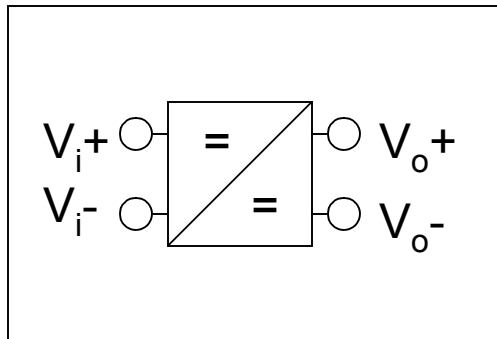


Simple Modular Half-Bridge

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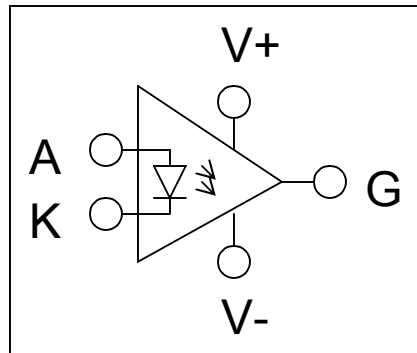
Rev.1.1
13 March, 2009

Simple Modular Half-Bridge Module Overview



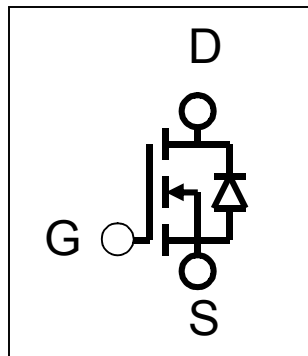
Isolated DC-DC Supply:

- Supplied by +12V from any battery or power supply.
- Creates +12V supply referenced to any MOSFET source.
- Creates high-side drive voltage.
- Isolates gate drive circuitry using AC coupling.



Gate-Drive Optocoupler:

- Supplied by +12V referenced to MOSFET source.
- Inputs optically-isolated PWM signal.
- Outputs 2.0A peak gate drive.

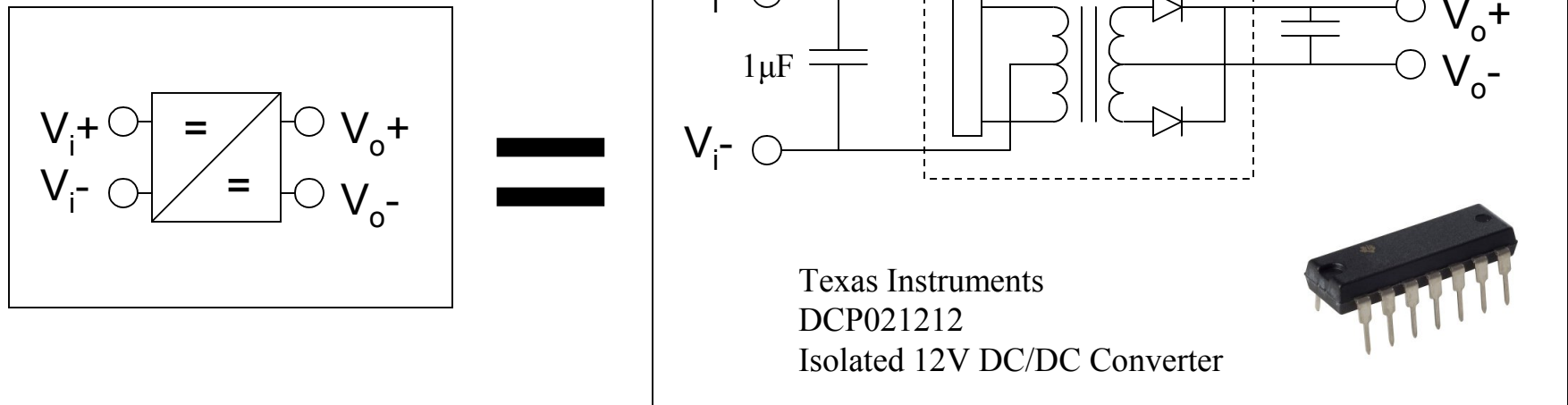


MOSFET:

- Could be virtually any single or parallel combination of MOSFETS.
- Choose to set power and voltage level of the half-bridge.
- Must include appropriate gate resistors.

