MOSFET-based Motor Controller

Yang, Zhijie & Du, Jia

1. Design Requirements

We built a PWM generation circuit and the controlling circuit with basic electric elements, which is capable of adjusting the duty cycle conveniently. The controlling circuit is able to speed up, speed down or break the DC motor by keys. We also added the forward-reverse driving function for the motor controller.

2. Circuit Diagram

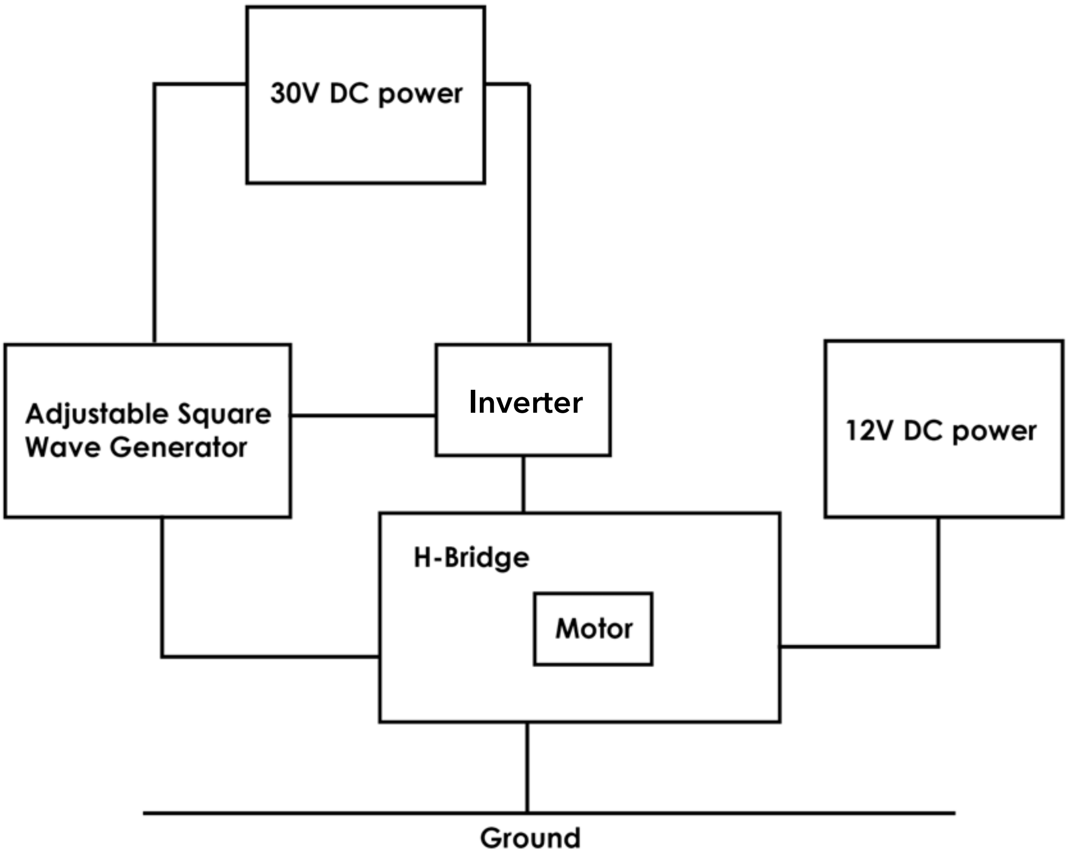


Figure Credit by Du, Jia

3. Simulation

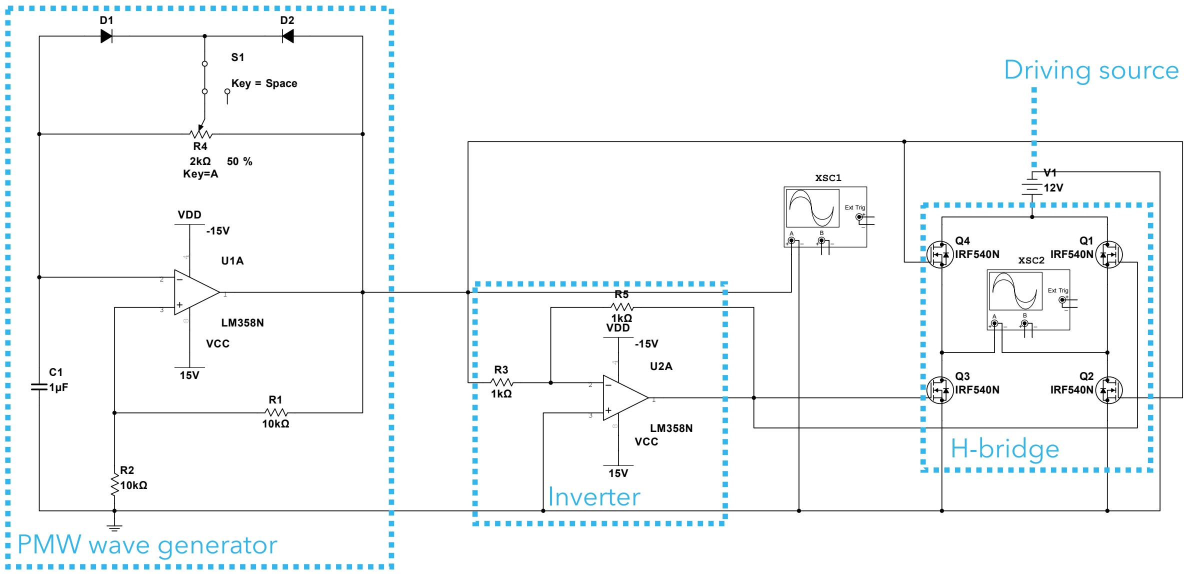


Figure Credit by Du, Jia & Yang, Zhijie

(1) PMW Wave Generator

In the circuit above, the PMW wave generator is composed by 2 diodes, a high voltage bearable operational amplifier (op amp), 3 resistors, 1 capacitor and a switch. When the switch is open, there is no current flow through the diodes, the resistances of both charging and discharging circuits are the same (2kΩ), which makes the duty cycle of the PMW wave maintain at 50%. To determine what capacitor and resistors we need to use, we calculated the function of the cycle with respect to the capacitor and resistors.

$$v_{-\,\min} = \frac{-V_{CC}R_2}{R_1 + R_2}$$

