

Mechatronics Fact Sheet 7: Metal Oxide Semiconductor Field Effect Transistor (MOSFET) and H-Bridge Driver Circuit
(Kita 2004)

1. Objective

- Learn about Metal Oxide Semiconductor Field Effect Transistors (MOSFET)
- Learn how to make H-bridge Driver circuit using MOSFETs

2. Introduction

Metal Oxide Semiconductor Field Effect Transistors (MOSFET) is a type of transistor. A MOSFET can be created so that the power required to turn it on is considerably less than bi-polar junction transistors (BJT) or Darlington transistors. MOSFETs can also be made to withstand more power and turn on faster than BJT or Darlington transistors. Most modern integrated circuits (IC) like micro-controllers are created using MOSFETs to increase their speed and lower power consumption. (NOTE: These are labeled as CMOS or HCMOS ICs) Modern actuator driver circuits are also created using MOSFETs due to their low resistance when on. MOSFET are discussed and used to make an H-Bridge driver circuit in this fact sheet.

3. MOSFETs

MOSFETS are transistors and can be used as switches. There are three pins on a MOSFET: gate, drain, and source. Gate voltage controls current flow through the transistor. There are four different types of MOSFETs as shown in Fig. 1- 4.

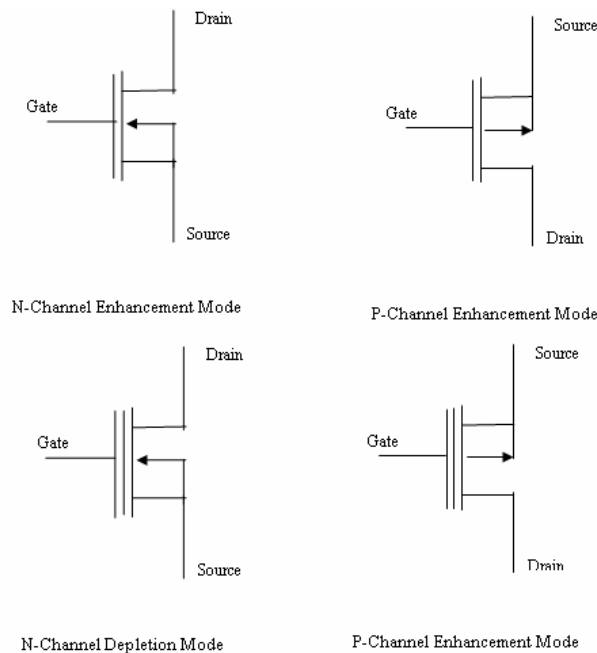


Fig.1 Mosfet Symbols

N-Channel Enhancement Mode:

Voltage Between Gate and Source	MOSFET state
Negative	OFF
0 V	OFF
Positive	ON

N-Channel Depletion Mode:

Voltage Between Gate and Source	MOSFET state
Negative	ON
0 V	ON
Positive	OFF

P-Channel Enhancement Mode :

Voltage Between Gate and Source	MOSFET state
Negative	ON
0 V	OFF
Positive	OFF

P-Channel Depletion Mode :

Voltage Between Gate and Source	MOSFET state
Negative	OFF
0 V	ON
Positive	ON

The voltage difference required to fully turn off or on a MOSFET is usually around 10 V. There are MOSFETS that only need a 5V difference to fully turn off or on. The devices that only need a 5V difference are called “Logic Level” MOSFETS.

Minimal current flows from the gate to source compared to a BJT or Darlington transistor. The gate and source can be viewed as a capacitor. Once the gate/source capacitor is charged, no more current flows into the gate but the voltage at the gate remains higher than the source. If there is no current flow there is no power flow from gate to source and therefore MOSFETS consume less power while turning on. This is one reason why MOSFETS are used in modern ICs to reduce power consumption.

Another important fact about MOSFETS is that the resistance between drain and source can be made very small when on compared to BJT or Darlington transistors. The resistance between drain and source when on is R_{sdon} . The N-Channel Enhancement mode MOSFET can be manufactured with R_{sdon} as low as 0.001 Ω . Since power the MOSFET itself must dissipate is current through the MOSFET squared times R_{sdon} , a lower R_{sdon} allows the MOSFET to pass more current before heating up. The P-Channel enhancement mode, N-Channel depletion mode, and P-Channel depletion mode have higher R_{sdon} in general but still lower than most BJTs or Darlington transistors.

Depletion mode MOSFETS are not as common as enhancement mode MOSFETS so they will not be used for the rest of the fact sheet.

4. When to use N-Channel or P-Channel Enhancement mode MOSFETS

Assume there is a maximum available voltage, V_{max} , in a system and all loads such as motors, solenoids, heating elements, etc. need the maximum available voltage to operate. It is desired to turn off and on the load using the 68HC11. There are two options available. The first option is shown in Fig. 2.

