

APPLICATION NOTE REGARDING H BRIDGE DESIGN AND OPERATION

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ABSTRACT

This application note is intended to be an explanation and design aid for H Bridges used in inverters and motor controllers. Typical H Bridge applications and a description of the device will be explained and then the methodology behind selecting specific parts will be discussed. After part selection is explained a method for switching is outlined and then a final is schematic is proposed.

KEYWORDS

- 3. H Bridge Description and Applications
- 4. Basic H Bridge Design
- 5. MOSFET Selection
- 7. Driving MOSFETs
- 8. Pulse Width Modulation
- 9. Full H Bridge Configuration

H BRIDGE DESCRIPTION AND APPLICATIONS

An H Bridge is a set of four switches that are assembled in such a way that an arbitrary load impedance is decoupled from a direct current (DC) power rail and ground. These switches can then be used to control the direction of current running from the DC source to ground in either direction across the connected impedance. The “H” in H Bridge comes from the shape of the bridge, where either side of the H is different two switches in series between the DC rail and ground while the centerline of the H is an arbitrary impedance. An example of a simple H Bridge with four switches and single load impedance is shown in Figure 1 to the right. Each of the switches in this figure are independent from each other and only have two positions, either conducting current (ON) or blocking current (OFF).

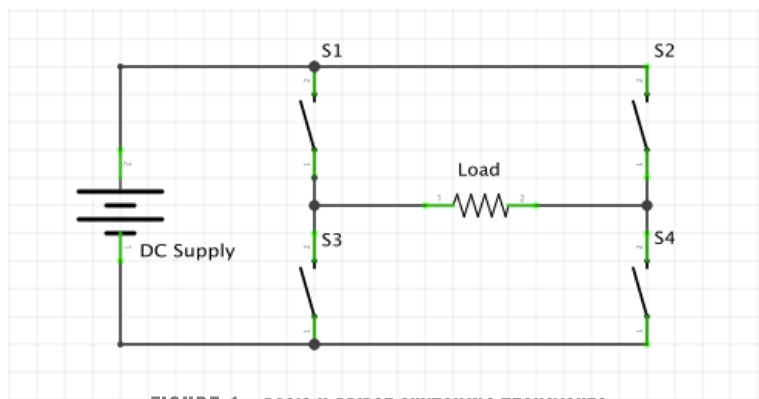


FIGURE 1. BASIC H BRIDGE SWITCHING TECHNIQUES

H Bridges can be found in many different applications where there is a desire to have control over the direction current can flow. Some common examples of this would be controlling the direction an electric motor can turn by allowing current to flow in one direction and then reversing that direction in the bridge, thus causing the motor to turn in the opposite direction. In the case of the high-powered inverter being constructed by Team 7 of ECE 480 Fall Semester 2014, an H Bridge is being utilized to create an Alternating Current (AC) waveform from a high voltage DC Rail. This is done by reversing the direction of current flow across the load impedance at a frequency of 60 Hz which in turn results in an alternating current signal at the same frequency of typical line current in the United States.

BASIC H BRIDGE DESIGN

Each of the switches shown in Figure 1 have different roles for typical operation of an H Bridge. The first important distinction between the different switches within the circuit is that the top two switches are referred to as the **High Side** and the bottom two switches are referred to as the **Low Side**. This clarification is important to the design of an H Bridge because the functionality of these sides varies based on the application that the bridge is being used in. The high side switches are responsible for controlling the availability of the DC Rail voltage across the load impedance while the low side switches are responsible for controlling the connection between load impedance and ground.

The next important clarification to make in designing an H Bridge is what

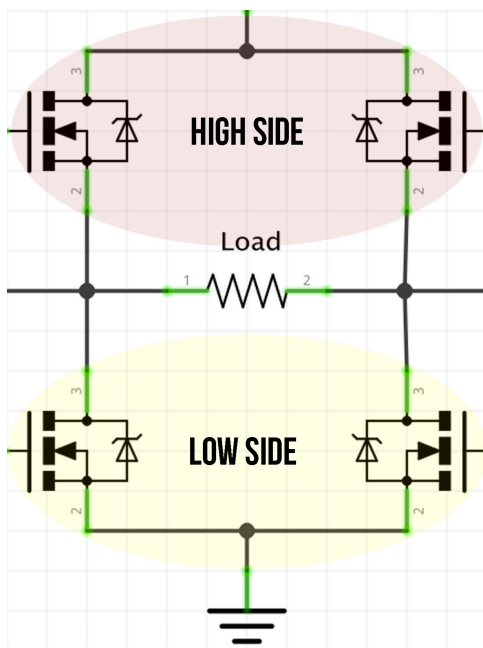


FIGURE 2. H BRIDGE WITH MOSFET DRIVERS

type of components will be used to act as the four switches within the final circuit design.