$$v_c = -V_{CC} + \left(\frac{R_2}{R_1 + R_2} + 1\right) V_{CC} e^{-t/(R_4 C)}$$

Let $v_c < v_{-\,\min}$

$$T_1 = R_4 C_1 \ln\left(1 + \frac{2R_2}{R_1}\right)$$

Where $T_1 = \frac{1}{2}T$

The duty cycle of the PMW is 50%

$\Rightarrow$ With $T = 2T_1 = 2 \cdot R_4 C_1 \ln\left(1 + \frac{2R_2}{R_1}\right)$

If we close the switch, the potentialmeter works as a adjustor that adjust the resistance in both the charging and discharging circuits. For example, if we set the potentiometer at a certain level that the the resistance in the charging circuit is twice as the resistance in the discharging circuit, the time it takes to charge the capacitor will also be twice as the time it takes to discharge, which makes the duty cycle becomes 66.67%.

(2) Inverter

The inverter is composed of an op amp with 2 resistors. The inventer has two effects. First, the inverter guarantees the motor has the ability to be driven reversely. Secondly, it can apply negative voltages on two MOSFETs when the other two MOSFETs are in "on" state since MOSFETs might leak and may cause short cut unless we apply a negative value voltage onto its gate. So the inverter is also protecting the H-bridge from short circuit.