Simple Modular Half-Bridge

Isolated DC-DC Supply: Individual Unit

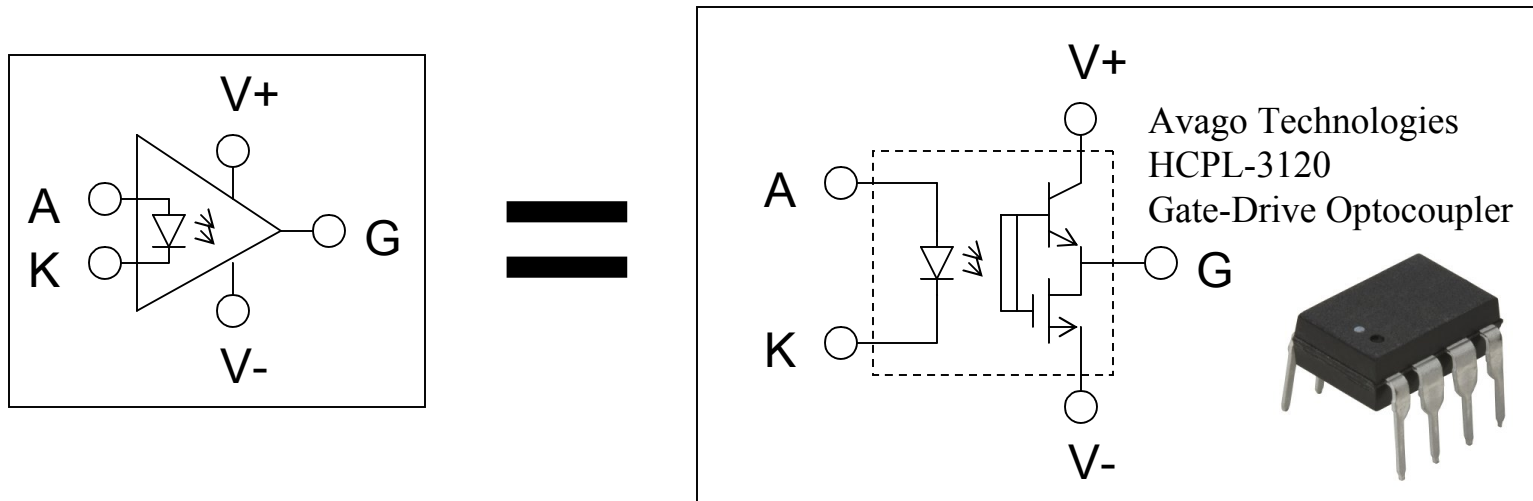


The **Texas Instruments DCP021212** is an isolated 12V to 12V DC-DC converter. It takes a 12V input, referenced to a common ground, and outputs 12V referenced to some other voltage. It uses AC and magnetic coupling to isolate the output from the input. This is used to supply +12V referenced to a MOSFET source pin, no matter where that is with respect to the system ground.

The two $1\mu\text{F}$ capacitors are used to smooth the input and output voltages.

This is the most expensive single component, at approximately \$12. However, it helps create a very well-isolated power system.

Simple Modular Half-Bridge Gate Drive Optocoupler: Individual Unit



The **Avago HCPL-3120** is an optically-coupled MOSFET or IGBT gate driver. The purpose of optical coupling is to isolate the input signal from the high-power electronics. When the LED is on, the MOSFET gate is sourced by $V+$. When the LED is off, the gate is sunk to $V-$.

Important Specifications¹:

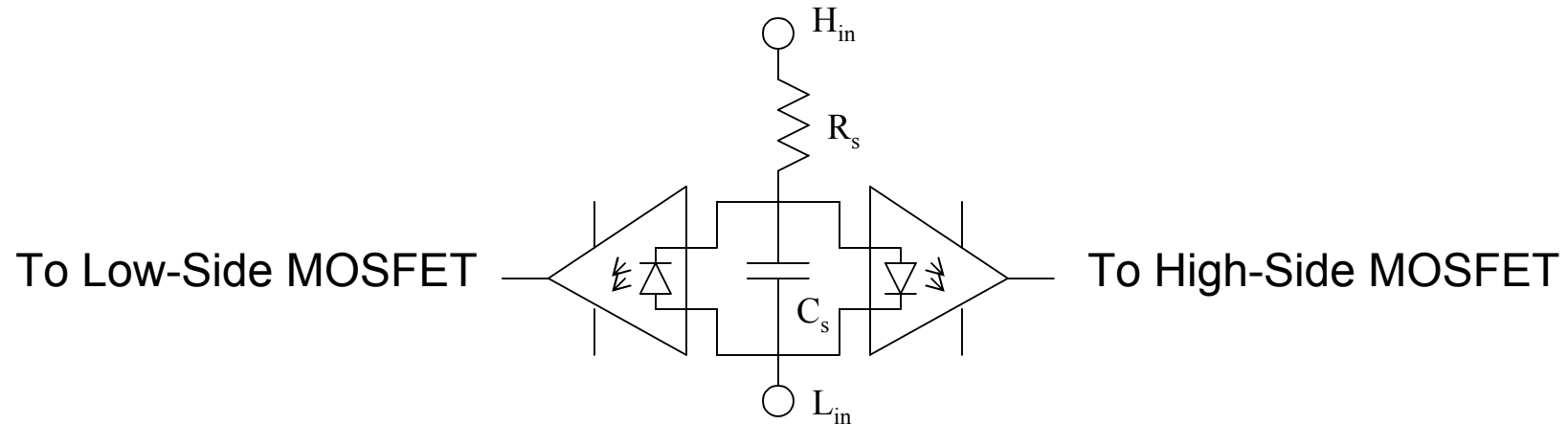
LED Forward Voltage, V_f : 1.5V

LED Forward Current, I_f : 10mA

¹HCPL-3210 Datasheet: <http://www.datasheetcatalog.org/datasheet/hp/HCPL-3120.pdf>

Simple Modular Half-Bridge

Gate Drive Optocoupler: Shoot-Through Delay Pair



The above circuit is a passive way to ensure that shoot-through cannot occur in a half-bridge. It introduces a delay between turn-off of one MOSFET and turn-on of the other. Note that the optocoupler LEDs are in reverse-parallel configuration.