Most applications of H Bridges use four Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) to act as voltage-controlled switches. These MOSFETs can be either P-Channel or N-Channel depending on the design requirements for any specific application. An example of an all N-Channel MOSFET H Bridge is shown in Figure 2 to the left. Each of the four MOSFETs shown in

figure 2 have now replaced the four switches that were previously used to control the direction of current across the load Impedance. Now that the direction of the current can be controlled at the circuit level the next step is to properly select switching MOSFETs to be utilized in the H Bridge.

MOSFET SELECTION

When selecting MOSFETs for an H Bridge application there are several criteria that are important to consider. In the context of a high power inverter one of the most important pieces of information is the Drain-to-Source resistance of the device. This measurement is the total amount of resistance present within the MOSFET between the drain and source of the device when it's operating in the active region, or when the gate of the device has been fully charged. This piece of information is especially important because when operating in a high current environment (like a high power inverter) the series resistance will result in the device absorbing a large amount of energy, which translates to the device dissipating a large amount of heat. This heat results in the device eventually suffering from thermal run away and latching open until it's finally destroyed by excessive energy absorption. In order to account for this possibility the series resistance of the device can be used to calculate an upper threshold of acceptable current that can be pulled through the device. In the case of a high power inverter, the DC Rail voltage will be set to 170 volts and the intended upper threshold of supplied power will be 1000 Watts. Using these pieces of information the upper current threshold can be calculated as:

$$1000 \text{ Watts} / 170 \text{ Volts} = \mathbf{5.88 \text{ Amps}}$$

This means that the most current that can ever be pulled through the Inverter at one period of time is 5.88 Amps. For this example VISHAY IRF530 N-Channel MOSFETs will be selected to create an H Bridge. Referencing the datasheet for these devices, the average series resistance is 160 milliohms¹. Using this figure, the maximum power dissipation across this device would be:

$$(.16 \text{ Ohms} * 5.88 \text{ Amps}) * 5.88 \text{ Amps} = \mathbf{5.53 \text{ Watts}}$$

Using this calculated value as the maximum continuous power dissipation that the device would have to endure the data sheet can again be referenced to see

¹ <http://www.vishay.com/docs/91019/91019.pdf>

what the upper possible threshold for power dissipation across the device is. According to the datasheet provided by VISHAY, the highest possible power dissipation across the device is **88 Watts**². Using this piece of information and the above calculation of maximum power dissipation within the designed circuit it is safe to assume that the IRF530 will successfully operate within the calculated current specification.

The next important decision to make in selecting MOSFETs for an H Bridge is the Gate-to-Source Threshold voltage required by the device. This is the total required voltage needed to switch the MOSFET from the “off” state to the “on” state. When the proper voltage is applied to the gate of the device it will begin conducting current between the Drain and Source terminals. Referencing the datasheet for the IRF530 N-Channel MOSFET, the Gate-to-Source Threshold Voltage (represented as $V_{GS(th)}$) is on average 3 Volts when 250 microamps are flowing at the drain³. An important piece of information that can again be gathered from the datasheet is how this voltage changes as more current flows between the drain and source of the device. The graph shown in Figure 3 is a representation of how the Gate-to-Source Voltage changes as the current increases⁴. This is an important factor to take into account for an H Bridge because as different load impedances are applied the current flowing through the drain will change, meaning $V_{GS(th)}$ will increase as the current increases.