(3) H-bridge

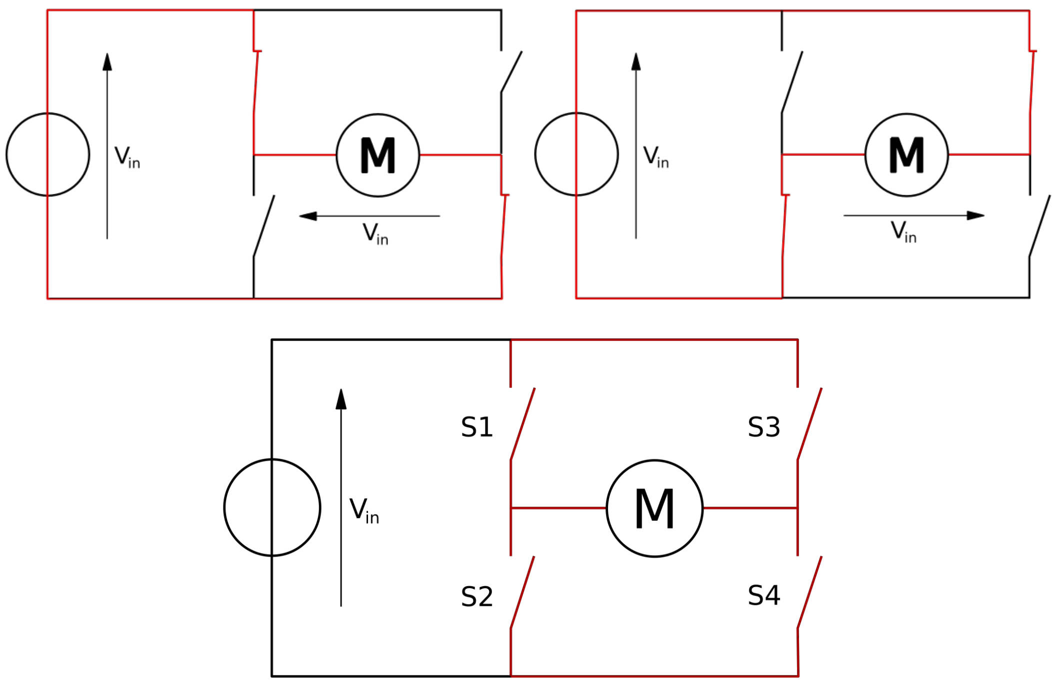


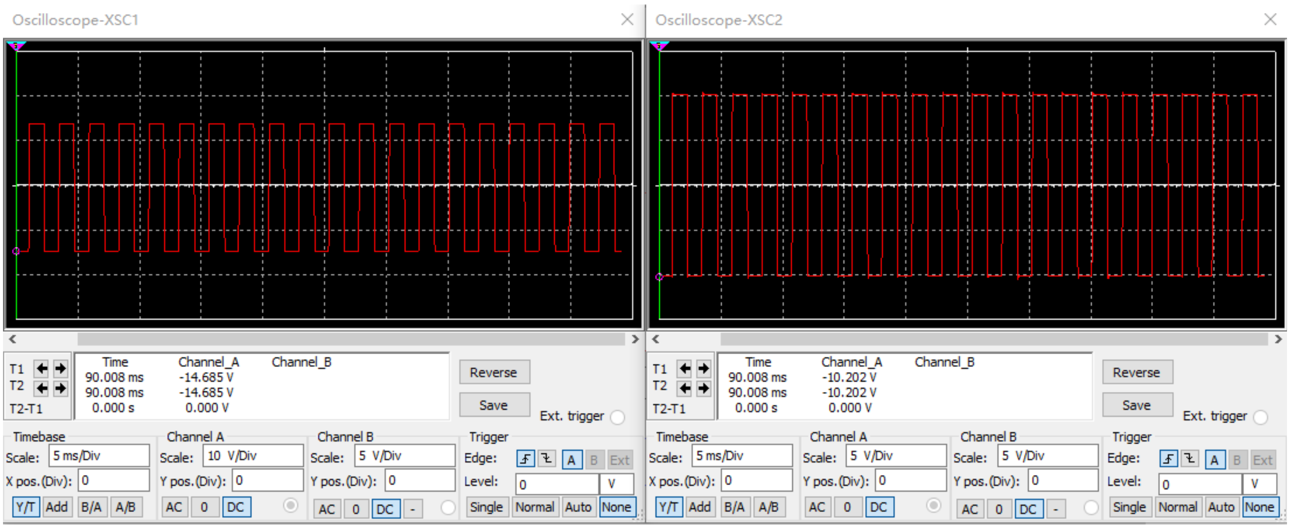
Figure Source: Wikipedia

Note: The oscilloscope surrounded by 4 *IRF540N*'s is to measure the wave delivered to the motor. The other oscilloscope is to examine the wave generated by the PWM generator.