The delay should be significantly longer than the turn-on/turn-off time of the MOSFETs. A few microseconds is usually sufficient. The exact delay is somewhat difficult to estimate, but a good approximation can be made using:

$$t_{delay} \approx R_s C_s \left(\frac{V_f}{V_{sig}} \right)$$

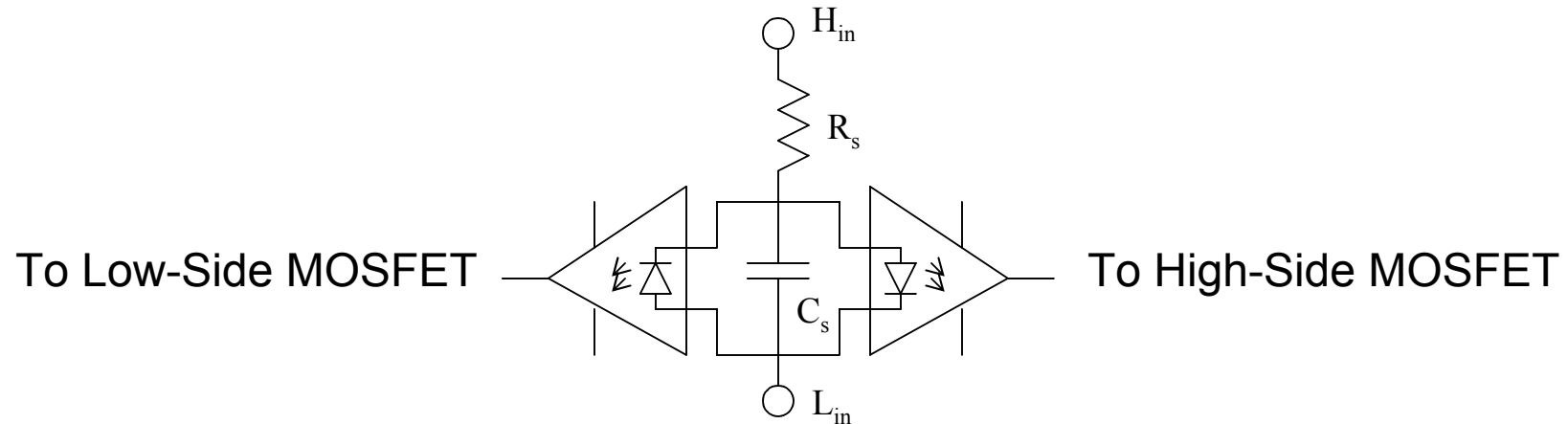
For single-quadrant control.
More to come on this.

$$t_{delay} \approx R_s C_s \left(\frac{2V_f}{V_{sig}} \right)$$

For two-quadrant control (synchronous rectification).
More to come on this.

Simple Modular Half-Bridge

Gate Drive Optocoupler: Choosing Passive Components



R_s should be chosen like a standard LED current-limiting resistor:

$$R_s = \left(\frac{V_{sig} - V_f}{I_f} \right)$$

C_s should be chosen based on the desired shoot-through delay time:

$$C_s \approx \left(\frac{t_{delay}}{R_s} \right) \left(\frac{V_{sig}}{V_f} \right)$$

Single-quadrant control.

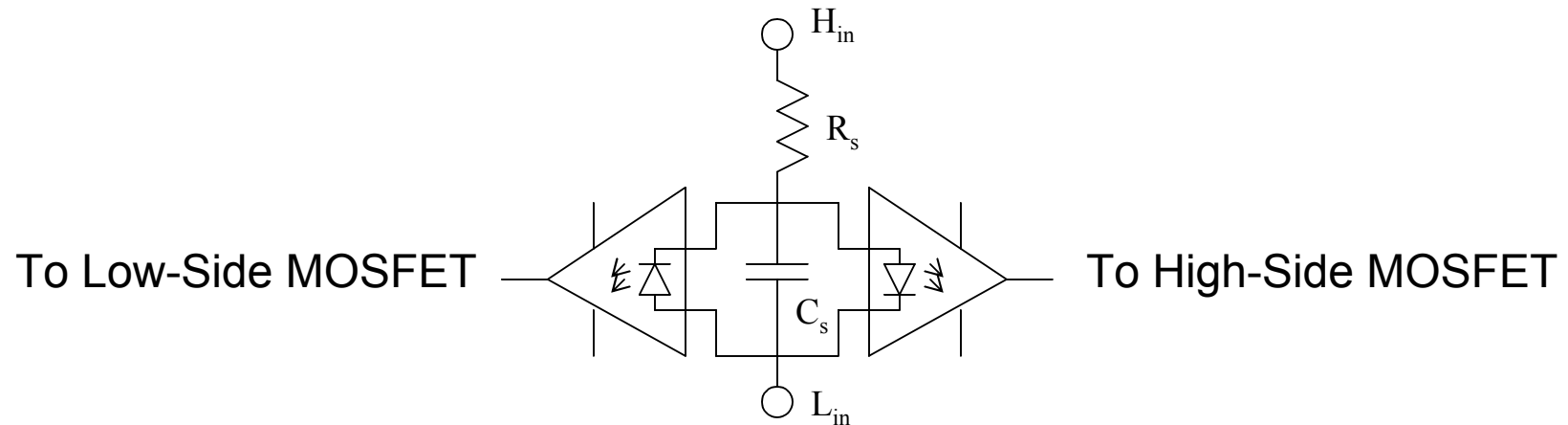
or

$$C_s \approx \left(\frac{t_{delay}}{R_s} \right) \left(\frac{V_{sig}}{2V_f} \right)$$

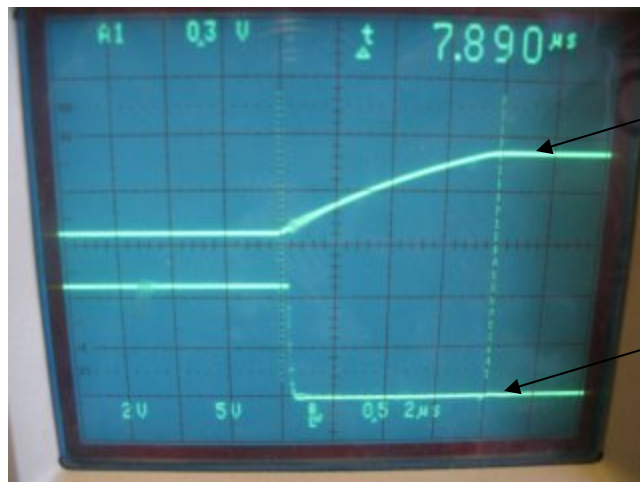
Synchronous rectification.