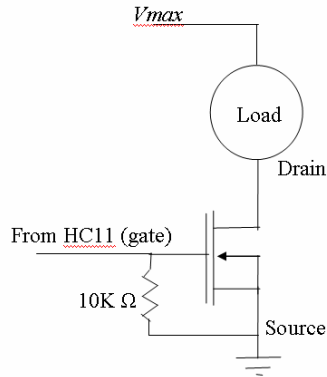


Fig2. Option 1 using a N-Channel “Logic Level” enhancement mode MOSFET

The following table explains the operation of option 1.

HC11 Signal	NChannel MOSFET state	LOAD
5V	ON	ON
0V	OFF	OFF

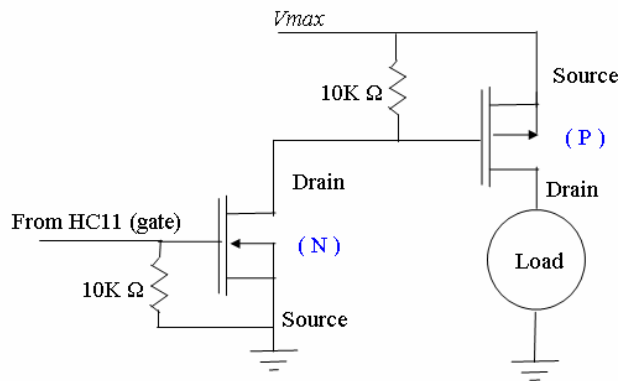


Fig3. Option 2 using a N-Channel and P-Channel “Logic Level” enhancement mode MOSFET

Two MOSFETs are used in the second option.

HC11 Signal	NChannel MOSFET state	PChannel MOSFET state	LOAD
5V	ON	ON	ON
0V	OFF	OFF	OFF

(Note: The N-Channel MOSFET can be omitted if Vmax is equal to 5V or less. The HC11 signal can be applied directly to the P-Channel Mosfet Gate.

HC11 Signal	PChannel MOSFET state	LOAD
5V	OFF	OFF
0V	ON	ON

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The difference between the two options is where the current into the load is controlled. The current is controlled between the load and ground in option 1. The current is controlled between V_{max} and load in option 2. The most efficient option is option 1 since it only requires one MOSFET and NChannel MOSFETs usually have a lower resistance when enabled. Option 1 is sometimes called a low side driver. Option 2 is called a high side driver.

A high side driver is only used when direction of current through a load needs to be switched. For example, the direction of current through a DC motor determines forwards and backwards rotation. A H-Bridge utilizing two high side driver circuits and two low side driver circuits are needed in order to control direction of current through a load.

5. Classic H-Bridge

The classic h-bridge circuit is shown in the following schematic.

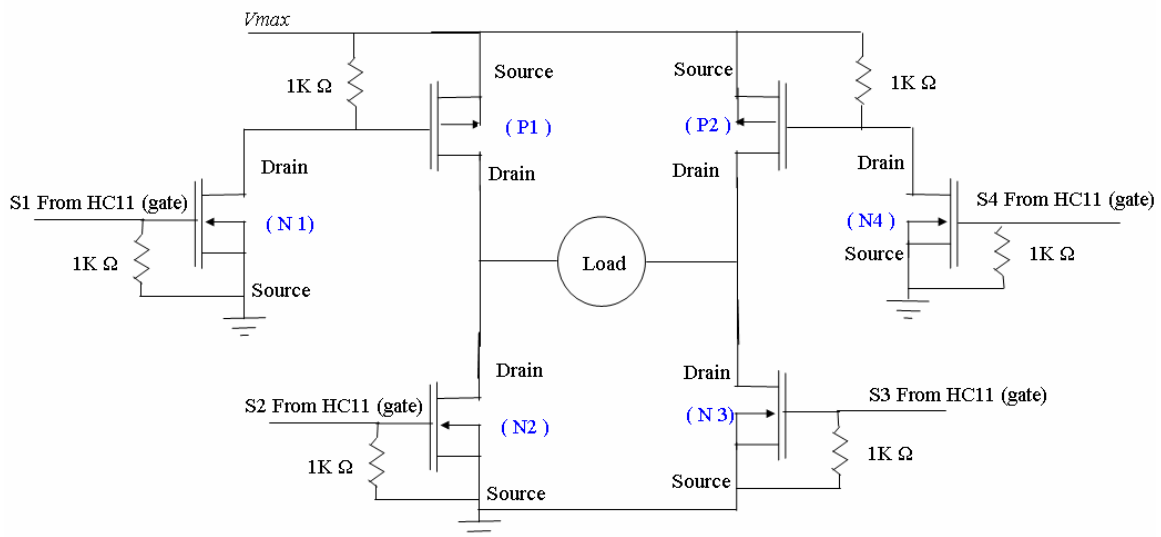


Fig 4. H-bridge using a N-Channel and P-Channel “Logic Level” enhancement mode MOSFET (Note: All MOSFETs are logic level. MOSFETs N1 and N4 can be omitted if $V_{max} = 5V$.)