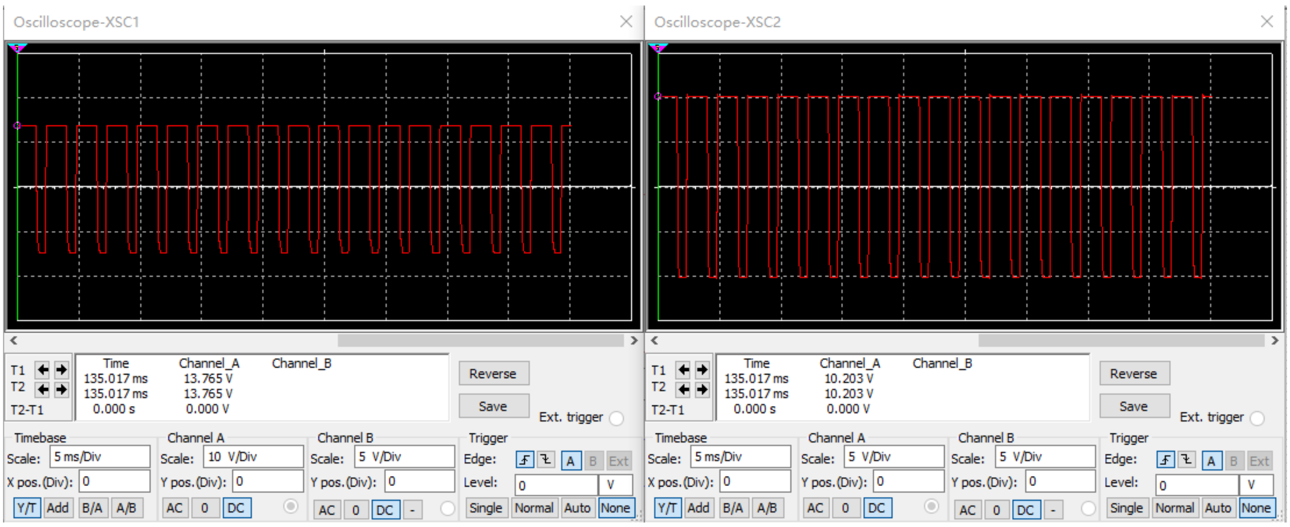
The minimum duty cycle we achieved is **2.0%**, and the maximum is **98.0%**. (According to the accuracy of the oscilloscope, we can only keep 1 decimal.)

The simulation result is attached on the next page.

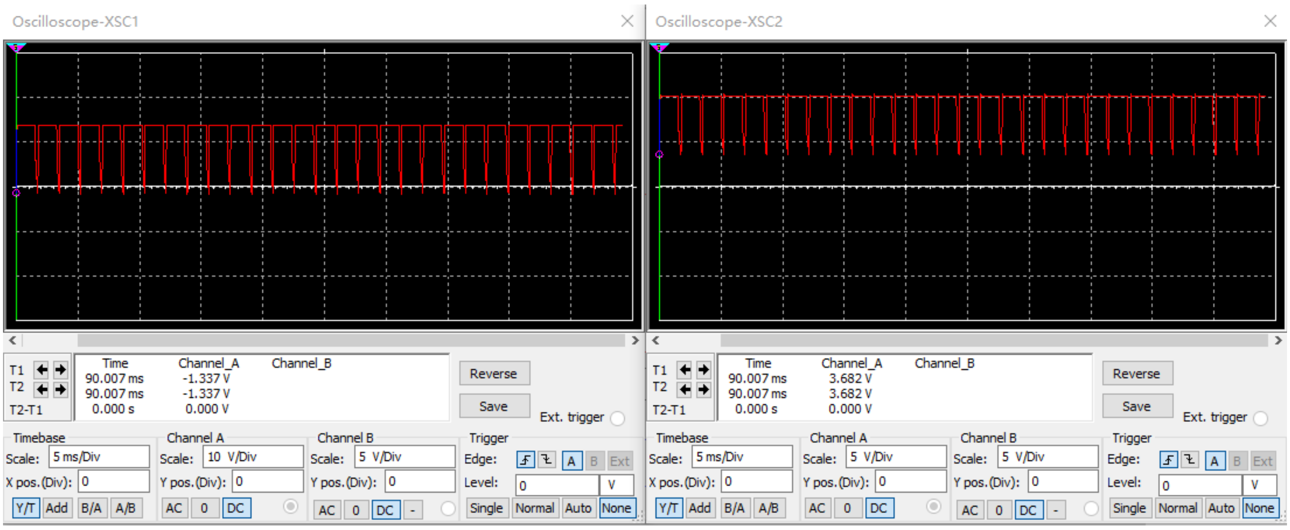
Simulation result:



Duty Cycle 50%

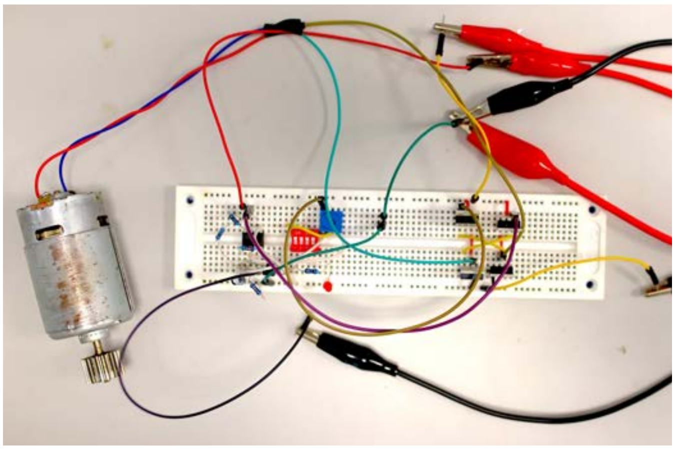


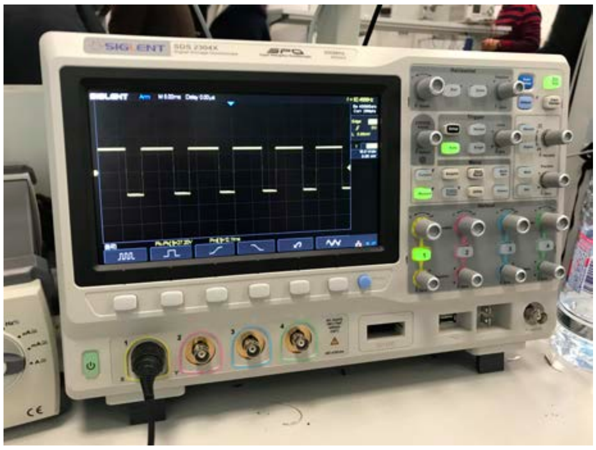
Duty Cycle 70%



Duty Cycle 98% (Maximum)

4. Actual Circuit with Comments





We used the oscilloscope to measure the wave at the output pin of the PMW generating op amp. The oscilloscope is showing an arbitrary duty cycle.

Components we actually used:

Component	Model(s)			Quantities	Cost
Resistor	1kΩ	10kΩ	10kΩ potentiometer	2+3+1=6	¥0.23
Amp op	LM358N (Texas Instruments)			1 (2 in 1 chip)	0 (Free)
MOSFET	IRF540N			4	¥4.60
Switch	DIF-8 switch			1	¥0.29
Diode	HER107		Red LED	2+1=3	¥0.11
Motor	550 Motor			1	¥9.90
Cable	/			Several	≈0
Subtotal:	/			/	¥15.13

Additional Works:

(1) Emergency Break

The PWM generator works normally with the switch closed, which enables manual control of the duty cycle. When brake is needed, we open the switch, so the duty cycle is forced to be 50%, which brakes the motor.

(2) Forward-Reverse Rotation

Since H-bridge is able to drive the motor forward and reversely, we can easily have the motor rotate in either direction by simply adjust the duty cycle. When the duty cycle is greater than 50%, the motor rotates forward, and when the duty cycle is less then 50%, it rotates reversely.

(3) Driving State Indicator

We built our circuit as the simulation diagram at first. Amazingly, were inspired of an idea after we have completed the circuit building. We added an LED to indicate the driving state of the motor——dim as the motor rotates at full speed reverse, slightly lit as the motor stops, and shines brightly as the motor rotates at full speed forward. The brightness is corresponding to the voltage at the point where the two diode connect, which changes continuously and smoothly .

5. Remarkable Features

All the components we used are basic elements in electric circuits.
We used the op amp to generate PMW wave with $V_{pp} = 30V$. We also replaced the BJTs with MOSFETs for better stability and better robust.
By adding the inverter in cascade to the PMW generator, there is no need to add a dead zone which prevents shorts when switching duty cycle in a short time, since the inverter can almost perfectly invert the electric level under any circumstances with almost absolutely no delay.

6. Acknowledgement

Thanks our TA Zhu, Jinghao for helping us build the circuit and pointing out critical mistakes we've made in the simulation that caused the circuit's not converge. We also need to thank Texas Instruments for providing us with free op amp sample chips.

