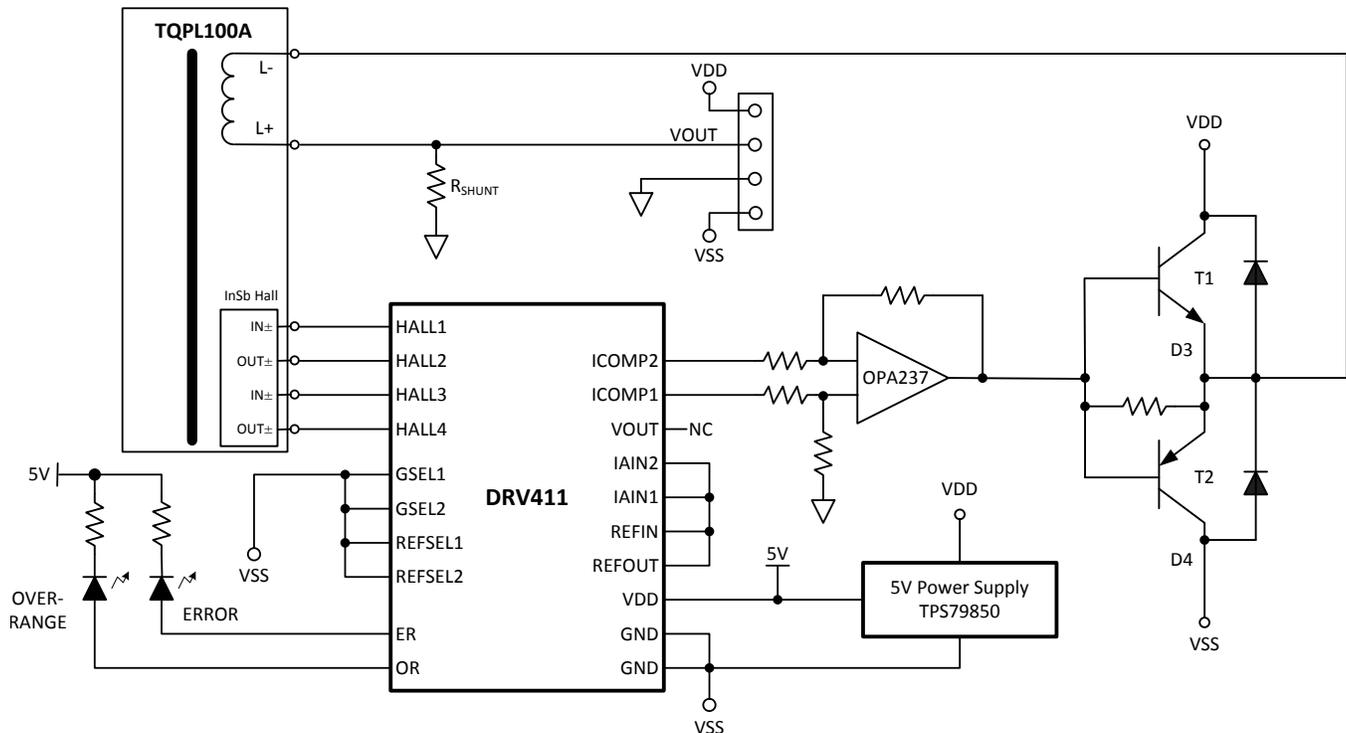


Figure 5. Bipolar Supply Implementation

The circuit provided in Figure 5 uses a 100-A passive sensor. As with the 50-A sensor, this sensor also contains an InSb Hall element and toroidal ferrite core. The compensation winding consists of 2000 turns with a coil resistance of 50 Ω . The negative rail (VSS) is used as the ground reference point for the 5-V source using the [TPS79850-Q1](#) and the DRV411. The coil driver output of the DRV411 is presented to an external difference amplifier powered from the VDD and VSS rails, which then drives a bipolar transistor stage. The transistor output stage drives the compensation coil and can deliver a wider bipolar output voltage range from the sensor.

5 Layout Considerations

The DRV411 operates with a relatively large current drive capability. The device is often exposed to large distortion energy from the primary signal passing through the magnetic core and from the harsh environments closed-loop modules are often deployed in. TI recommends that the wiring layout provide some level of shielding and low-impedance connections between critical points (such as the compensation coil and shunt voltage connections).