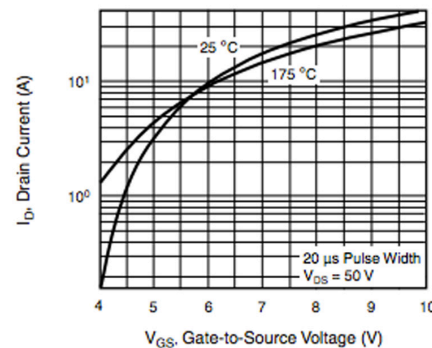


FIGURE 3: IRF530 ID VS. VGS CURVE

² <http://www.vishay.com/docs/91019/91019.pdf>

³ <http://www.vishay.com/docs/91019/91019.pdf>

⁴ <http://www.vishay.com/docs/91019/91019.pdf>

DRIVING MOSFETS

After selecting acceptable MOSFETs for the designed H Bridge the next critical step is to select a proper Integrated Circuit (IC) that will act as a buffer between the signal generator for High Side / Low Side control and the actual gates of the MOSFETs. This piece of hardware is called a **gate driver**. One of the main roles of a gate driver is its ability to create a high enough charge to activate the high side MOSFETs in an H Bridge. In a typical H Bridge configuration as shown in Figure 2 there are two High Side MOSFETs, each located on opposite sides of the bridge. In order to bias these MOSFETs in the active region a voltage must be applied to the gate that meets the $V_{GS(th)}$ value as specified in that particular MOSFETs data sheet. For example, the datasheet for the VISHAY IRF530 shows that $V_{GS(th)}$ is approximately 3 Volts at 250 milliamps⁵. This value is important for the high side drivers because the source of these devices will be tied to the load impedance while the drain is tied to the DC Rail, meaning there is only a small difference between the drain voltage and source voltage. If the DC Rail voltage were set to 20 Volts that would mean that the drain of the high side device would be at a potential of 20 Volts and the source would be at almost exactly the same value. In order to activate the high side device the voltage applied to the gate must be the value of $V_{GS(th)}$ higher than the source voltage. If the source voltage is approximately 20 volts and $V_{GS(th)}$ is 3 volts, the voltage applied to the gate of the high side driver must be:

$$3 \text{ Volts} + 20 \text{ Volts} = \mathbf{23 \text{ Volts}}$$

This means that in order to activate the High Side drivers a total voltage of 23 Volts must be applied to the gate. If a gate driver is used in the design of an H Bridge then the IC itself has a built in charge pump that can be used to amplify a charge that will in turn trigger the high side MOSFET. This internal charge pump is combined with a bootstrap capacitor that supplies the required charge needed to activate the high side drivers.

⁵ <http://www.vishay.com/docs/91019/91019.pdf>

PULSE WIDTH MODULATION

The final piece required in understanding H Bridge design is the type of signals that can be supplied to the bridge. The MOSFETs in the bridge will only react to either a high (ON) or low (OFF) signal, meaning all signals run to the gate drivers must be a mixture of these two states. The easiest way to go about creating different waveforms with this constraint is to use a form of modulation called Pulse Width Modulation (PWM). PWM is created by allocating a slot of time and then varying the amount of time the signal is on compared to off within that originally determined slot. The signal can be off or on anywhere from 0% to 100% of the time, as long as the percentage of both the off time added to the percentage of on time is equal to 100%. This percentage of time on to time off is called the Duty Cycle of the signal. Once the PWM signal is created it can be fed into the Gate Drivers that will then amplify the high side and low side signals in order to meet the $V_{GS(th)}$ requirement of each driver within the H Bridge configuration. An example of several PWM control signals is shown in Figure 4⁶ below.