7. References

[1] Foundations of Analog and Digital Electric Circuits. Anant Agarwal and Jeffrey H. Lang. Chapter 15.8.1
[2] Wikipedia H bridge
[3] ShanghaiTech Electric Circuits Fall2017 Laboratory 7

8. Supplementary Materials

Display video:

(1) The initial prototype:
http://pan.shanghaitech.edu.cn/cloudservice/outerLink/decode?c3Vnb24xNTE1OTE4MTU0NTgxc3Vnb24=

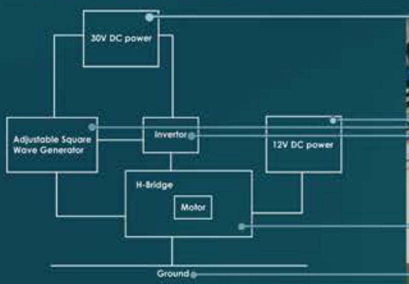
(2) Display prototype (added driving indicator):
http://pan.shanghaitech.edu.cn/cloudservice/outerLink/decode?c3Vnb24xNTE1OTE4MTk3MzAyc3Vnb24=

Poster *(Attached on next page)*

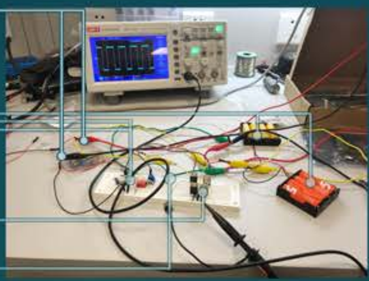
Motor Controller

ShanghaiTech Uniersity Fall 2017 EE111 Course Project

Block Schematic



Demostration



Components

Resistor: 1kΩ, 10kΩ, 10kΩ potentiometer

Amp op: LM358N (Texas Instruments)

MOSFET: IRF540N

Switch: DIP-8 switch

Diode: HER107

Necessary cables are used.

Main Features

Features **high voltage** and high current bearable **MOSFET**!

Uses only **N-MOS**, easy to repair!

High voltage bearable Op-Amp

—— less probability to get damaged!

No need for extra function generator!

Duty cycle and motor speed **fully adjustable**!

No gap forward/reverse switch!

Emergency brake available!

Fully **programmable**! (Requires programmable MCUs.)

Open source!

Acknowledgement

TA Zhu, Jinghao for directing us in doing this project.

Texas Instruments for providing us five LM358N sample chips for free.

The goal of our project is to drive a DC motor without using a function generator, and also realize the brake function.

First, we decided to use PWM (Pulse Width Modulation) to control the motor. A function generator is usually used to generate square wave with adjustable duty cycle to control the speed. However, in this project, we used an Op amp to generate adjustable square wave, which only requires pure DC power input.

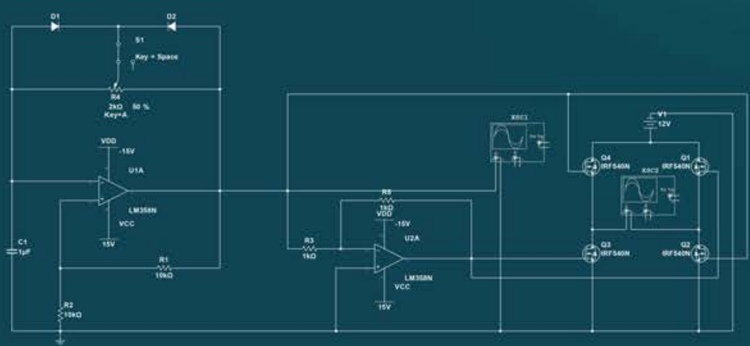
To accomplish our plan, we selected LM358N, which has 36V maximum input voltage, and also 4 high-speed MOSFETs—IRF540N to build the H-bridge. The reason why we chose LM358N is that the MOSFETs require relatively high voltage ($2\ V \le VGS \le 4V$) to drive. If we chose an Op amp like LMC6482, its output voltage is too low to drive the MOSFETs.

We also put a switch on the charging/discharging circuit of the capacitor to be the emergency brake activator. When the switch is closed, the duty cycle is controlled by the variable resistor; when the switch is open, the duty cycle is forced to be 50%, which brakes the motor.

(2) Simulation

During our simulation, we also found that using Op amps to simultaneously generate the wave function and its inverse leads to almost no possibility to shortcut the H-bridge. Hence, we dismissed the necessity of adding dead zones (inserting an interval in PWM signal to avoid shortcut at flipping).

15V V_{cc} and -15V V_{dd} are supplied to the Op amps and 12V DC is supplied to the H-bridge. Since the minimum V_{GS} is 2V, the 15V voltage applied to the H-bridge should be sufficient to drive the high level MOSFETs.



Even shows on the university's promotion!

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