Power-supply decoupling requires low-ESR capacitors. The combination of a 4.7-nF NP0-type ceramic capacitor and a second capacitor of 1 μF or larger are recommended, as shown in Figure 6. Use low-impedance tracks to connect the capacitors to the pins of the DRV411. Connect the ground (GND) to a local ground plane.

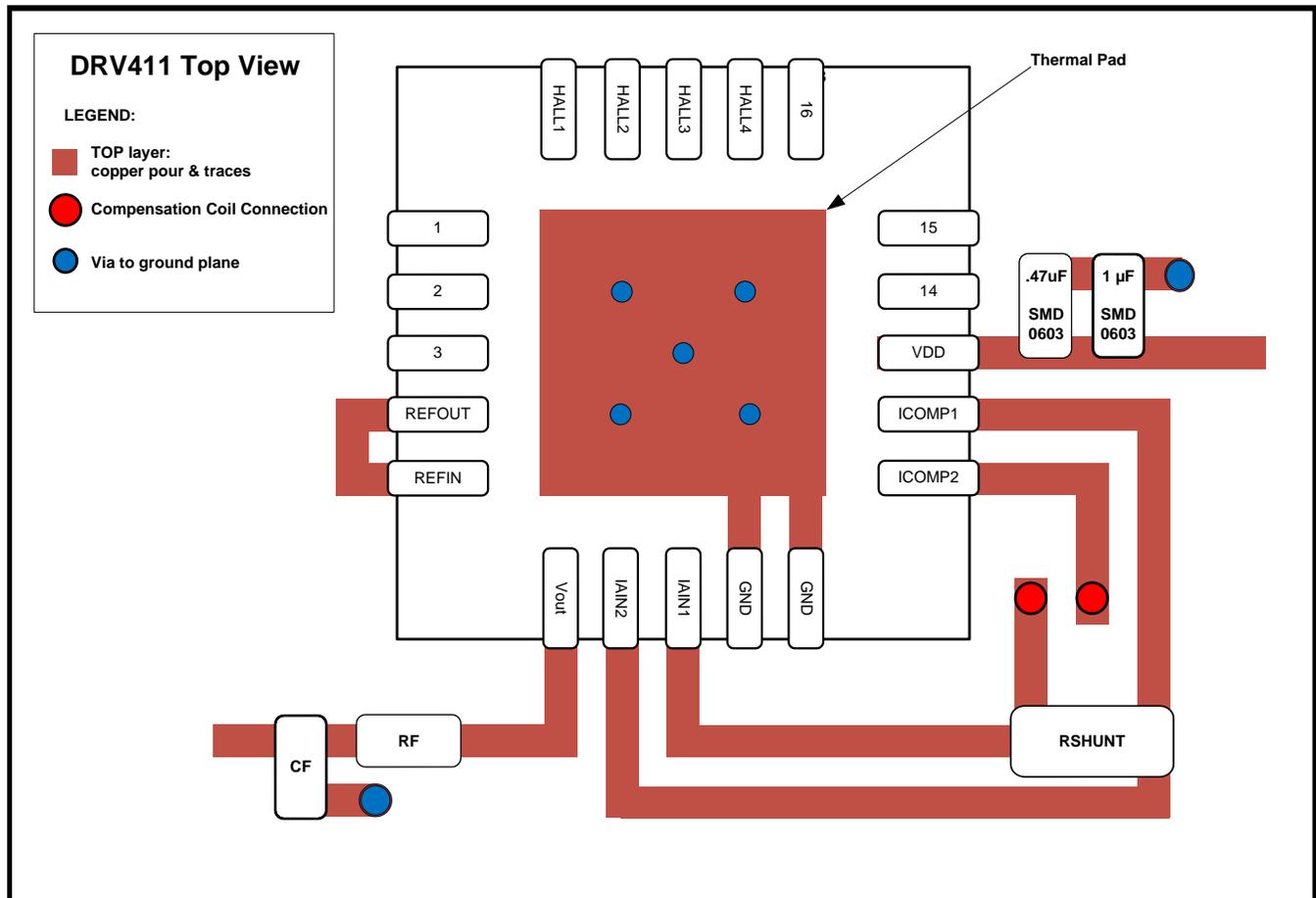


Figure 6. DRV411 Layout Considerations

The exposed thermal pad, or PowerPAD™, on the bottom of the package must be soldered to GND because it is internally connected to the substrate that must be connected to the most negative potential. In high-current modules, the localized ground plane helps dissipate the power developed by the DRV411 coil driver stage. See application report *PowerPAD™ Thermally Enhanced Package* (SLMA002) for more details.

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