Simple Modular Half-Bridge

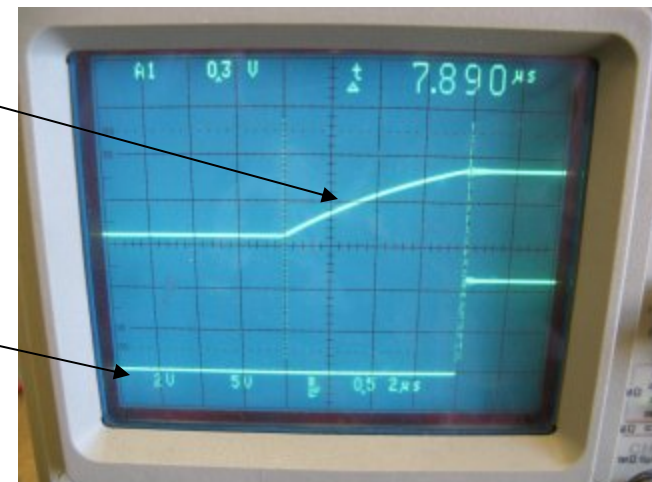
Gate Drive Optocoupler: Shoot-Through Delay Example



Conditions: $V_{sig}=3.3V$, $R_s=200\Omega$, $C_s=0.047\mu F$, Synchronous Rectification
Predicted Delay: $8.5\mu s$ (using the equation for the previous slide)

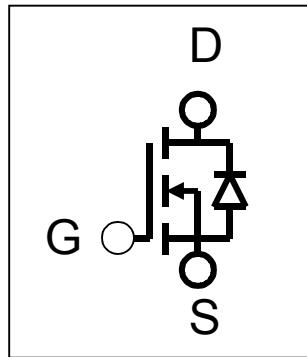


Turn-off is almost instant.



Turn-on is delayed by 7.89 μs .

Simple Modular Half-Bridge MOSFET: Flexible Configuration



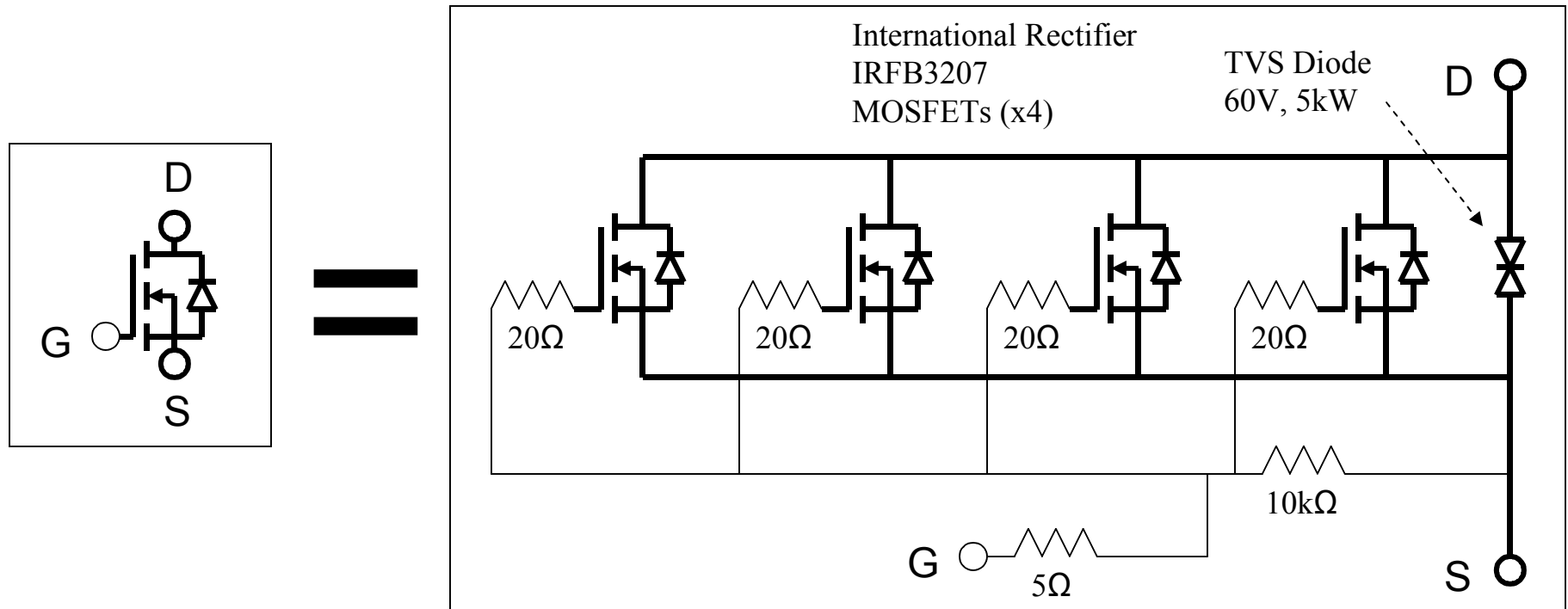
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Almost Anything...