The following table explains the operation of the H-Bridge.

HC11 Signals				NChannel MOSFETs				PChannel MOSFETs		Current Direction Through Load
S1	S2	S3	S4	N1	N2	N3	N4	P1	P2	
ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	Left to Right
OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	Right to Left

S1 can be pulse width modulated if power needs to be varied when the current is going left to right through the load. S4 can be pulse width modulated if power needs to be varied when the current is going right to left through the load. The h-bridge or power supply might self destruct if S1 and S2 or S3 and S4 are turned on at the same time since this will create a short between V_{max} and ground. This is commonly referred to as “shoot through” current.

The following is an example for calculating efficiency of the h-bridge. Assume R_{sdon} of P1 and P2 is 0.03Ω and N1,N2,N3, and N4 is 0.001Ω . Assume that V_{max} is 10 V and the Load resistance is 2Ω . The total resistance between V_{max} and ground when P1 and N3 are on is:

$$R_t = R_{sdon} \text{ of P1} + R_{sdon} \text{ of N3} + \text{Load resistance}$$

$$R_t = 0.03\Omega + 0.001\Omega + 2\Omega = 2.031\Omega$$

Total Amperage from Vmax to Ground:

$$I_t = V_{max} / R_t = 10V / 2.031\Omega = 4.9237 A$$

Total Power from Vmax to Ground:

$$\text{Power Total} = V_{max} * I_t = 10 V * 4.9237 A = 49.237 W$$

Power dissipated through P1:

$$\text{Power P1} = R_{sdon} \text{ of P1} * I_t * I_t = 0.03 \Omega * 4.9237 A * 4.9237 A = 0.7273 W$$

Power Dissipated through N3:

$$\text{Power N3} = R_{sdon} \text{ of P1} * I_t * I_t = 0.001 \Omega * 4.9237 A * 4.9237 A = 0.0242 W$$

Power used by Load:

$$\begin{aligned} \text{Power Load} &= \text{Power Total} - \text{Power P1} - \text{Power N3} \\ \text{Power Load} &= 49.237 W - 0.7273 W - 0.0242 W = 48.237 W \end{aligned}$$

Efficiency of h-bridge:

$$\begin{aligned} \eta &= 100 * \text{Power Load} / \text{Power Total} \\ \eta &= 100 * 48.237 W / 49.237 W = 98.47 \% \end{aligned}$$

There are two things that determine the efficiency of the h-bridge. The resistance of the load and R_{sdon} of the MOSFETs. The efficiency of the h-bridge in the above example will drop to 96.99 % if the resistance of the load is 1 Ω . The efficiency of the h-bridge will increase to 99.9 % if R_{sdon} of the PChannel MOSFET was reduced to the R_{sdon} of the NChannel MOSFET.

P1 and P2 can be replaced with NChannel MOSFETs only if there is a voltage available greater than $V_{max} + 5V$ as shown in the following circuit.