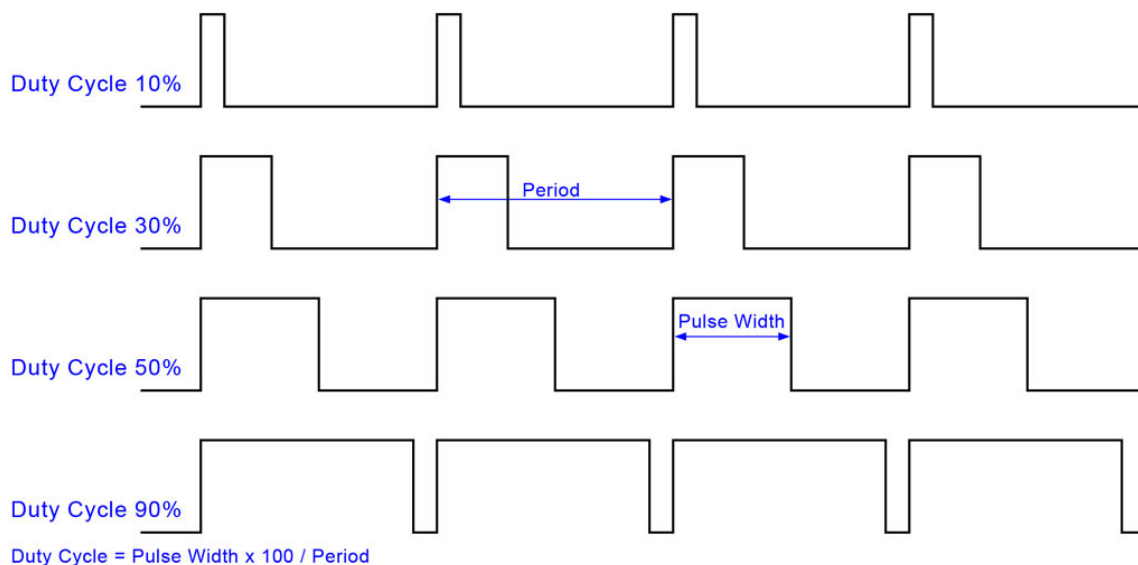


FIGURE 4. TYPICAL PWM SIGNAL

⁶ http://d32zx1or0t1x0y.cloudfront.net/2011/06/atmega168a_pwm_02_lrg.jpg

FULL H BRIDGE CONFIGURATION

A final example of an H Bridge and required control devices is shown in the diagram below. Figure 5 includes the four required MOSFETs needed for a complete H Bridge, two gate drivers for each side of the bridge with the associated boot strap capacitors, and an Arduino Uno used to create the PWM signals that are fed into the gate drivers. There are three different DC sources, one for the Arduino at 5 Volts DC, one for the gate drivers at 15 Volts DC, and one for the H Bridge DC rail at 170 Volts DC. All power supplied share the same common ground.

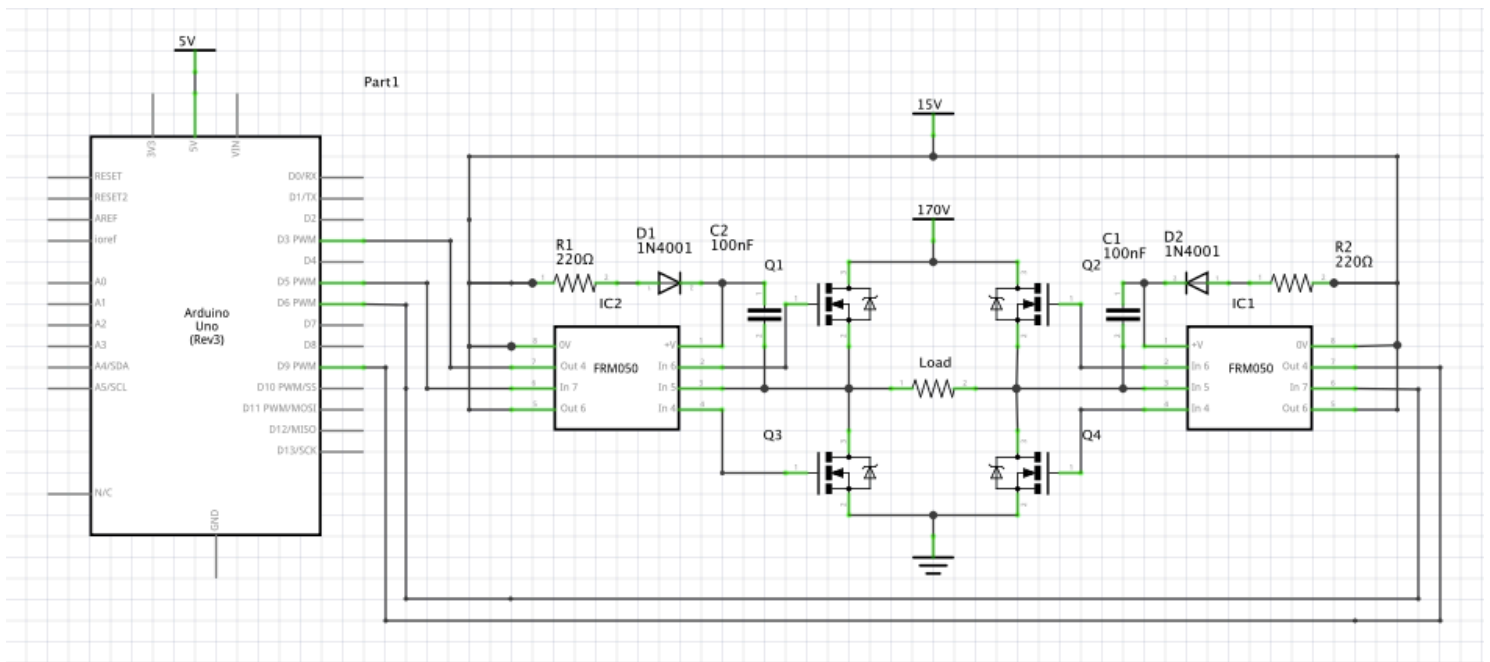


FIGURE 5. FULL H BRIDGE CONTROL SCHEMATIC