Because the floating supply and optocoupled gate driver are very modular, the MOSFETs used can be virtually anything. They can be individual small MOSFETs, many small MOSFETs in parallel, or large MOSFETs with huge current-handling capabilities. They can be in almost any configuration, including half- and full-bridges. The modular gate driver treats high- and low-side MOSFETs the same. There are a few general guidelines to follow:

1. Use gate resistors. The optocoupled gate drivers can handle a peak output of 2A @ 12V. So the total effective gate resistance should be no less than 6Ω .
2. Use TVS diodes from source to drain to protect MOSFETs from inductive spikes.
3. For parallel MOSFETs, observe good gate resistor practices to prevent ringing. See next slide.
4. Use a pull-down resistor on all gates to ensure that MOSFETs turn off in the event of a gate driver failure.
5. Check the gate capacitance specification in the MOSFET data sheet to determine the approximate turn-on and turn-off time, given your chosen gate resistance. Set the shoot-through delay at the optocoupler accordingly.

Simple Modular Half-Bridge MOSFET: One Example



IRFB3207: These are serious workhorse MOSFETs. Even though they are in a small TO-220 package, each one can handle 75A at 48V if properly heatsinked.

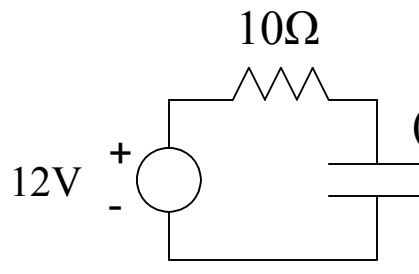
Gate Resistors: Four 20Ω resistors in parallel and one 5Ω resistor in series with all. This gives a 10Ω effective gate resistance as seen by the optocoupled gate driver, but a larger gate resistance as seen from one MOSFET to the rest. This helps prevent ringing issues in parallel MOSFETs.

TVS Diode: This protects against large inductive spikes, absorbing energy when the voltage across it is too high. It may or may not be necessary, depending on the application.

Simple Modular Half-Bridge

MOSFET: Computing the Turn-On/Turn-Off Time

The switching time of the MOSFET module can be found with the gate capacitance specification of the MOSFET. For example, the gate capacitance of a single IRFB3207 MOSFET is 7.6nF¹. The capacitance of parallel MOSFETs is summed. For a quick estimate of the switching time, the “RC time constant” of the total gate drive circuit can be calculated. A full switching period might take four time constants:


$$(4)(7.6\text{nF}) = 30.4\text{nF}$$
$$4\tau_{sw} \approx 4R_g C_g = (4)(10\Omega)(30.4\text{nF}) = 1.2\mu\text{s}$$

This has a few practical implications. For one, the shoot-through delay should be significantly longer than one switching time period. In this case, a few microseconds is enough. Also, the time spent switching should be several orders of magnitude less than the time spent fully-on or fully-off, to ensure high efficiency. In many cases, PWM frequencies up to 10-100kHz may still satisfy this condition.

¹IRFB3207 Datasheet: <http://www.irf.com/product-info/datasheets/data/irfs3207.pdf>

Simple Modular Half-Bridge MOSFET: Heat Dissipation

The MOSFETs will create heat in three ways: conductive, switching, and diode dissipation:

Conductive: When the MOSFET is on, it behaves like a very small resistor. The “on-resistance” is specified in the MOSFET datasheet.

Switching: Energy is lost as the MOSFET crosses through a partially-on state. This dissipation is proportional to switching frequency.

Diode: In single-quadrant control, one MOSFET module is used as a diode. Diode dissipation is usually greater than conductive dissipation because of the relatively high voltage drop, which is why synchronous rectification is beneficial. Diode dissipation is easy to estimate and make a good worst-case scenario in many cases.

Example: 4 x IRFB3207 in parallel @ 300A (4 x TO-220 package limit). Diode drop is 1.3V¹. Total thermal resistance junction to greased heat sink is 0.95°C/W¹.

