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Sense Power Switch Current Without Increasing Losses Or Parasitics

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Conventional approaches to current sensing such as the use of current-sense resistors or transformers add power losses and cost to power supply applications. Those drawbacks can be eliminated with the application of a new current-sensing IC, the IR25750.

This chip provides a simple and innovative solution for measuring the $V_{DS(ON)}$ of a power MOSFET or the $V_{CE(ON)}$ of an IGBT. Unlike existing current-sensing ICs employing series-connected methods, the IR25750 implements a parallel-connected solution so it does not add to the circuit's power loss or its parasitic inductance. This article describes the functionality of this new IC, presents simulation and experimental results, and provides helpful guidelines for PCB layout.

Functional Description

The IR25750 performs two main functions that include measuring the $V_{DS(ON)}$ of a MOSFET or $V_{CE(ON)}$ of an IGBT during the transistor's on-time, and, withstanding high drain or collector voltages during its off-time. The IC is connected directly to the existing pins of a power MOSFET or IGBT (Fig. 1.)

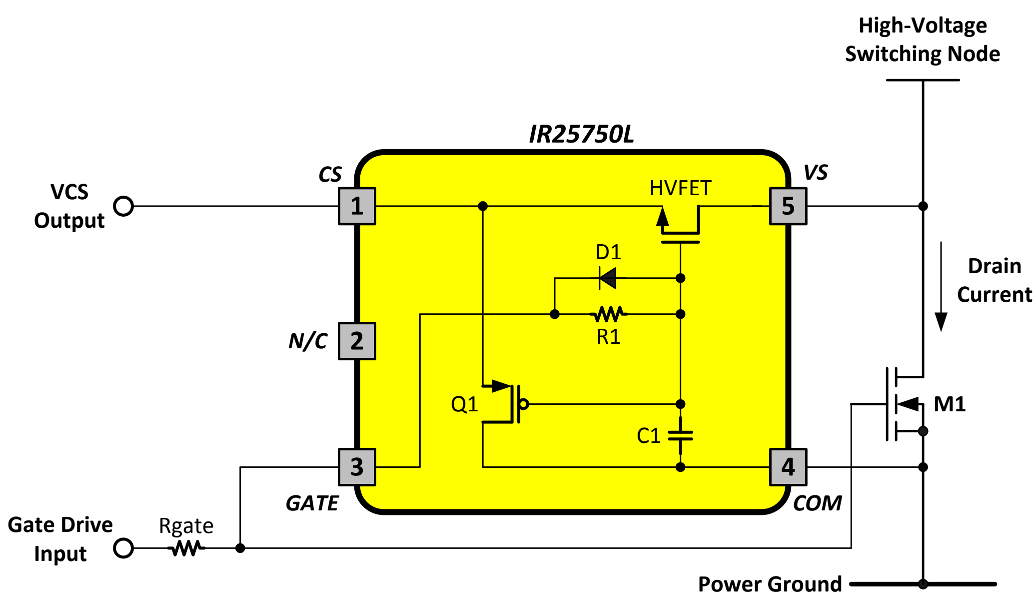


Fig. 1. IR25750 internal block diagram and pin out with connections made to key external components.

The V_{IN} pin (labeled VS in Fig. 1) connects to the drain (or collector), the COM pin connects to the source (or emitter), and the GATE pin connects to the gate. The $V_{DS(ON)}$ or $V_{CE(ON)}$ voltage level across the switch can then be measured at the CS output pin during the switch's on-time.

The IR25750 does not require an additional V_{CC} pin so no other connections are necessary. The IC includes an internal 600-V NMOS (HVFET) that is connected from the V_{IN} pin to the CS pin (Fig. 1.) The gate of the HVFET is connected to the GATE pin so that the HVFET is turned on and off synchronously with the external MOSFET or IGBT.

An internal resistor (R1) and capacitor (C1) produce a turn-on delay (200 ns) for the HVFET after the GATE pin turns on to ensure that the power MOSFET or IGBT is fully on before the internal HVFET is turned on. When the HVFET is on, the $V_{DS(ON)}$ or $V_{CE(ON)}$ voltage at the V_{IN} pin is transmitted to the CS pin.