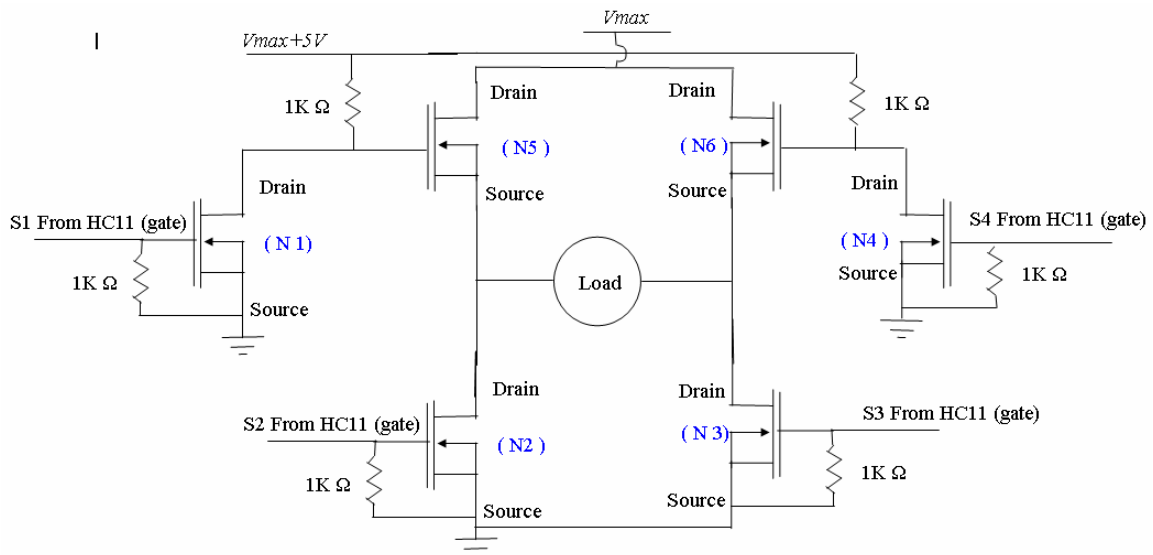


Fig 5. H-Bridge using N-Channel “Logic Level” enhancement mode MOSFET
(Note: All MOSFETs are logic level.)

A charge pump can be used to create $V_{max}+5V$ if not available. A NChannel h-bridge can also be created using a HIP 4081A h-bridge driver chip from Intersil Technologies (<http://www.intersil.com>) if V_{max} is between 10 V and 80V. The following schematic is a modified schematic from the HIP4081 datasheet.

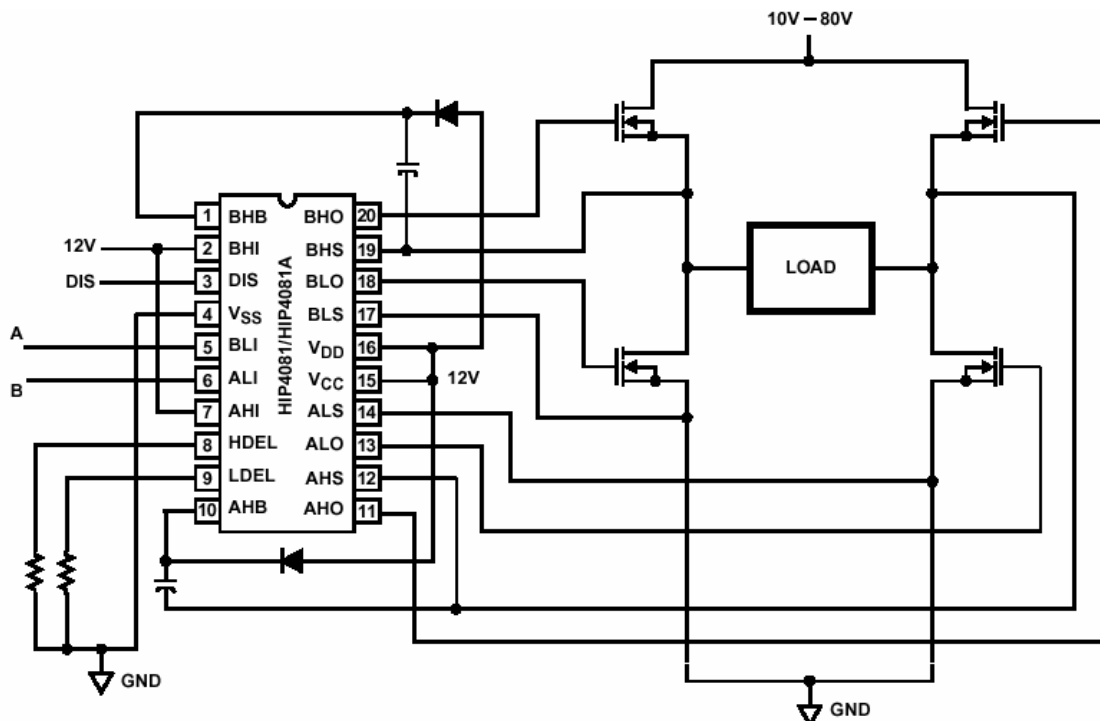


Fig 5. H-Bridge using N-Channel MOSFETs and HIP4081A driver

(Note: Capacitors should be 10 times the capacitance between MOSFETs gate and source. The Capacitors should be rated for a voltage greater than V_{max} .)

Current will go through the load from left to right if pin 6 (ALI) is high. Current will go through the load from right to left if pin 5 (BLI) is high. Both pin 5 and 6 can be pulse width modulated to control current going through the load.

6. Conclusion

A student should be able to design actuator driver circuits using MOSFETs after reading this fact sheet. Basic MOSFET terminology and usage was covered. The most complicated actuator driver circuit commonly used for forward/reverse control of DC motors was introduced.

7. Tips

1. Always try to get the MOSFETs with the lowest $R_{s_{don}}$ to drive high power loads.
2. Make sure you can never “shoot through” current through an H-Bridge
3. Put a heat sink on a MOSFET if it is dissipating more than 0.25 W