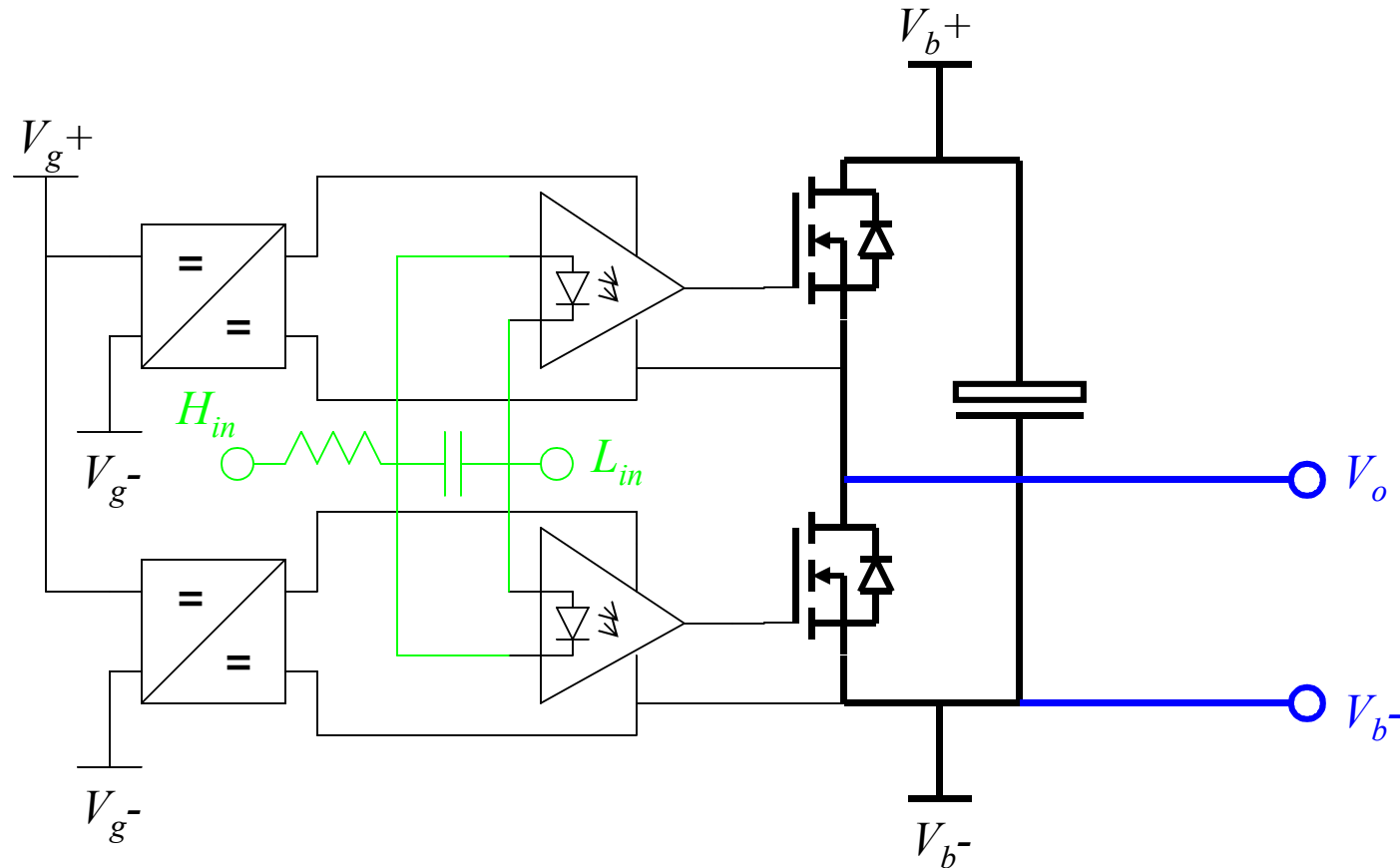
$$P_{dis} = IV = (300A)(1.3V) = 390W \quad (\text{Shared by four MOSFETS})$$
$$\Delta T = \frac{1}{4} P_{dis} R_{th} = \frac{1}{4} (390W)(0.95^\circ C / W) = 93^\circ C$$

This is amazingly still within operating temperature as long as the heat sinks remain near ambient.

¹IRFB3207 Datasheet: <http://www.irf.com/product-info/datasheets/data/irfs3207.pdf>

Simple Modular Half-Bridge

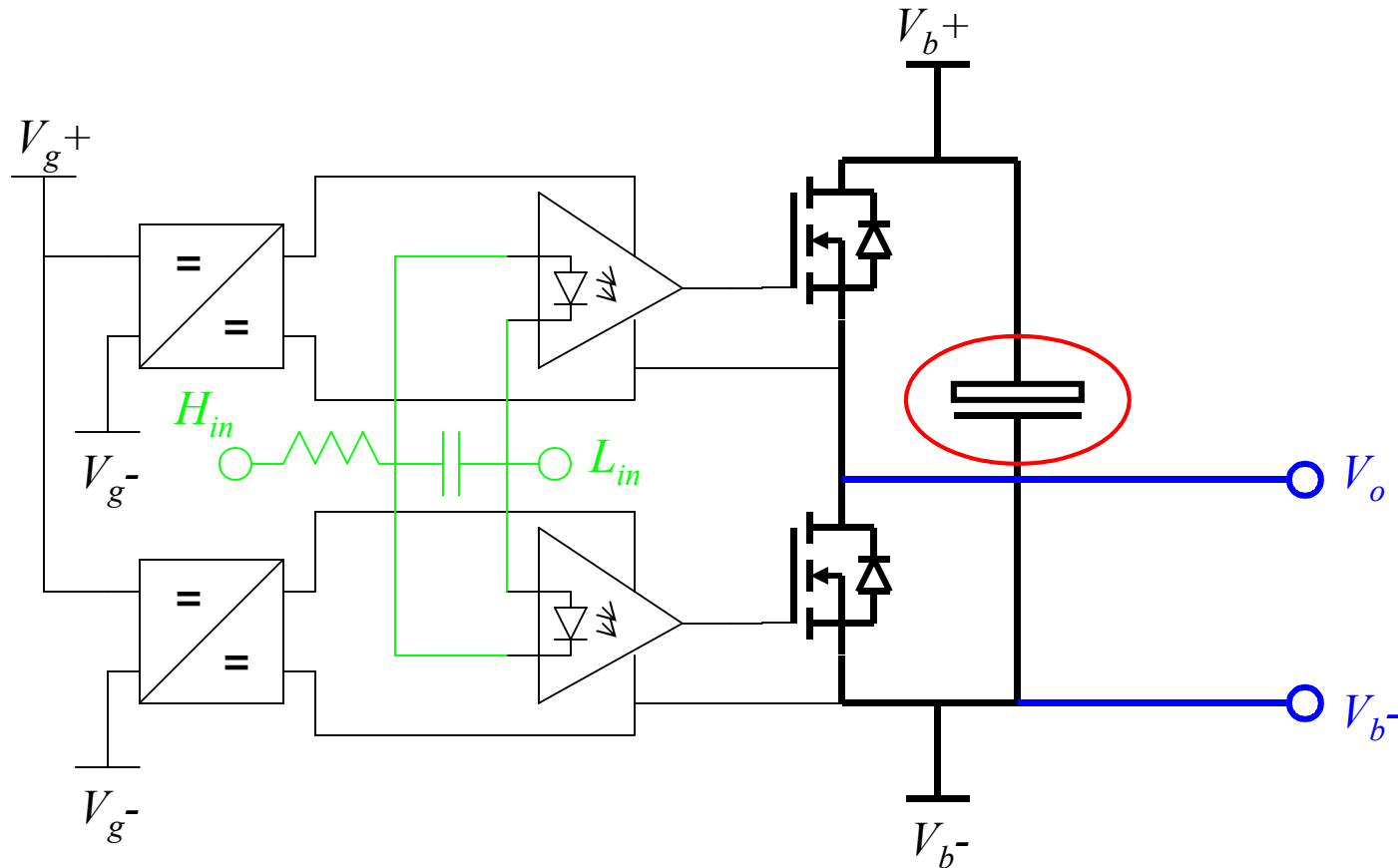
Putting It All Together: Completely Isolated Half-Bridge