When the external MOSFET or IGBT is turned off, the GATE pin goes low and the internal diode (D1) pulls the gate of the HVFET down quickly and turns the HVFET off. During the off-time, the internal PMOS (Q1) turns on and holds the CS pin down to COM.

MOSFET $V_{DS(ON)}$ Sensing

A test circuit has been implemented for sensing high peak currents in a power MOSFET during switched-mode operation. The circuit, which is depicted in Fig. 2, includes the power MOSFET (M1), the IR25750 (IC1), a high-current power inductor (L1), a high-current fast diode (D1), a dc input voltage (VIN), an output capacitor (C2) and parallel load resistor (RL), a one-shot on/off gate-drive pulse generator (PGEN), and an optional temperature-compensation circuit (components shown inside dotted lines.)

When M1 is turned on by the PGEN gate drive, current flows from the input voltage (VIN+) through L1, then through M1 and to ground (VIN-). The inductor current ramps up linearly to a peak level and M1 is then turned off. During the off-time, the current discharges through L1, through diode D1, through the output capacitor (C2) and load resistor (RL), and to ground.

The IR25750 is connected in parallel with M1—the drain of M1 is connected to the VS pin and the transistor's source is connected to the COM pin. The gate PGEN is connected through a 47-Ω gate resistor to the GATE pin of the IC and to the gate of the MOSFET. The on-time of the MOSFET can be set using the PGEN, and the $V_{DS(ON)}$ is then measured between the CS pin (VCS+) and COM (VCS-). The gate resistor is placed *before* the IR25750 and the MOSFET gate to ensure that the IR25750 turns on a short delay time (200 ns) after the MOSFET turns on.

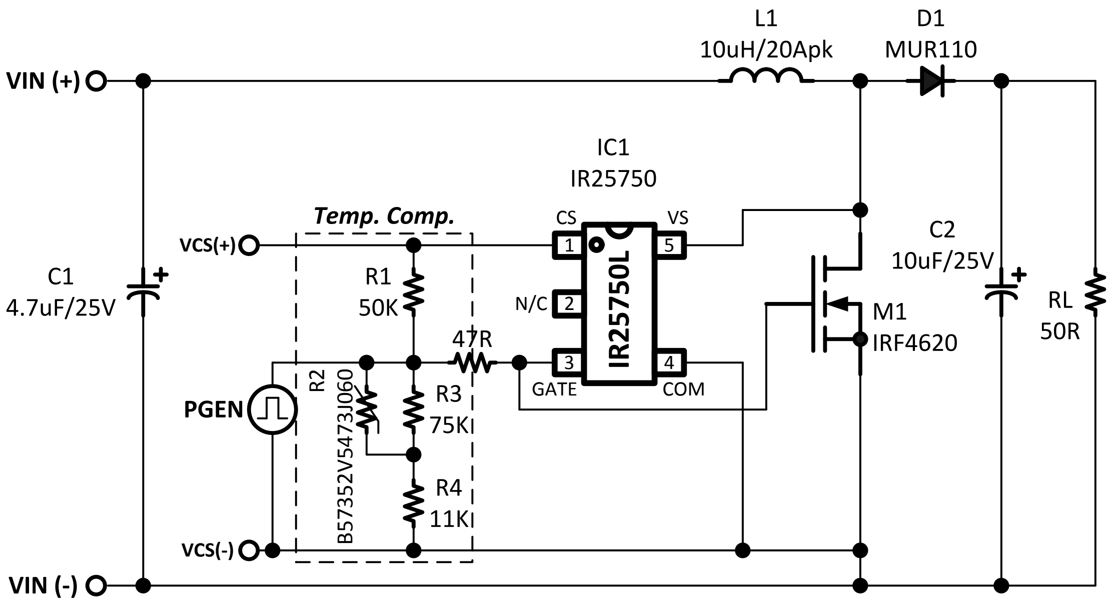


Fig. 2. $V_{DS(ON)}$ sensing test circuit.

The circuit's switching waveforms (Fig. 3) include the GATE pin voltage (V_GATE), the inductor current (I_L1), the MOSFET drain voltage (V_VS), and the CS pin output voltage (V_CS). During the on-time, the inductor current (and MOSFET drain current) ramps up linearly due to the voltage across the inductor. At the end of the on-time, the current reaches a peak level of about 10 A pk and the V_CS output measurement reaches a peak voltage of about 0.7 V.

When the MOSFET is turned off, a momentary voltage spike occurs at the CS pin. This is due to the fast rising edge of the MOSFET drain voltage that occurs just after the MOSFET turns off as well as the capacitance of the internal HVFET of the IR25750. This voltage spike, however, occurs during the off-time and can easily be blanked by the detection circuit by only measuring the peak current during the on-time.

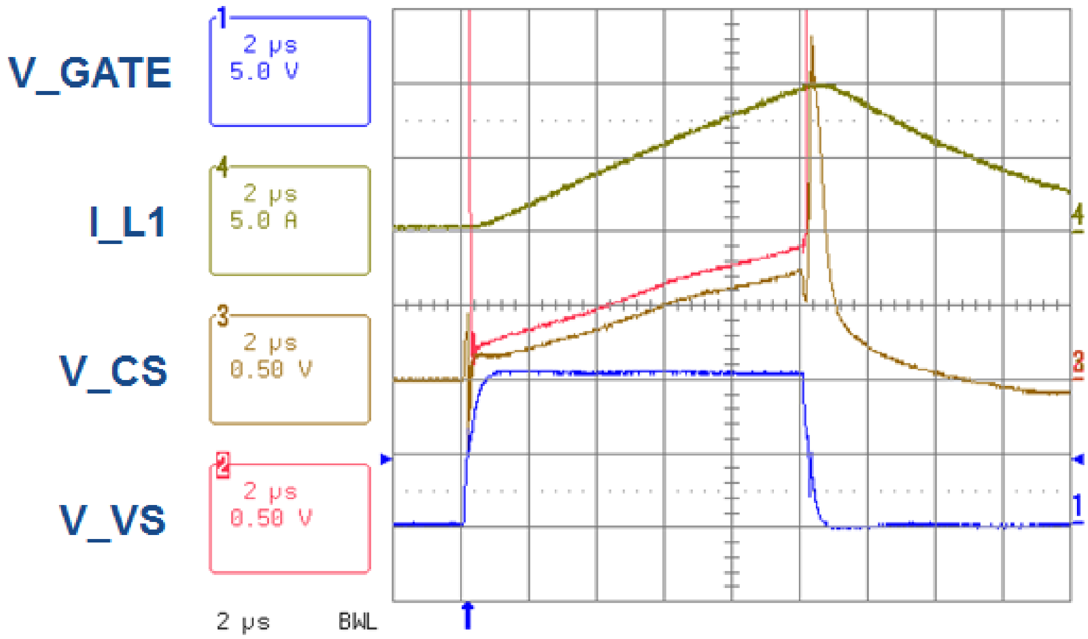
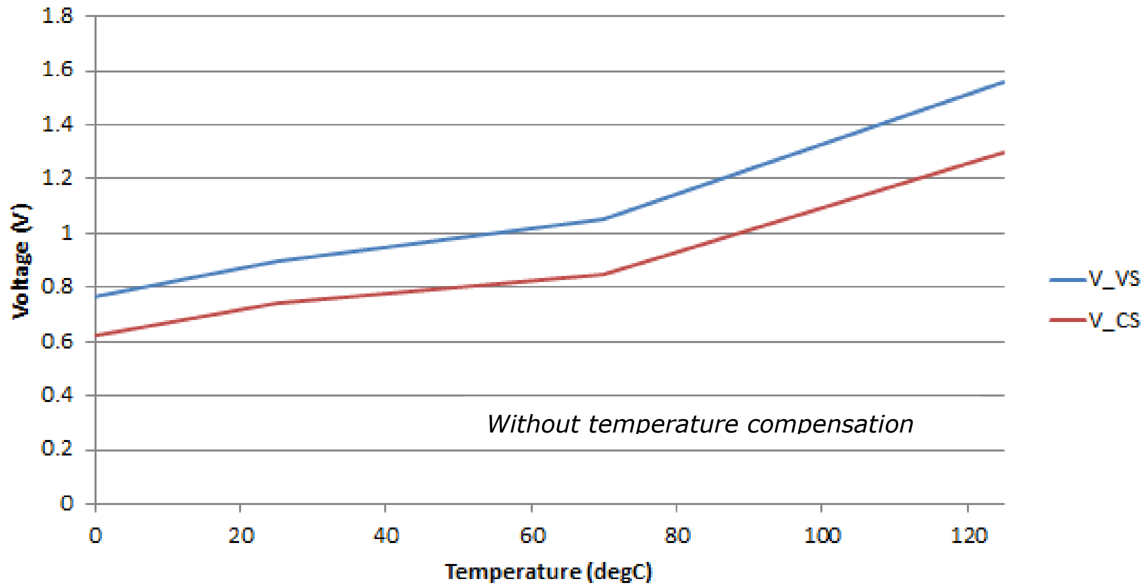


Fig. 3. $V_{DS(ON)}$ sensing waveforms (V_GATE = lower blue, V_CS = middle brown, V_VS = middle red, I_L1 = upper olive). MOSFET = IRFR4620 ($R_{DS(ON)}$ = 64 mΩ.)

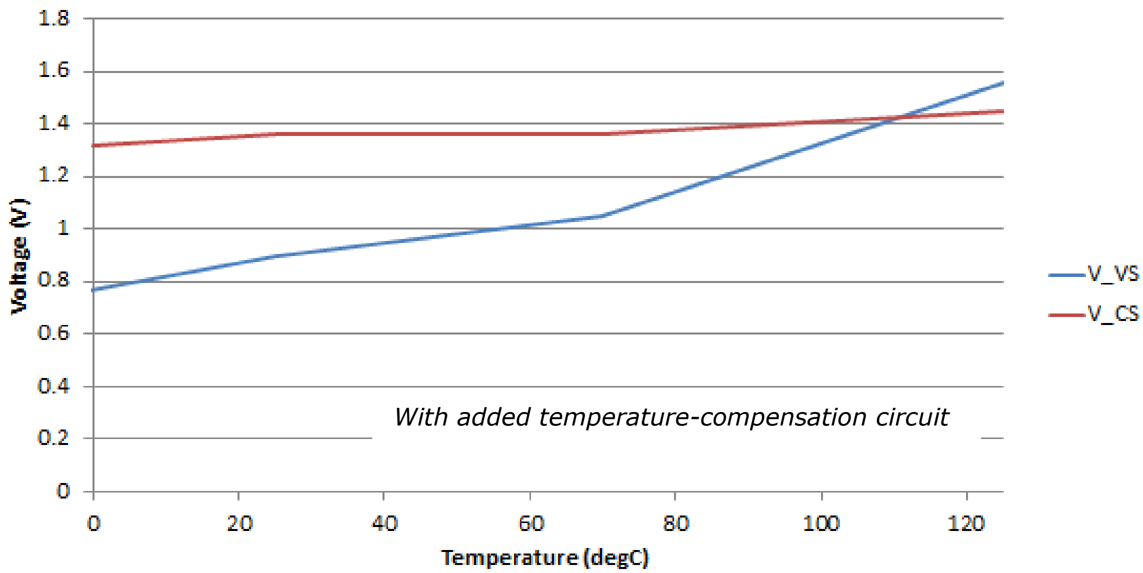
It is well known that the $V_{DS(ON)}$ of a MOSFET or the $V_{CE(ON)}$ of an IGBT can have a temperature coefficient that can give an additional measurement variation over temperature. In order to compensate for ambient temperature variations, an additional resistor and NTC network circuit can be connected at the CS pin (see Fig. 2 again.)

The temperature compensation circuit includes a resistor (R1) connected from the GATE pin to the CS pin, two series resistors (R3 and R4) connected from the GATE pin to COM, and an NTC resistor (R2) connected across resistor R3. This resistor divider circuit allows for the CS pin voltage to be adjusted up or down with an offset, and, the NTC resistor allows for the $V_{DS(ON)}$ or $V_{CE(ON)}$ temperature variation to be compensated.

Fig. 4 shows the graphs comparing voltages measured by the IR25750 with and without the additional temperature-compensation circuit. The curves presented in Fig. 4 are the VS pin and CS pin peak voltage levels measured at the end of the MOSFET's on-time. Without the temperature-compensation circuit, the CS pin voltage directly follows the VS pin voltage as the $V_{DS(ON)}$ of the MOSFET (M1) varies with decreasing or increasing ambient temperature. With the additional compensation circuit, the CS pin voltage is now almost flat over the complete temperature range with a slight positive slope.



(a)

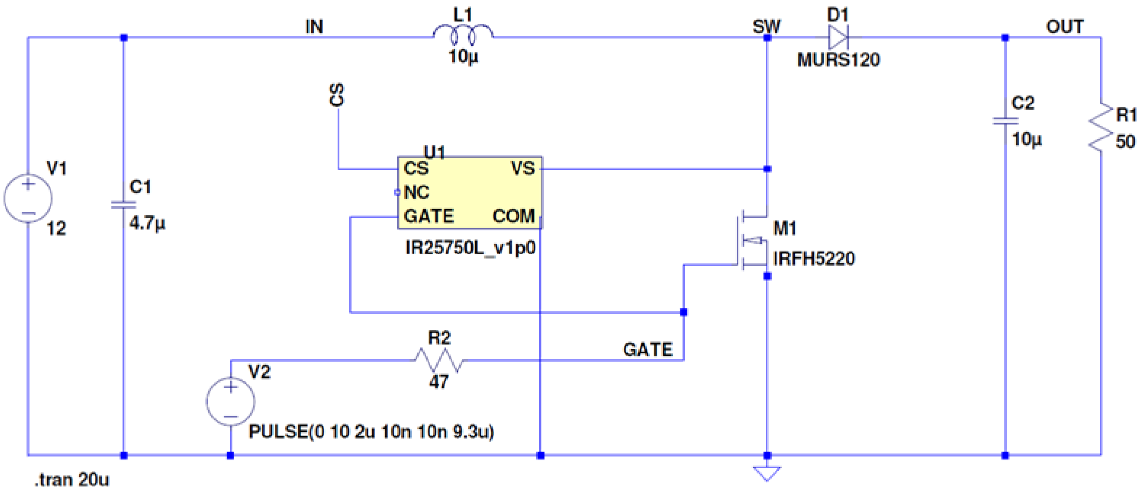


(b)

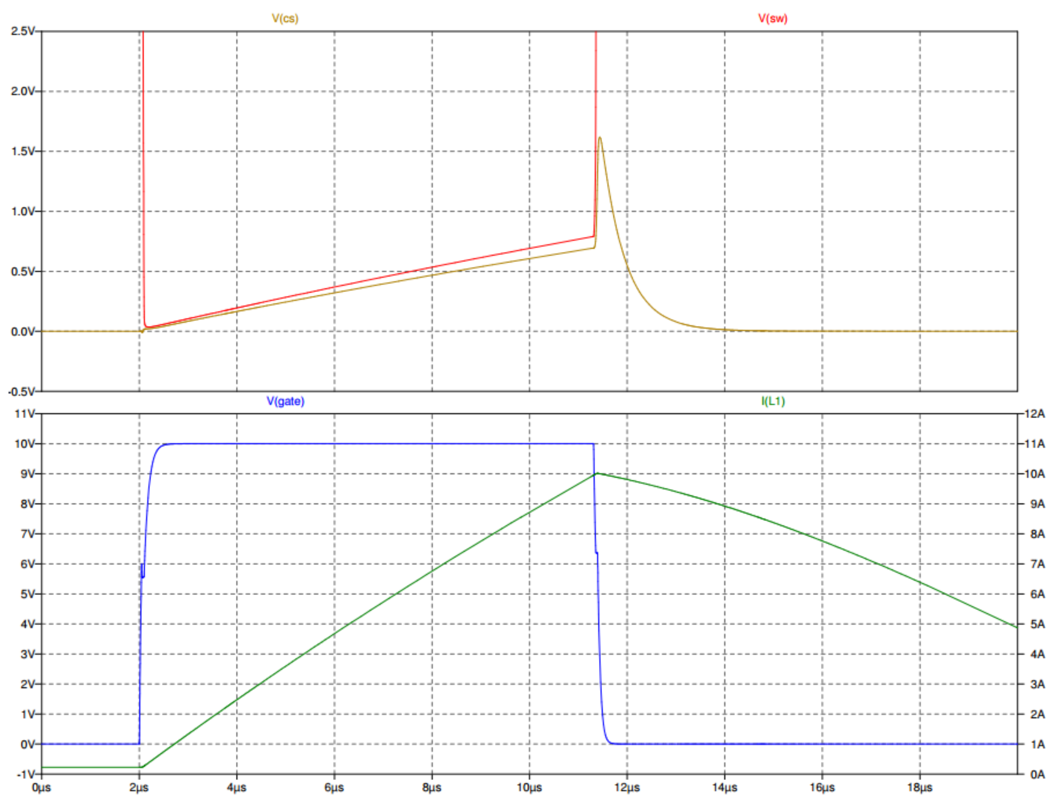
Fig. 4. VS pin voltage (blue trace) and CS pin (red trace) peak voltage levels for $V_{DS(ON)}$ sensing versus temperature without temperature compensation circuit (a) and with the additional temperature-compensation circuit (b).

SPICE Model

A SPICE model for the IR25750 is available and can be used to quickly simulate the IC functionality inside a switching circuit. Fig. 5 shows the boost simulation circuit together with the simulated waveform results.



(a)



(b)

Fig. 5. Simulation circuit (a) and simulated waveforms (b) for a MOSFET $V_{DS(ON)}$ sensing circuit based on the IR25750. VS = upper graph, red trace; CS = upper graph, yellow trace; GATE = lower graph, blue trace; and I_L = lower graph, green trace.

The simulated waveforms match the experimental waveforms (shown in Fig. 3) except that the turn-off spike is lower. This discrepancy is due to the value of the internal capacitance of the HVFET and the dv/dt rate of the VS node during the rising edge of the turn-off waveform. If desired, both of these can be adjusted inside the simulation circuit to better match the experimental results.

PCB Layout

To ensure the circuit functions correctly and to avoid high-frequency noise problems, it is recommended that designers implement a layout like the example shown in Fig. 6. The following layout tips should be followed as early as possible in the design cycle in order to minimize circuit problems and shorten design time.

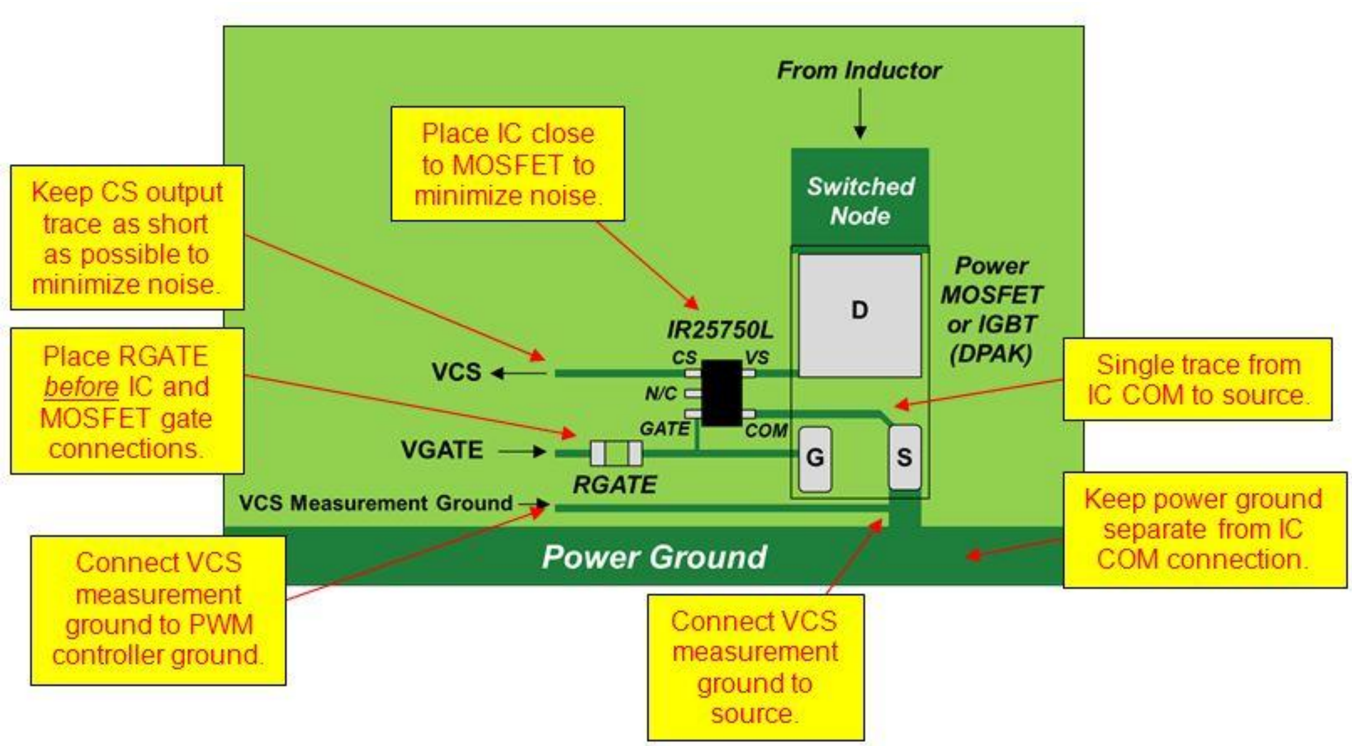


Fig. 6. PCB layout for an IRS25750-based circuit used to sense current in a DPAK- or D^2PAK-style MOSFET or IGBT, which is shown here mounted to the top layer of the PCB.

Adapter Board

A small adapter board (IRuCS1) is available for fast evaluation of the IR25750 inside an actual switched-mode application. The board, which is shown in Fig. 7, includes the footprint for a switching power MOSFET or IGBT (M1) in a D^2PAK or DPAK package, which the customer supplies. The board also contains the IR25750L SOT-23 current sensing IC (IC1), the gate resistor (RG), and optional temperature-compensation circuitry (R1, R2, R3, and R4.)

The IR25750L is placed directly next to M1 and connected to the existing gate, drain and source signals of M1. The current-sensing circuit does not have a V_{CC} pin so no additional V_{CC} trace or supply voltage is required. The IRuCS1 board includes test points for ease of measurement with an oscilloscope probe and can be easily connected into an existing switched-mode power circuit for fast in-circuit evaluation using the gate-drive input, the drain or collector connection pads, and the source or emitter connection pads.

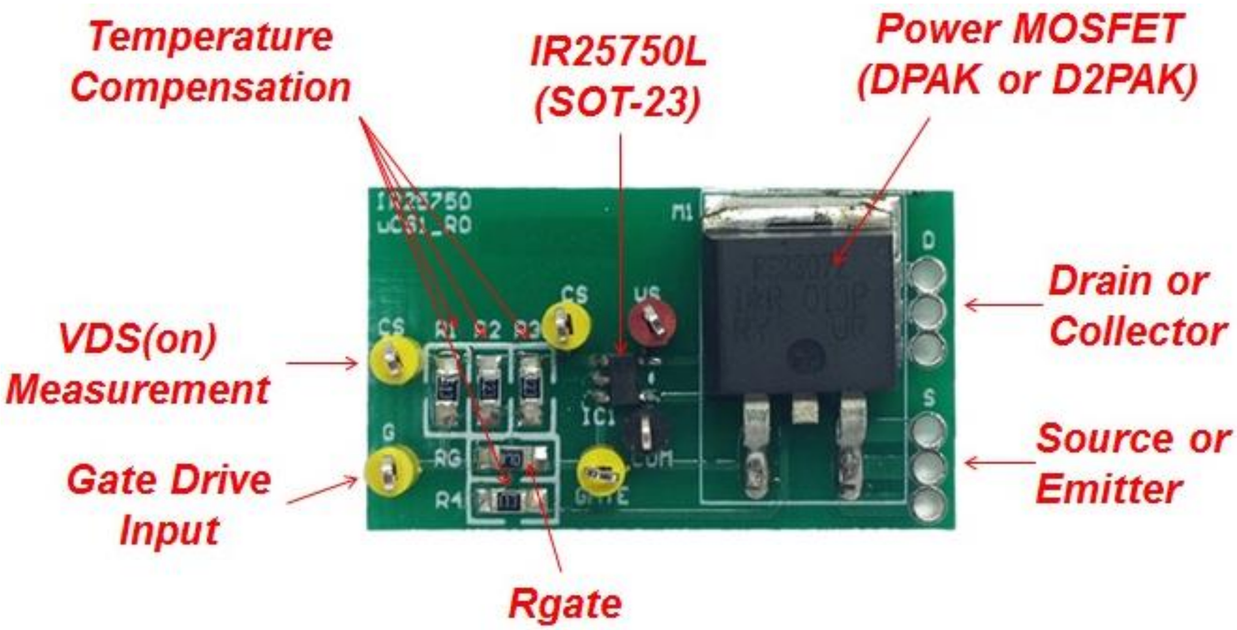


Fig. 7. IRuCS1 in-circuit evaluation board.

Conclusion

The new IR25750 offers a simple method to detect current through your power switch while eliminating the losses and parasitic inductance associated with traditional techniques. The IR25750 has a tiny SOT-23 footprint, allowing the IC to be placed conveniently next to the power switch and connected easily to existing gate, drain and source nodes. The experimental waveforms show proper functionality inside a typical high-current switching application and this IC can be used with MOSFETs, DirectFETs, IGBTs, and other available switch technologies.

Applications include high-current industrial, power tools, brick converters for servers, motor control, high-power dc motor drive, forklifts, induction heating, class-D audio, and general-purpose overcurrent protection. By eliminating traditional series-connected current-sensing elements, the overall system efficiency and cost performance can be increased dramatically.

References

1. IR25750 datasheet.
2. "Sensing Current with IR25750," application note AN-1199.
3. IR25750 SPICE simulation model and evaluation adapter board are available on request at www.irf.com.

About The Author

Tom Ribarich is director of the Lighting Design Center at International Rectifier, where he is responsible for developing control ICs for the global lighting market, including fluorescent, halogen, HID, LED and LCD backlighting applications. Prior to joining IR in 1996, Tom was employed by Knobel Lighting Components, Switzerland where he designed dimmable electronic ballast systems for a variety of applications *including general-purpose office lighting, low-temperature applications and outdoor Swiss Alp tunnel lighting.*

Tom received a BSEE degree from California State University, Northridge, and later a Master's degree in ASIC design from the University of Rapperswil, Switzerland. Tom believes the strength in a good design team comes from a creative and motivating environment combined with an international mixture of design cultures. He enjoys beach volleyball, surfing, snowboarding, video production and traveling.

For further reading on design of current sensing, see the How2Power Design Guide, and do a keyword search for "sensing."