V_g^- (gate drive supply ground), V_b^- (main power supply ground), and logic ground for optocoupler inputs are all isolated! You can do whatever you want with them. If everything is supplied by one battery, all grounds will be the same. You can tie grounds together with small resistors and use lots of extra capacitance to protect the logic from noise on the power ground. Or, you can supply the logic and/or gate drivers with a separate battery for complete isolation.

Simple Modular Half-Bridge

Putting It All Together: Input Capacitance



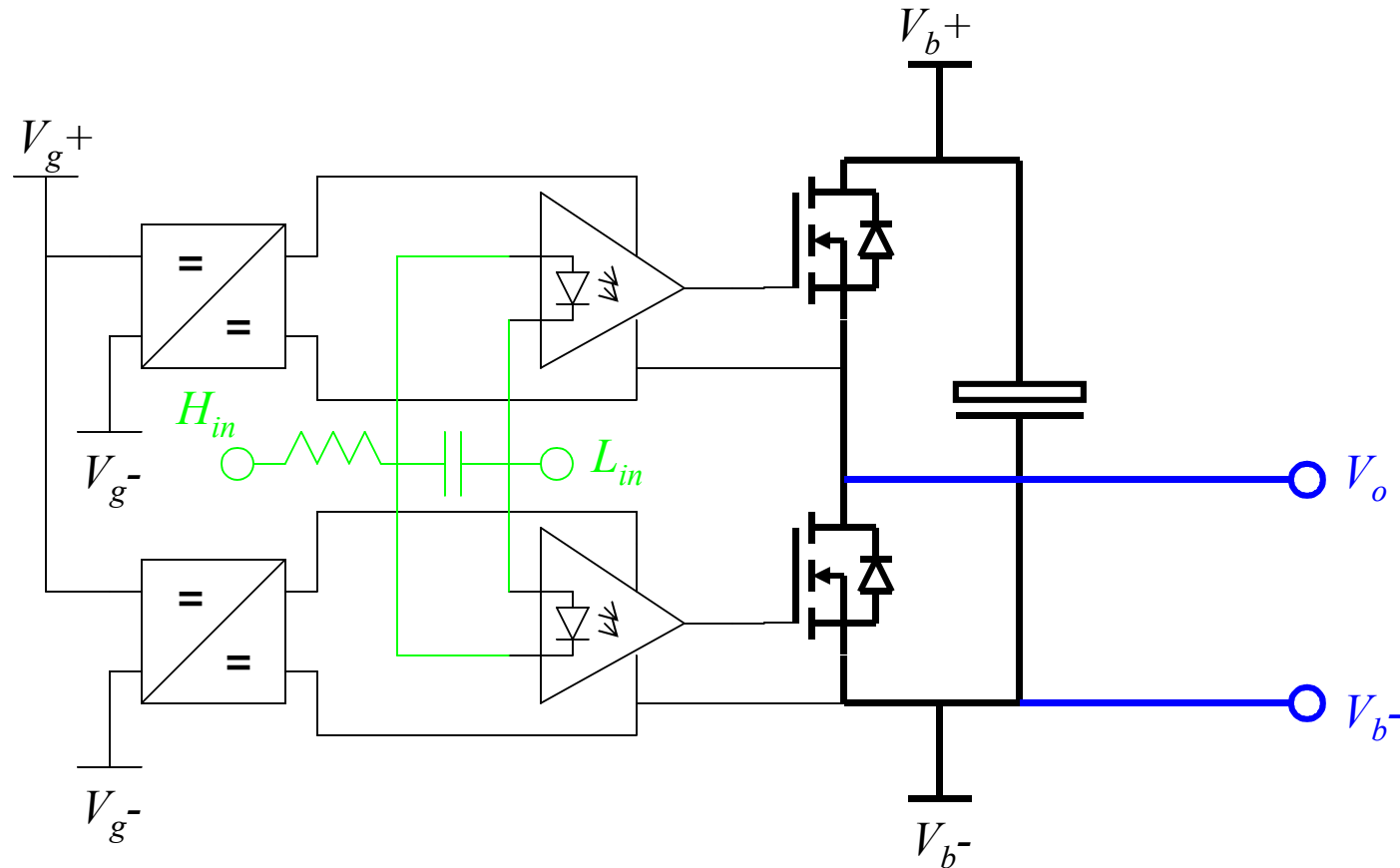
The input capacitance holds the voltage across the half-bridge stable against inductive voltage spikes from the battery cables. Its exact value depends on many factors, but a very conservative worst-case estimate can be made by considering the voltage ripple if the battery cable inductance was very large:

$$\Delta V = \frac{I_{\max}}{C} \frac{1}{f_{PWM}}$$

- Keep ΔV reasonable based on working voltage.
- Keep battery cables short and together.
- This capacitor may need a pre-charge circuit.

Simple Modular Half-Bridge

Putting It All Together: Driving the Half-Bridge

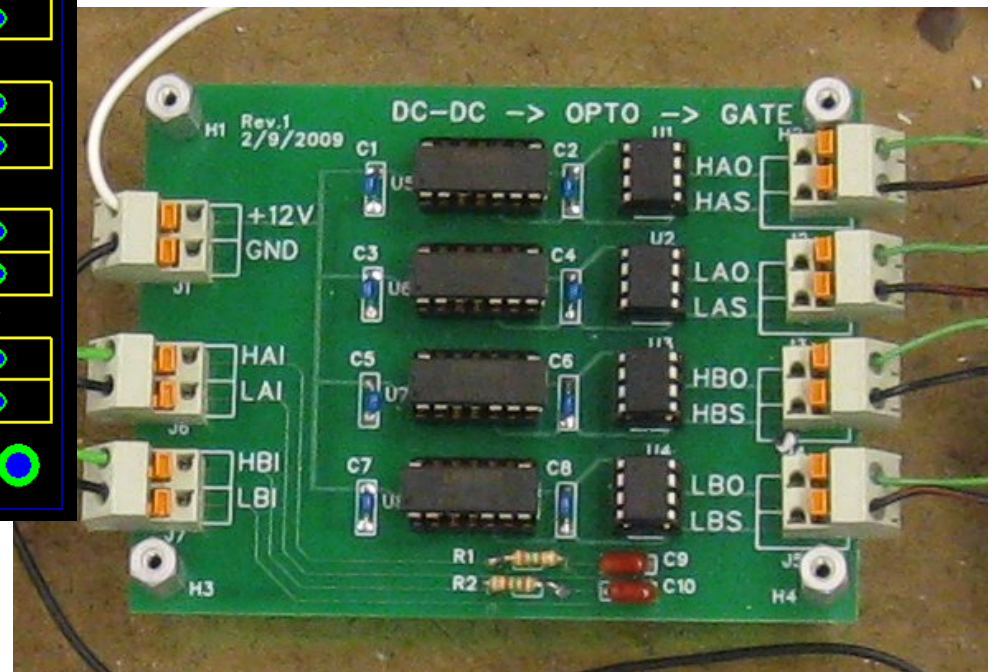
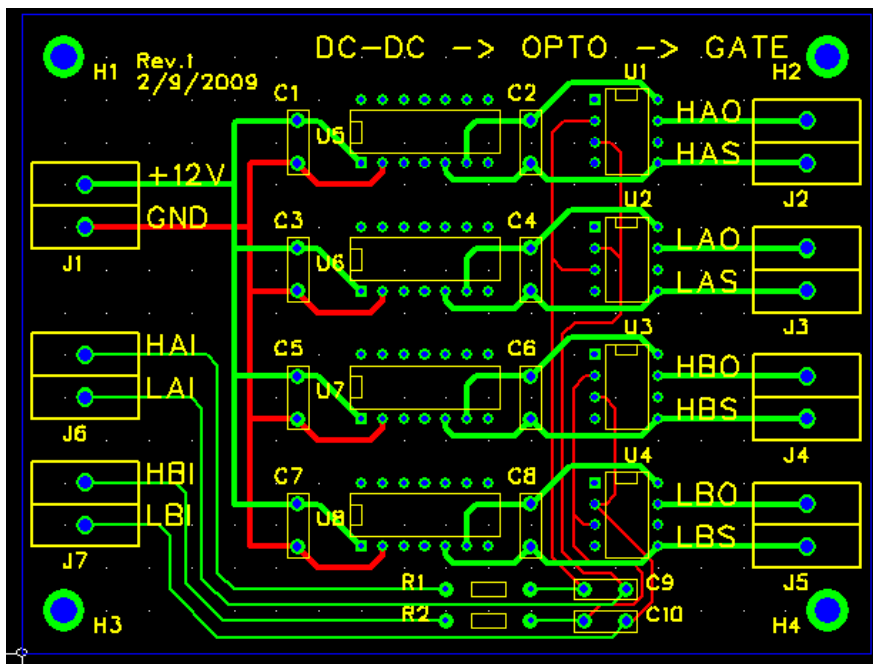


H_{in}	L_{in}	V_o	Notes	
HIGH	LOW	V_{b+}	On	Drive H_{in} with PWM while L_{in} is low for single-quadrant control. The low-side MOSFET will act as a flyback diode.
LOW	LOW	X	Coast	
HIGH	HIGH	X	Coast	Drive H_{in} with PWM and L_{in} with complementary PWM for two-quadrant control / synchronous rectification /
LOW	HIGH	V_{b-}	Brake	regenerative braking.

Simple Modular Half-Bridge

Putting It All Together: Physical Layout

The isolated DC-DC supplies and optocouplers can be easily built onto a breadboard, protoboard, or printed circuit board. One example of a printed circuit board layout for four sets of these modules is shown below. This board could handle two half-bridge, or one full-bridge. (The PCB manufacturing files are also available.)



Simple Modular Half-Bridge

Putting It All Together: Physical Layout

Physical construction of the MOSFET module is very important to achieving the maximum performance and reliability, especially if your application pushes the limits of the MOSFETs used.

Good heat sinking is critical! You can use smooth, faced-off aluminum bars or commercially-available heat sinks. Use thermal paste on the drain tabs and fans to cool the heat sinks.

One quick and easy way to achieve good thermal and electrical conductivity is to use the heat sinks to carry current as well. Brass screws through the drain tabs can give a very low resistance electrical connection. This also minimizes soldering and makes replacing individual MOSFETs very simple. The following shows a high-current half-bridge made with minimal soldering:

