ECED3901 Design Methods II

LECTURE #4: DC MOTOR DRIVING

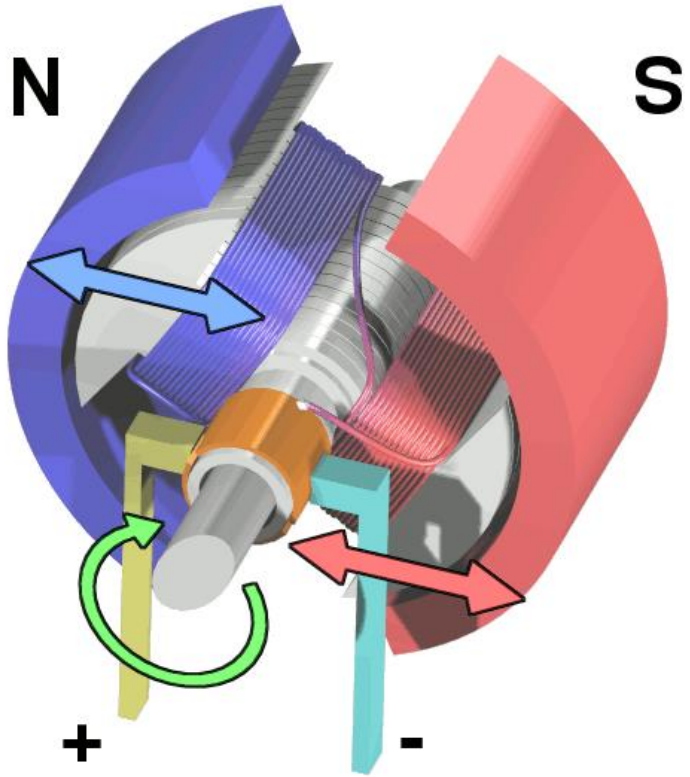
Colin O'Flynn

What are we covering?

- DC Motors
  - Brushed
  - Brushless
- Driving Motors
  - Simple (On-Off)
    - Faraday's Law in real life
    - Snubbing / Diode Circuits
    - EMC Capacitor
  - Half-Bridge
  - Full-Bridge
- Transistors as Switches
  - Bipolar
  - MOSFET
- Driving transistors as switches

DC Motor Types

Motor Types: Brushed



Source: http://commons.wikimedia.org/wiki/File:Electric_motor_cycle_1.png

How DC Motors Work

Note: to avoid trying to draw complex diagrams, I'm instead going to refer you to this YouTube video for basics of the DC motor: https://www.youtube.com/watch?v=LAtPHANEfQo

If you view the video version of this lecture the video will be missing, but instead see the youtube video. Note we are only dealing with permanent motor stators (i.e. up to 2:50 in the video).

Steady-State Operation

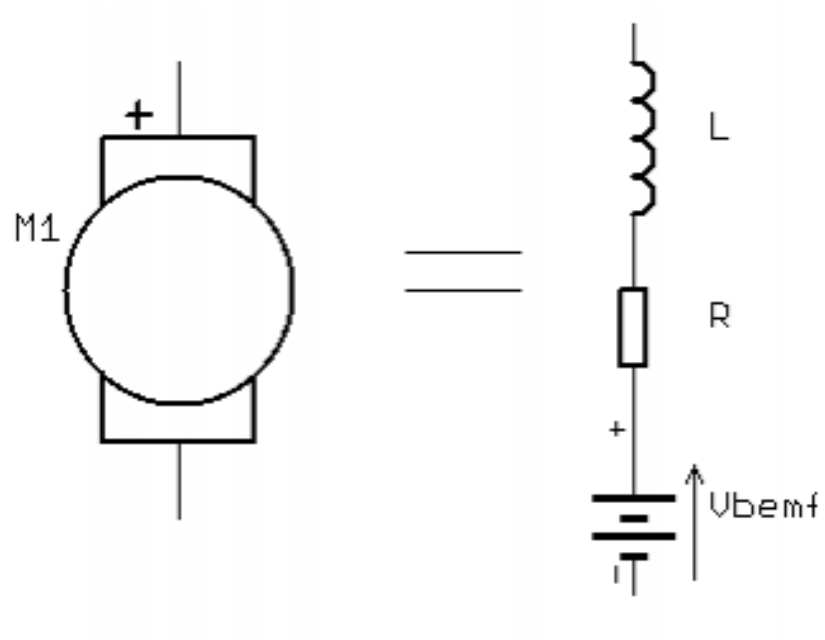
$$V_M = K_\omega \omega + I_a R. \tag{4.1}$$

In this equation,

$$\begin{aligned} V_M &= \text{the applied motor voltage} \\ K_\omega &= \text{motor speed constant (volts per radians/sec)} \\ \omega &= \text{angular speed of the motor (radians/sec)} \\ I_a &= \text{armature current (this is the motor current)} \\ R &= \text{motor resistance (armature resistance + commutator resistance.} \end{aligned} \tag{4.2}$$

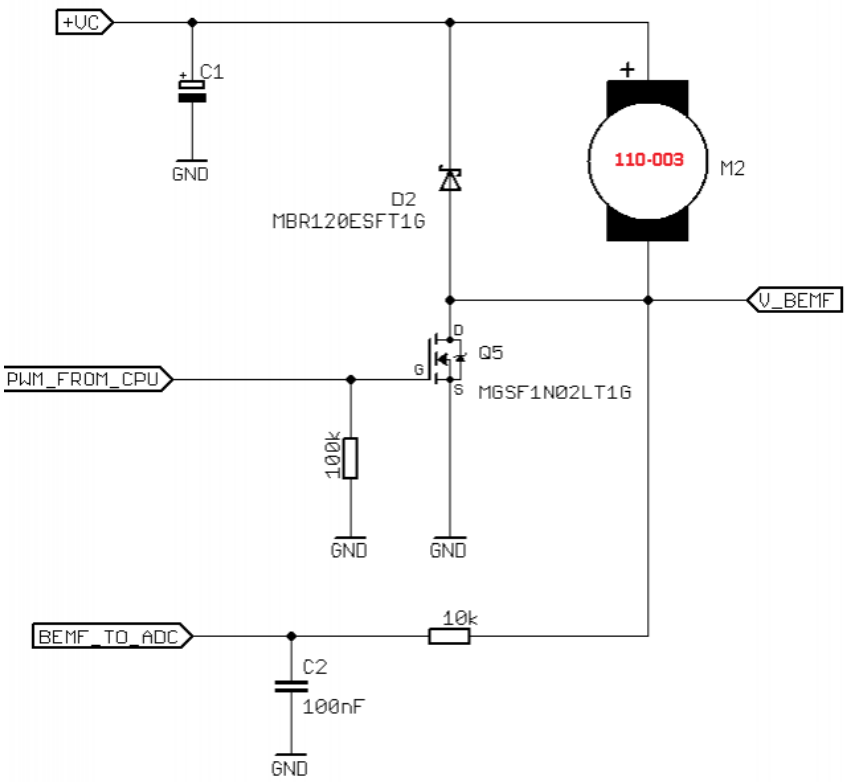
Source: Dr. Gregson's Design Methods II ECED 3901 Manual, 2005.

Back-EMF Measurement



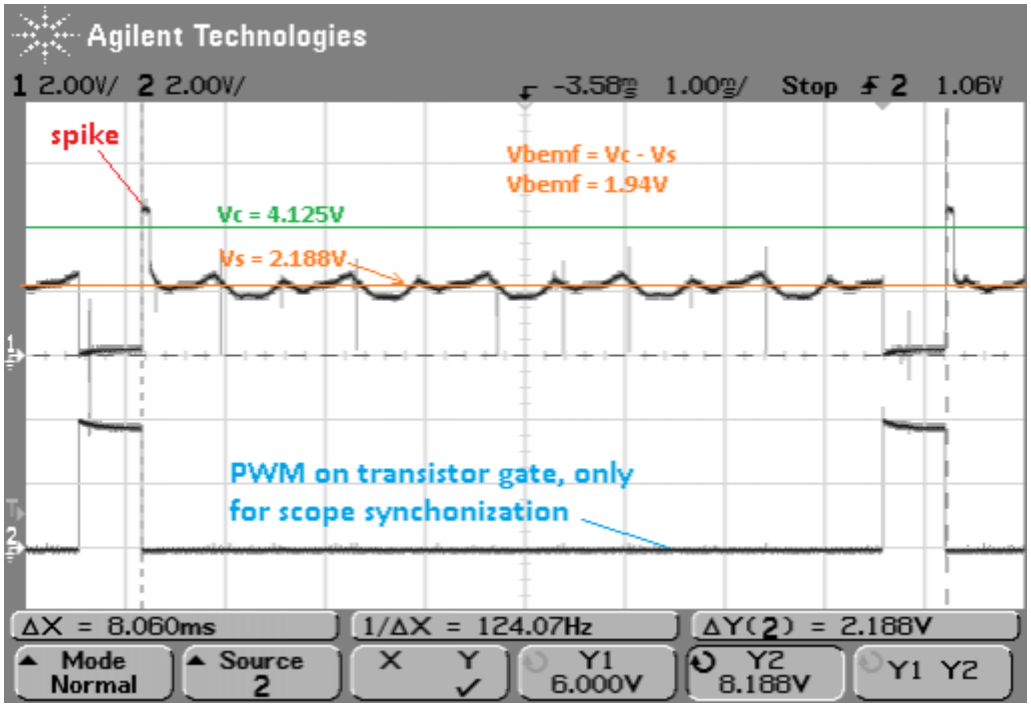
Source: http://www.precisionmicrodrives.com/application-notes-technical-guides/application-bulletins/ab-021-measuring-rpm-from-back-emf

Back-EMF Measurement



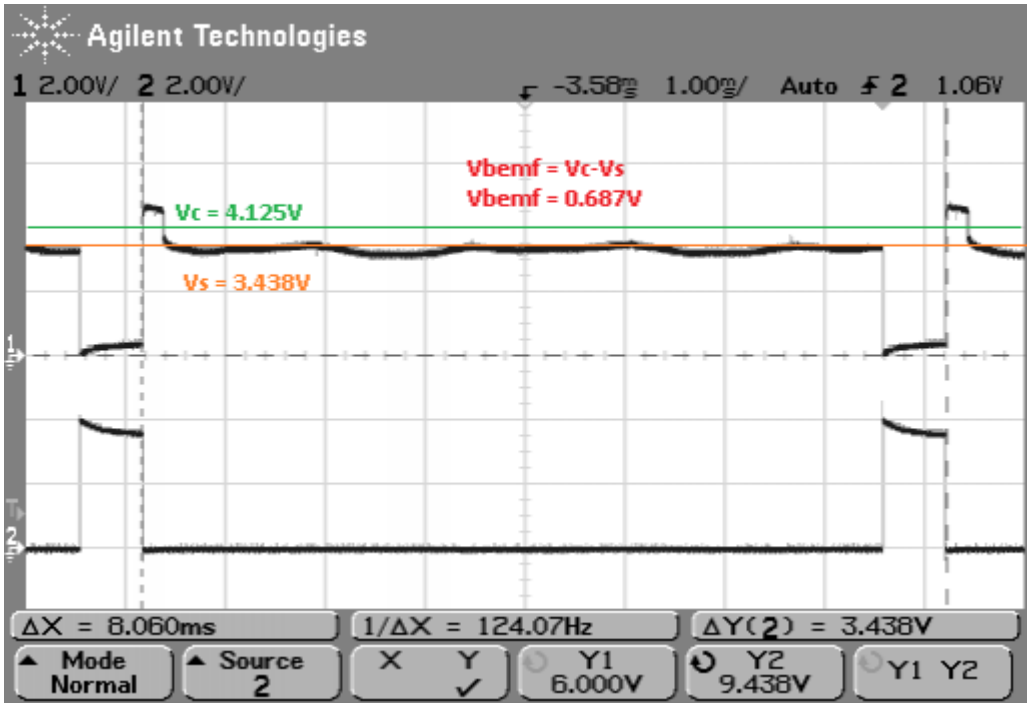
Source: http://www.precisionmicrodrives.com/application-notes-technical-guides/application-bulletins/ab-021-measuring-rpm-from-back-emf

Back-EMF



Source: http://www.precisionmicrodrives.com/application-notes-technical-guides/application-bulletins/ab-021-measuring-rpm-from-back-emf

Back-EMF



Source: http://www.precisionmicrodrives.com/application-notes-technical-guides/application-bulletins/ab-021-measuring-rpm-from-back-emf

Motor Inductance

$$V = L\frac{di}{dt}$$

Motor Inductance

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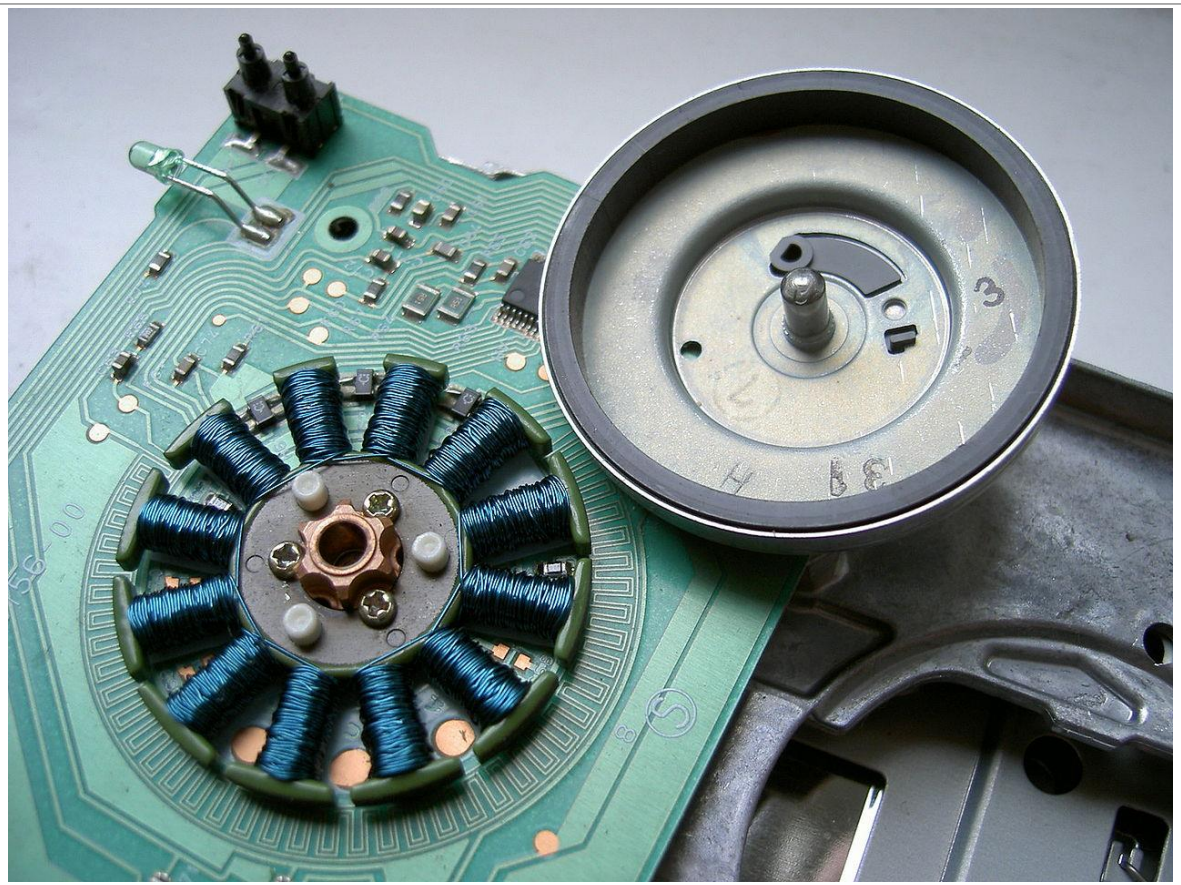
Additional Motor Dynamics

See Dr. Gregson's ECED3901 Manual for information on additional motor dynamics. Due to lecture timing this material is omitted from these lectures.

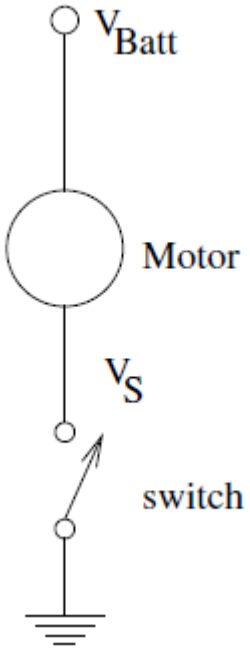
Motor Types: Brushless



Source: http://en.wikipedia.org/wiki/Brushless_DC_electric_motor#/media/File:Floppy_drive_spindle_motor_open.jpg

Driving DC Motors

Driving a motor… easy!



Source: Dr. Gregson's Design Methods II ECED 3901 Manual, 2005.

Example Circuit

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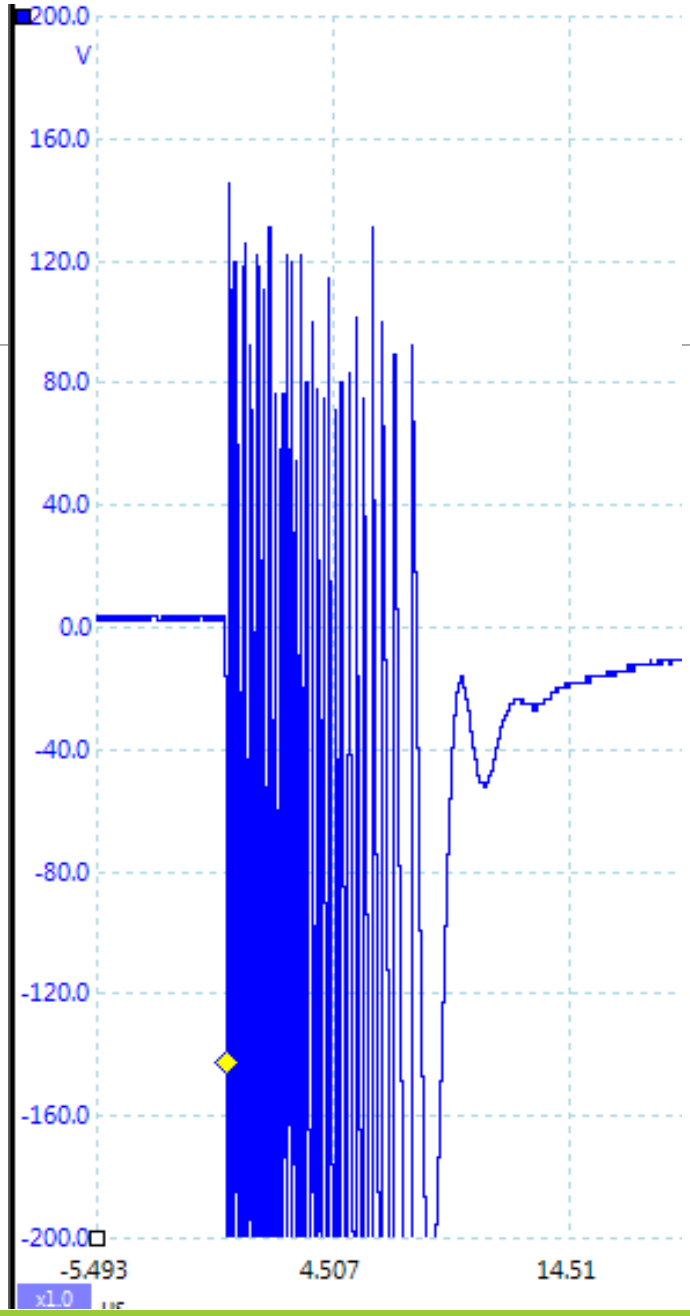

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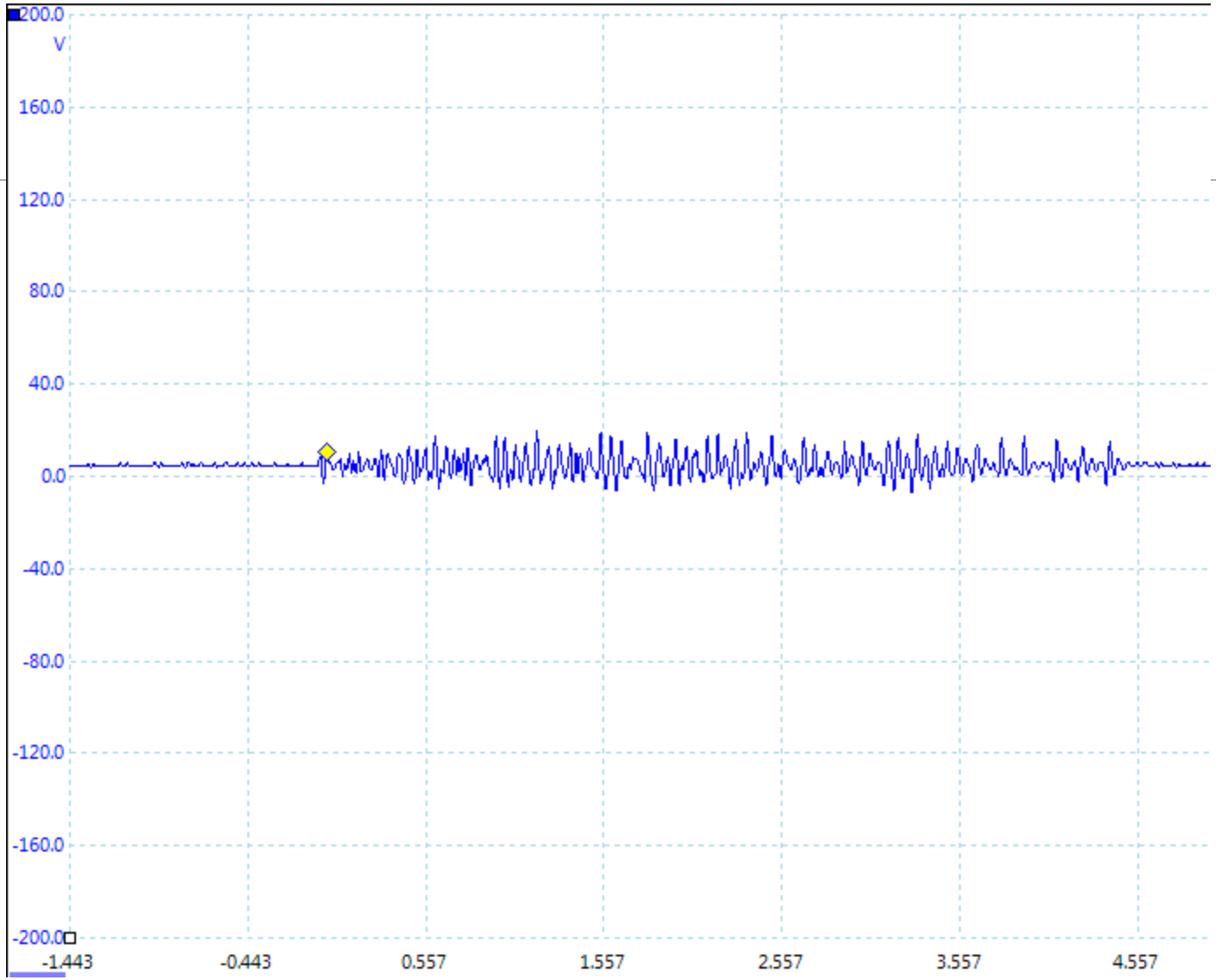
Adding a Diode



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Capacitor for Noise Suppression

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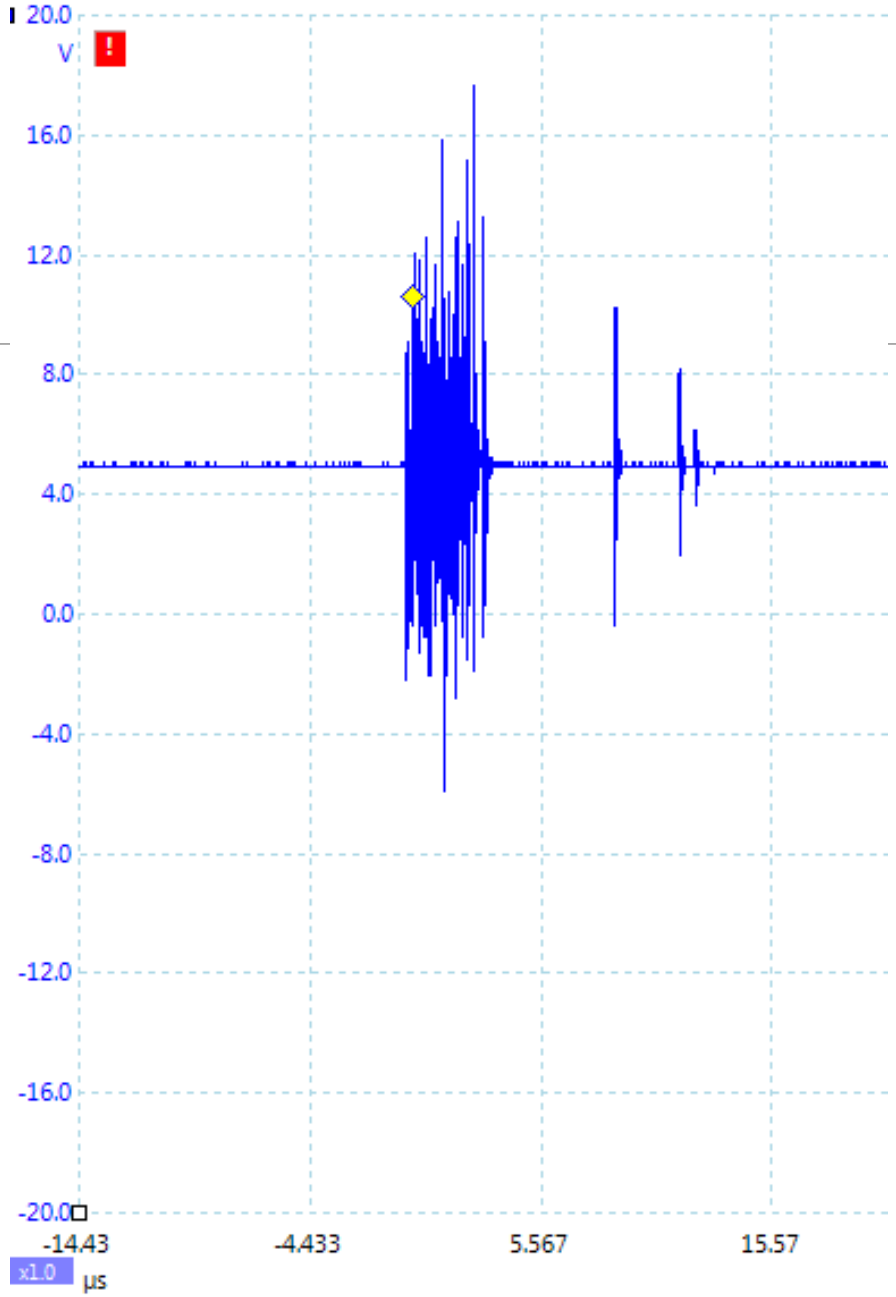

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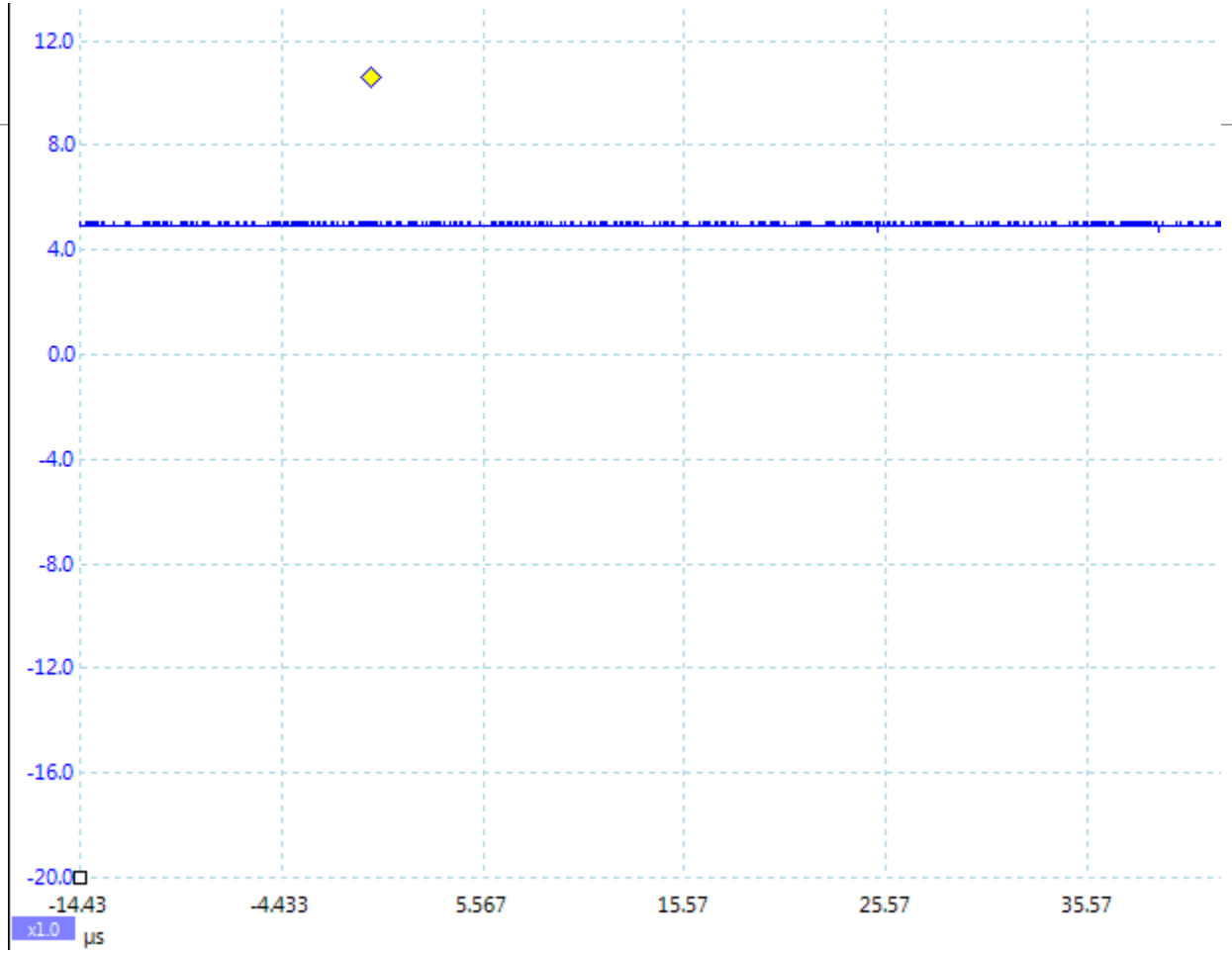
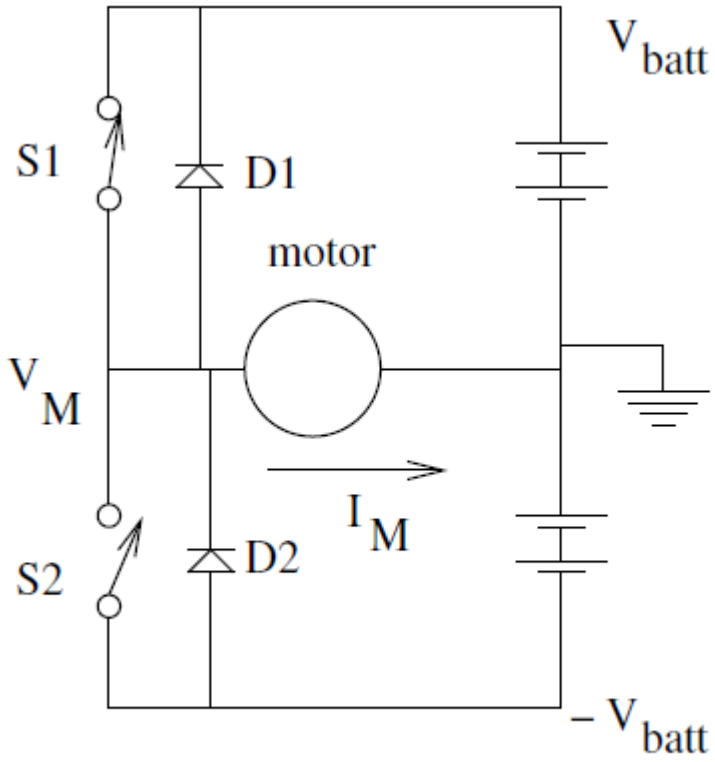
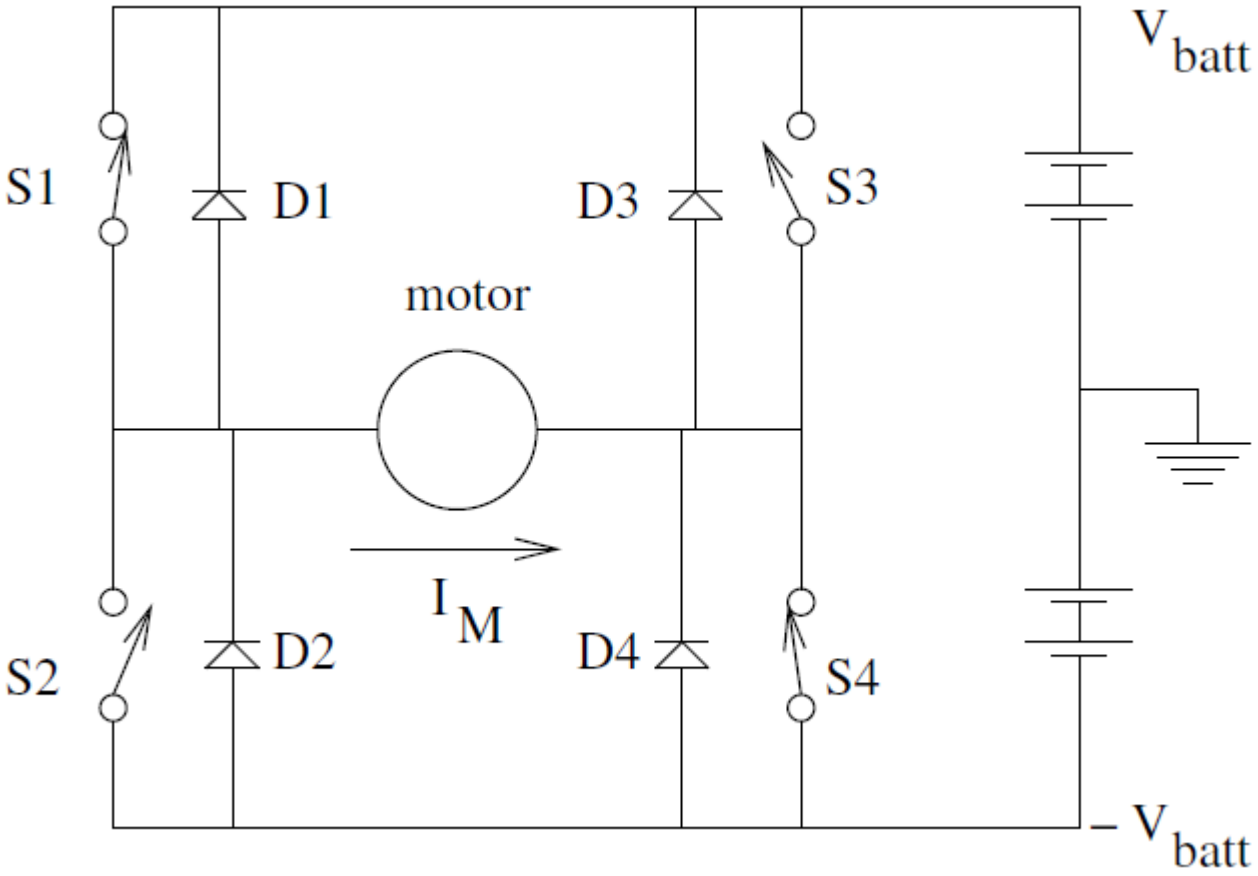

12.0
8.0
4.0
0.0
-4.0
-8.0
-12.0
-16.0
-20.0
-14.43
-4.433
5.567
15.57
25.57
35.57
x1.0
µs

Half-Bridge



a

Full-Bridge



Motor Brake

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A long use of braking…

Dynamic Braking resistor from train

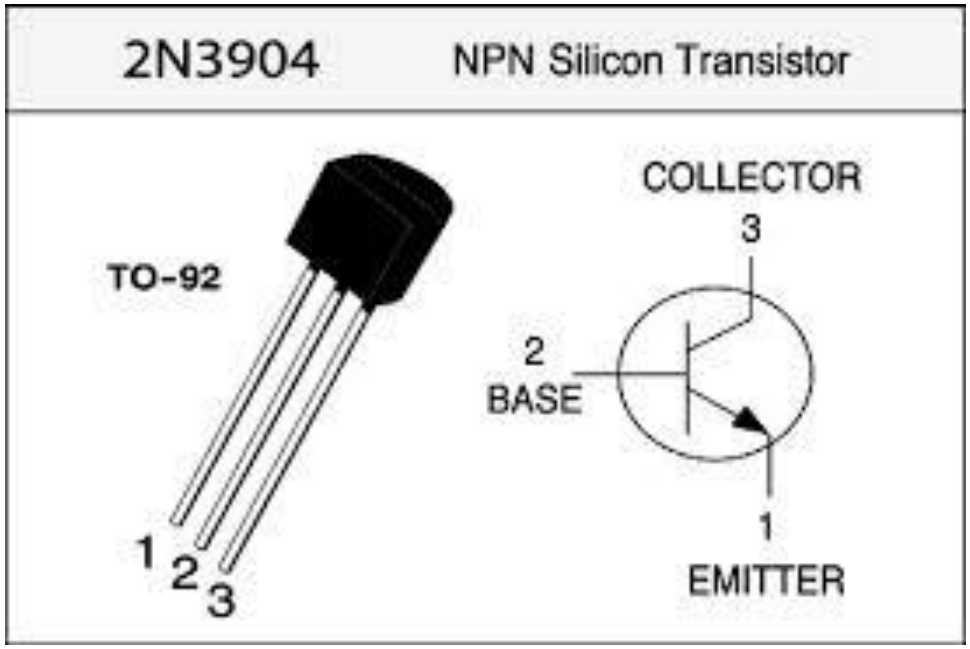
Source: http://www.resistorguide.com/braking-resistor/

Regenerative Braking on Tesla

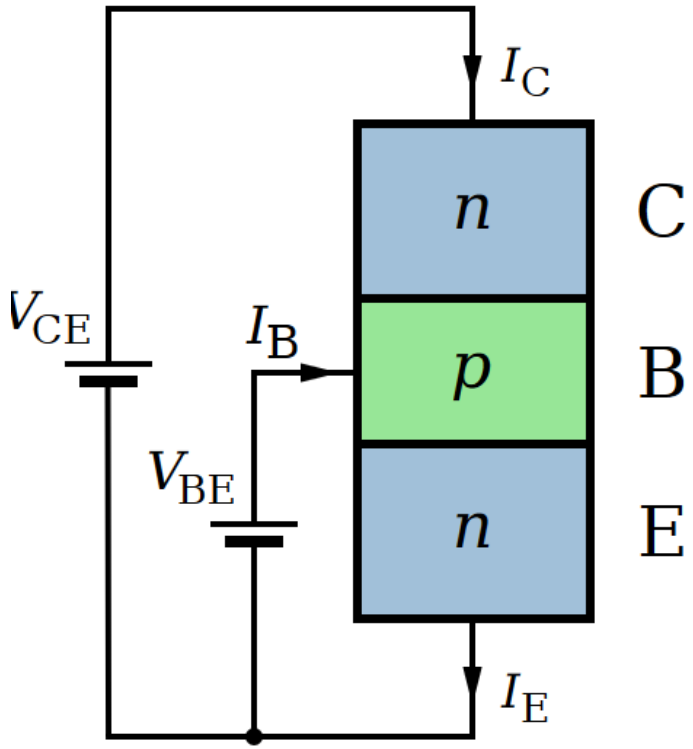
Source: http://upload.wikimedia.org/wikipedia/commons/5/5c/Tesla_Model_S_P85%2B_60_kW_Regenerative_Braking_%28cropped%29.jpg

Transistors as Switches

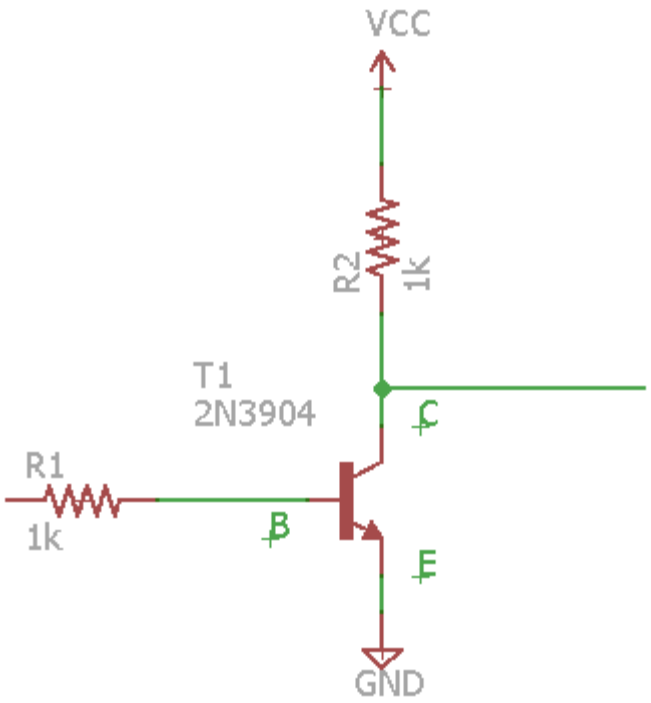
NPN Transistor Operation



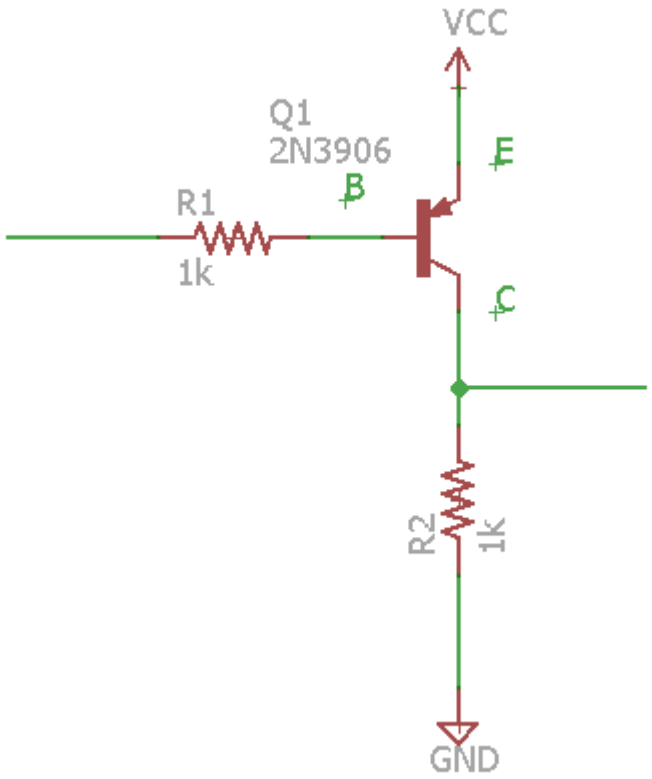
Current Amplifier



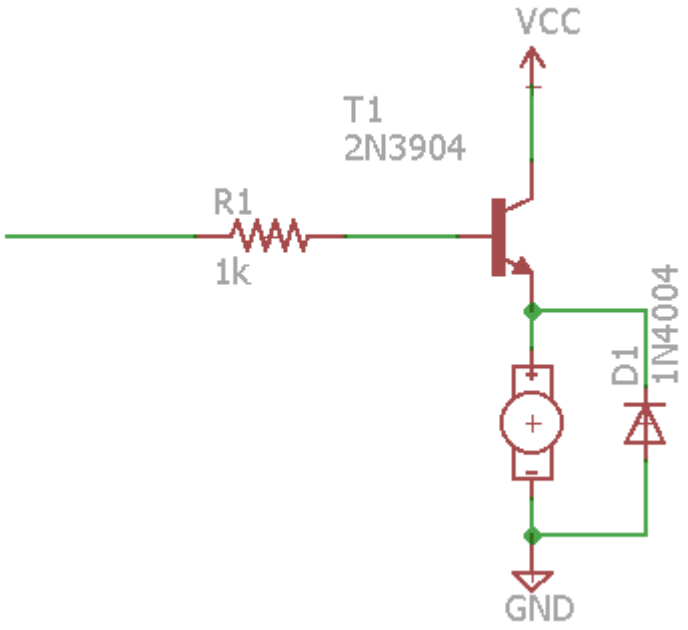
NPN Transistor Switch



PNP Transistor Switch



Example: On/Off Control



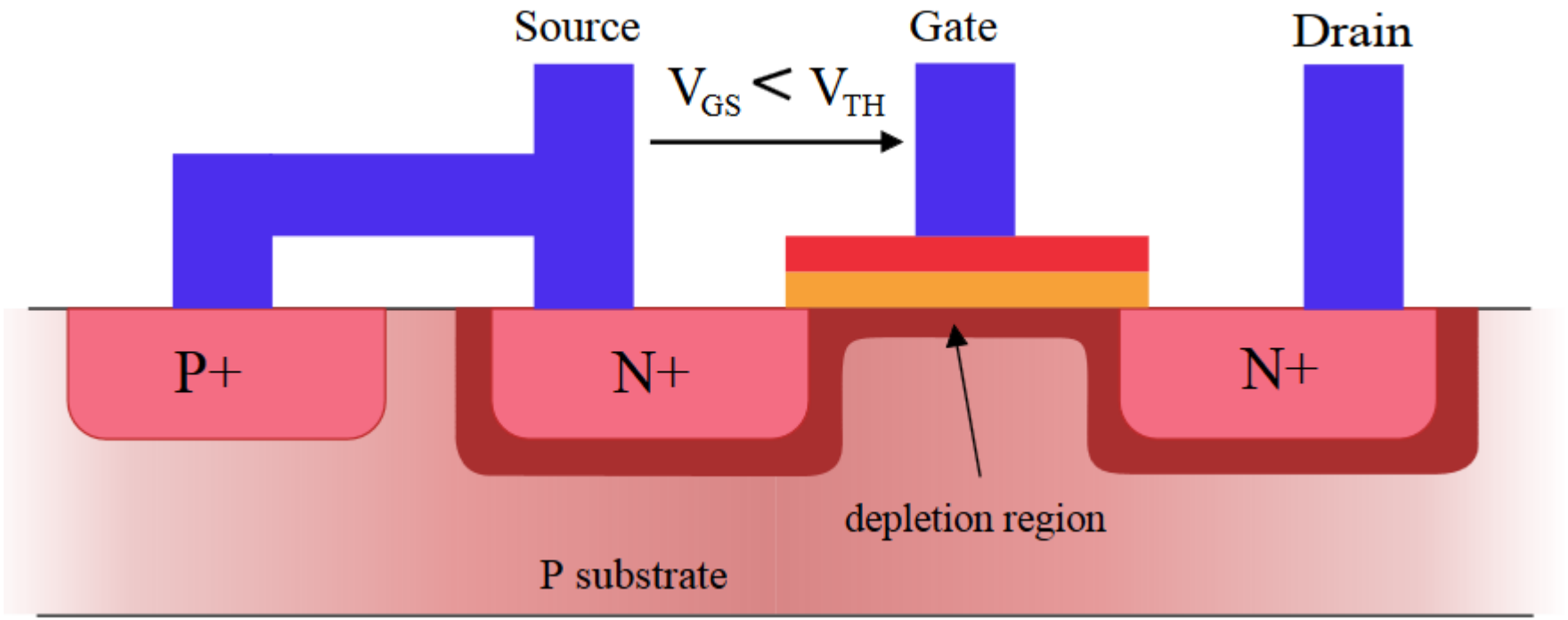
…need more power

Absolute Maximum Ratings* T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

MOSFETs

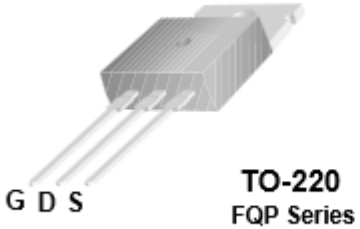


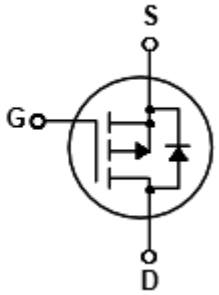
Quick Comparison

Characteristic	MOSFET	Bipolar
Drive Voltage	Medium (1.8V-10V)	Low (< 1V)
Gate current	Low	Medium
Gate charge	Medium	Low
Static Sensitive	Yes	No
Gain vs Temp	Negative	Positive

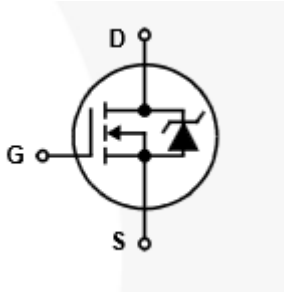
MOSFET Types

P-Channel

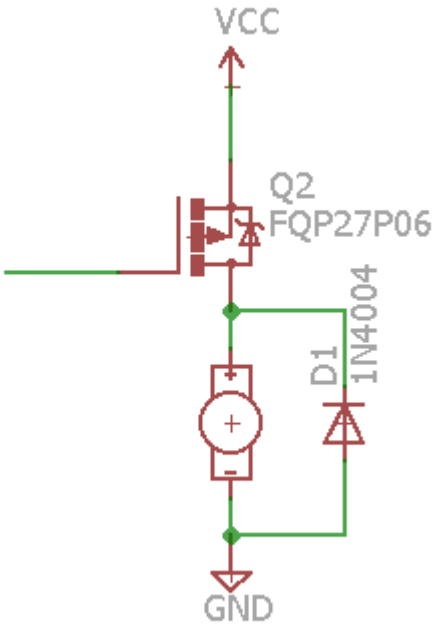




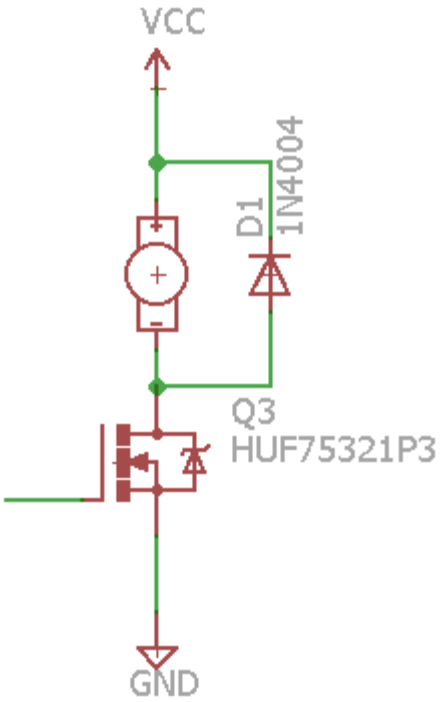
N-Channel



P-Channel as Switch



N-Channel as Switch



Note on Gate Capacitance

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MOSFET Characteristics

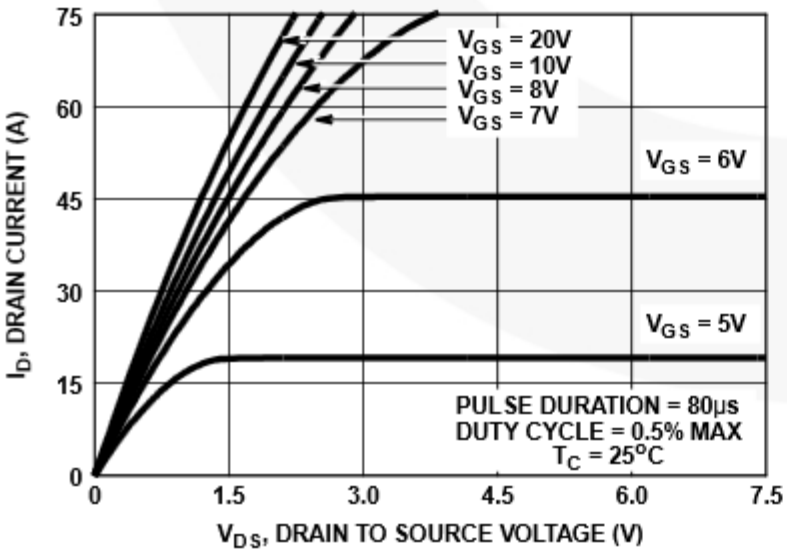


FIGURE 7. SATURATION CHARACTERISTICS

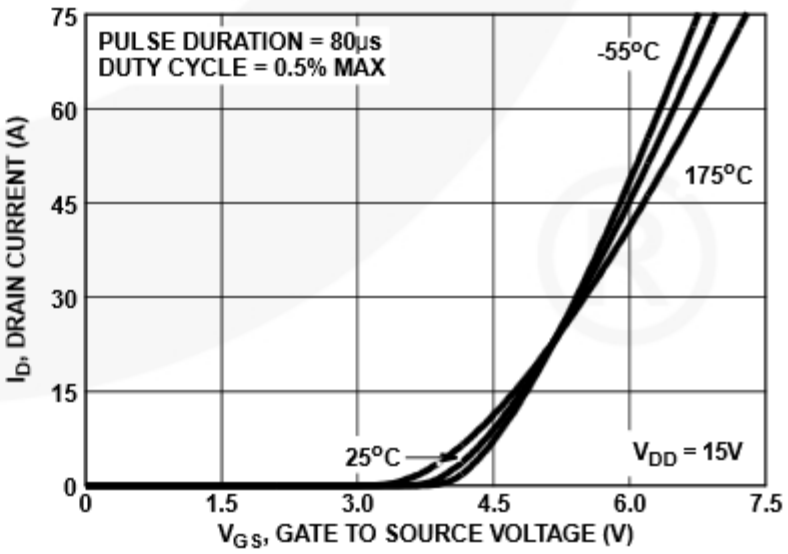
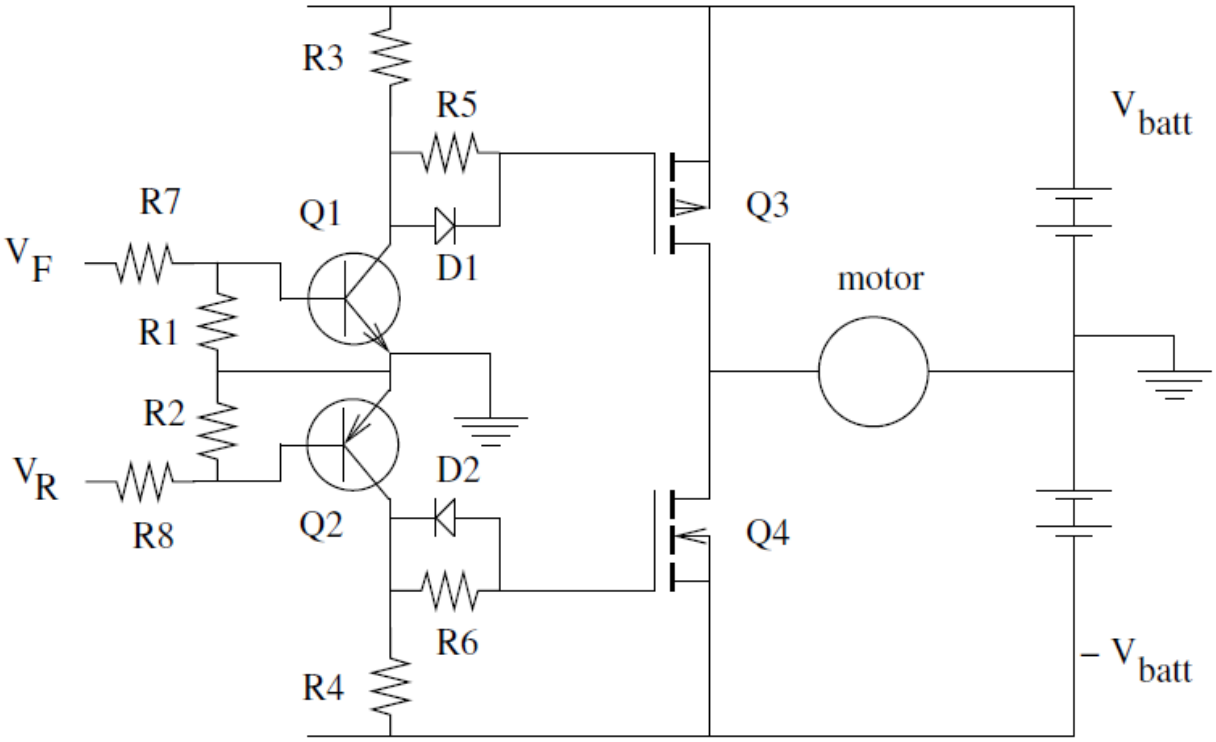
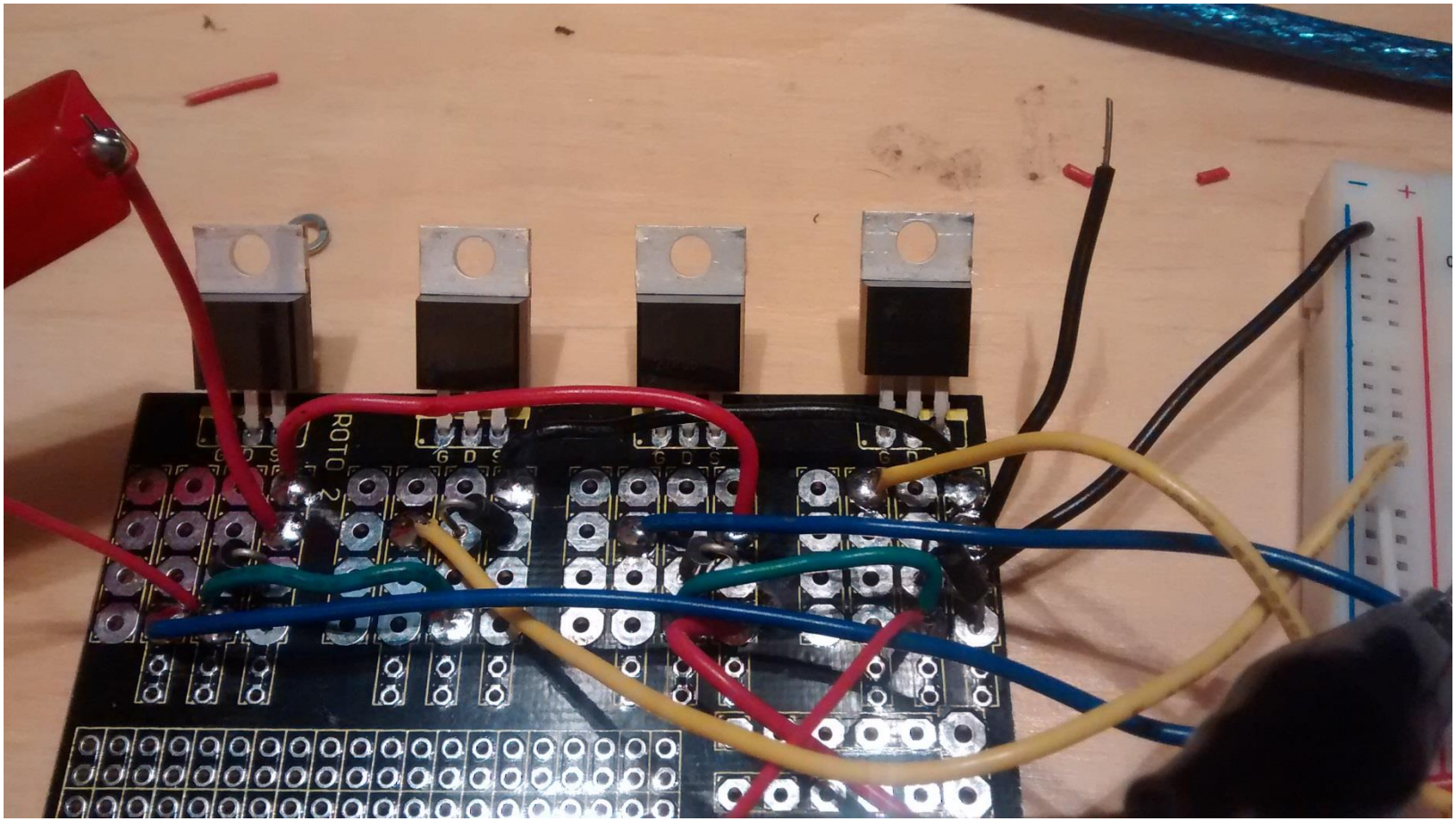


FIGURE 8. TRANSFER CHARACTERISTICS

Example Half-Bridge Driver



Slew Rate Tests



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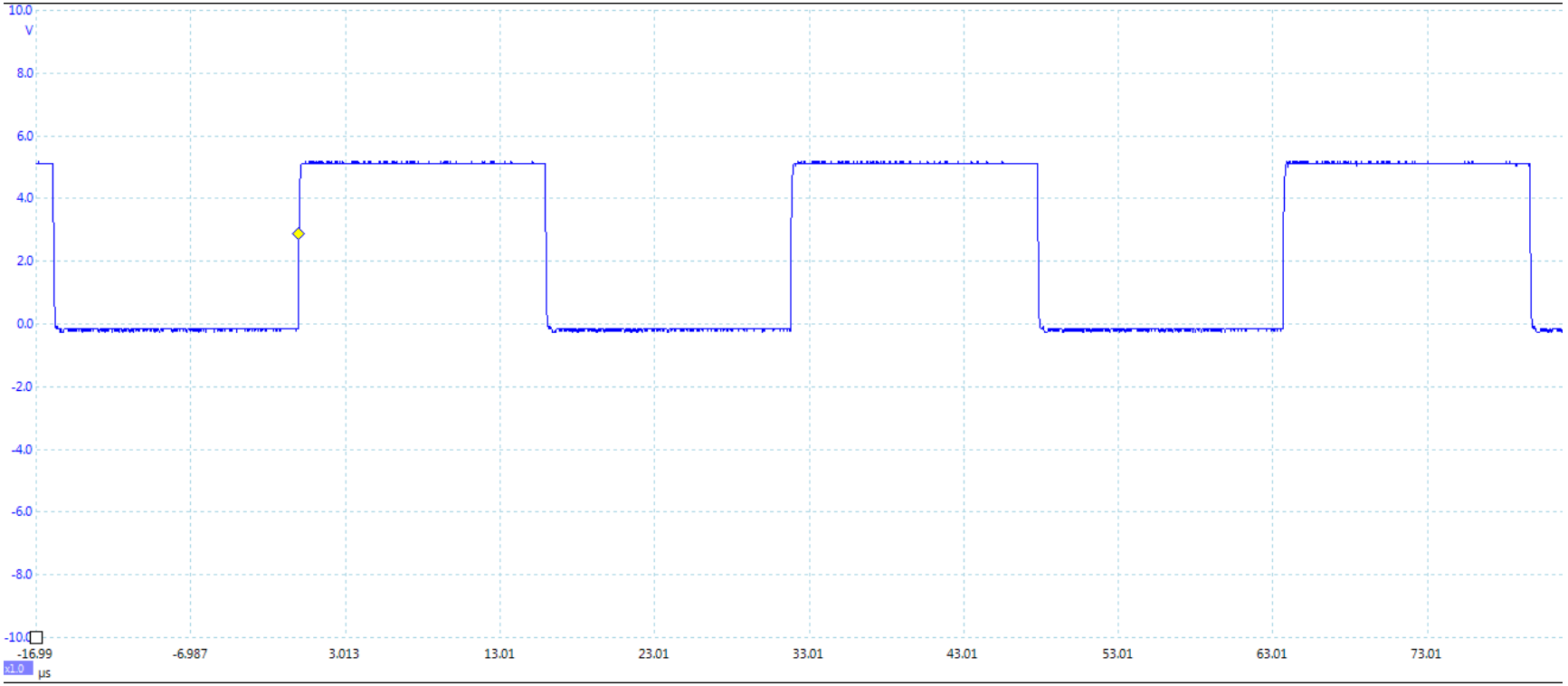
MOSFET Switching Speed



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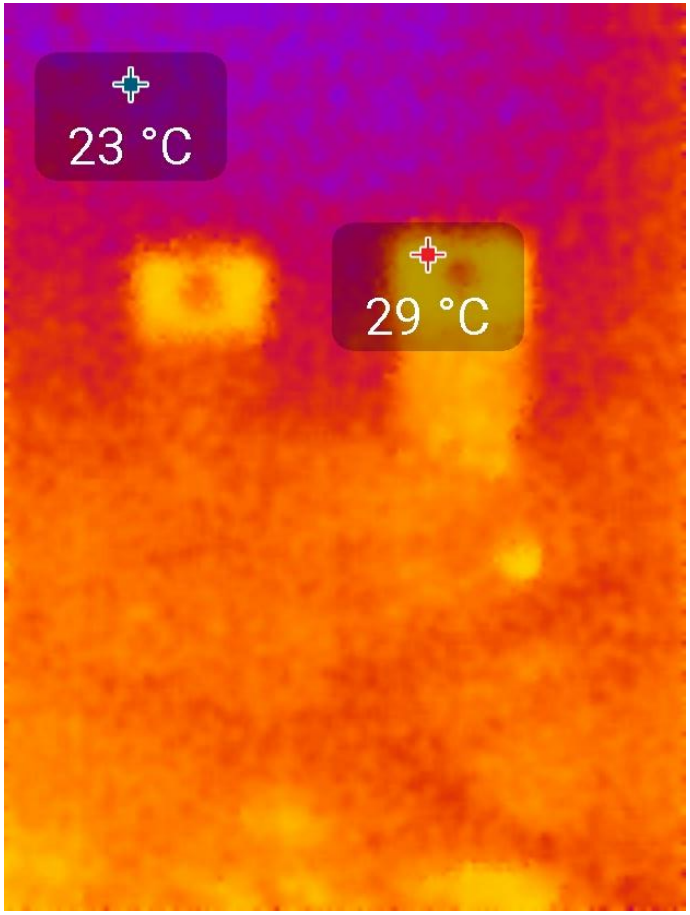
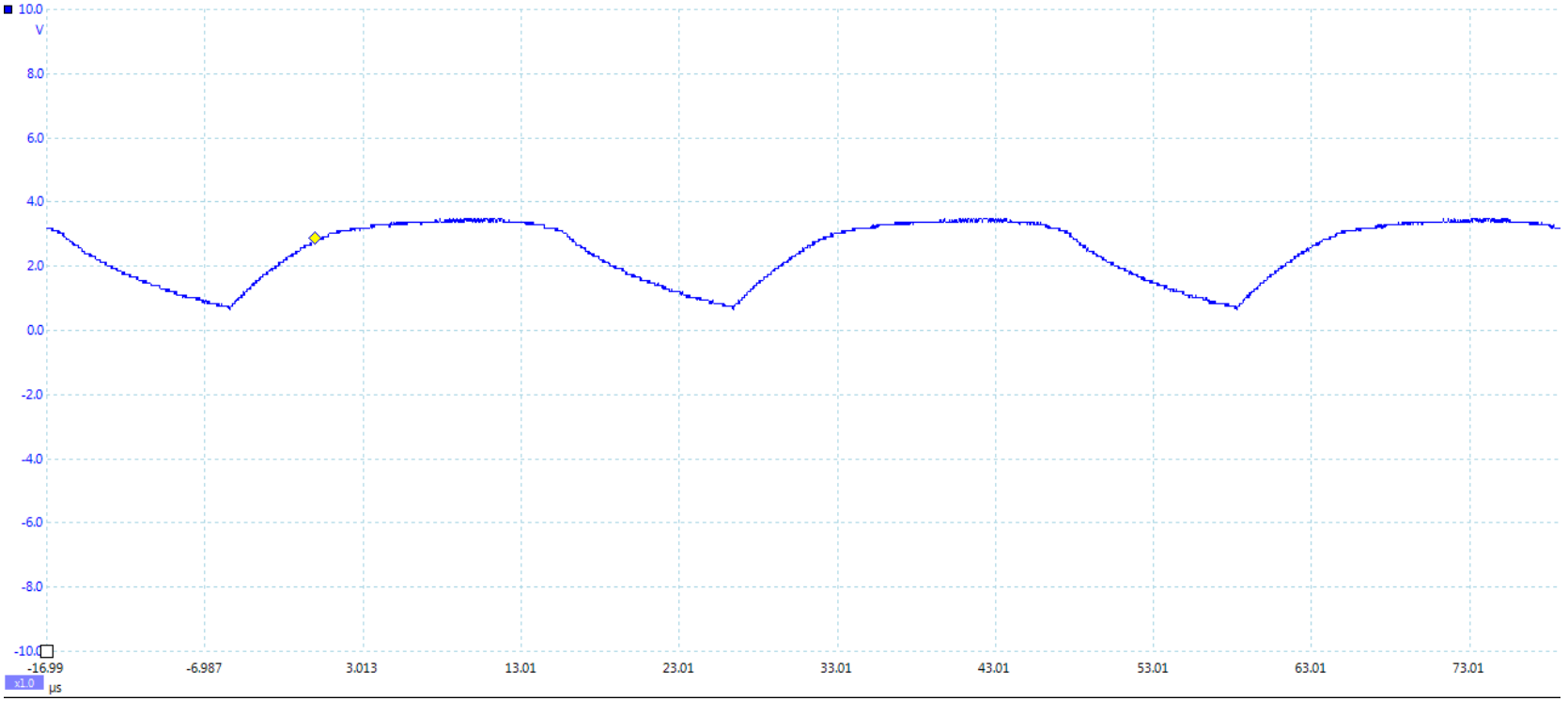
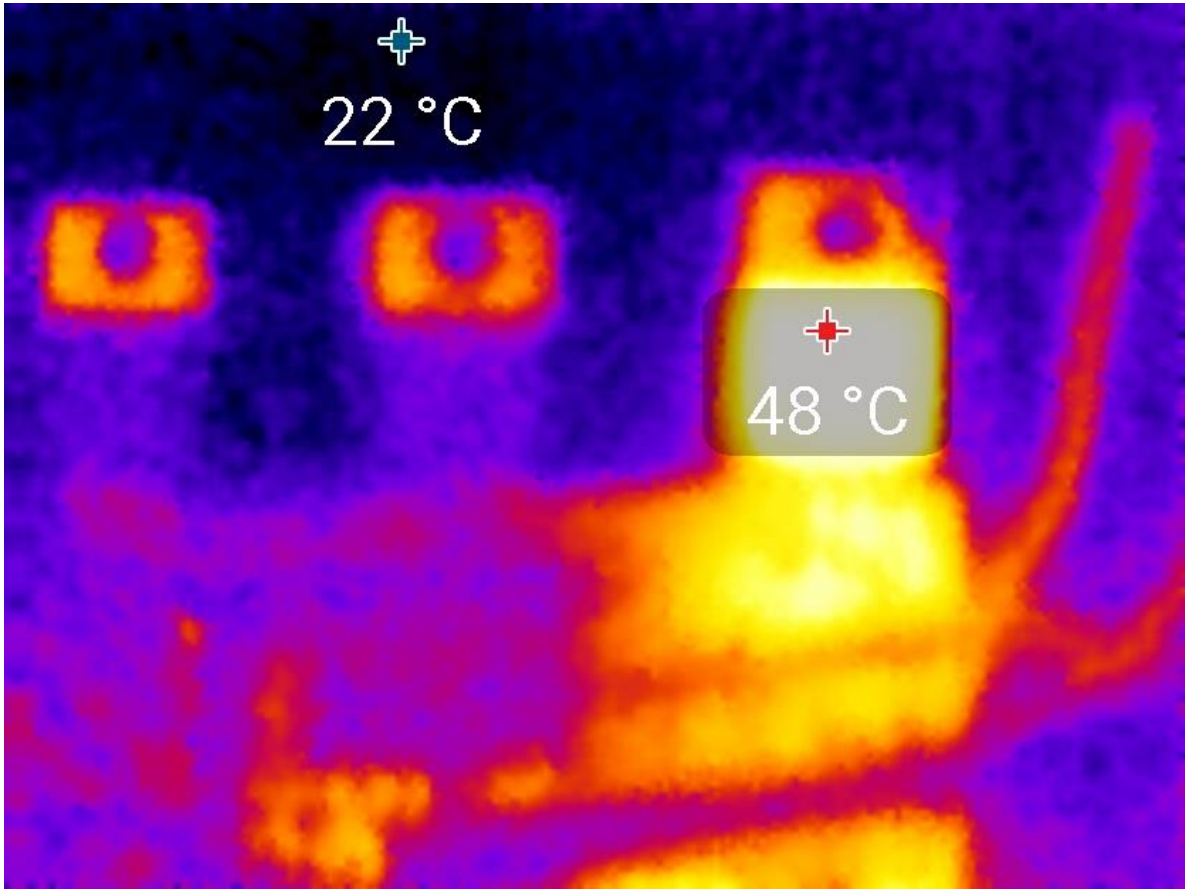
Fast Slew Rate



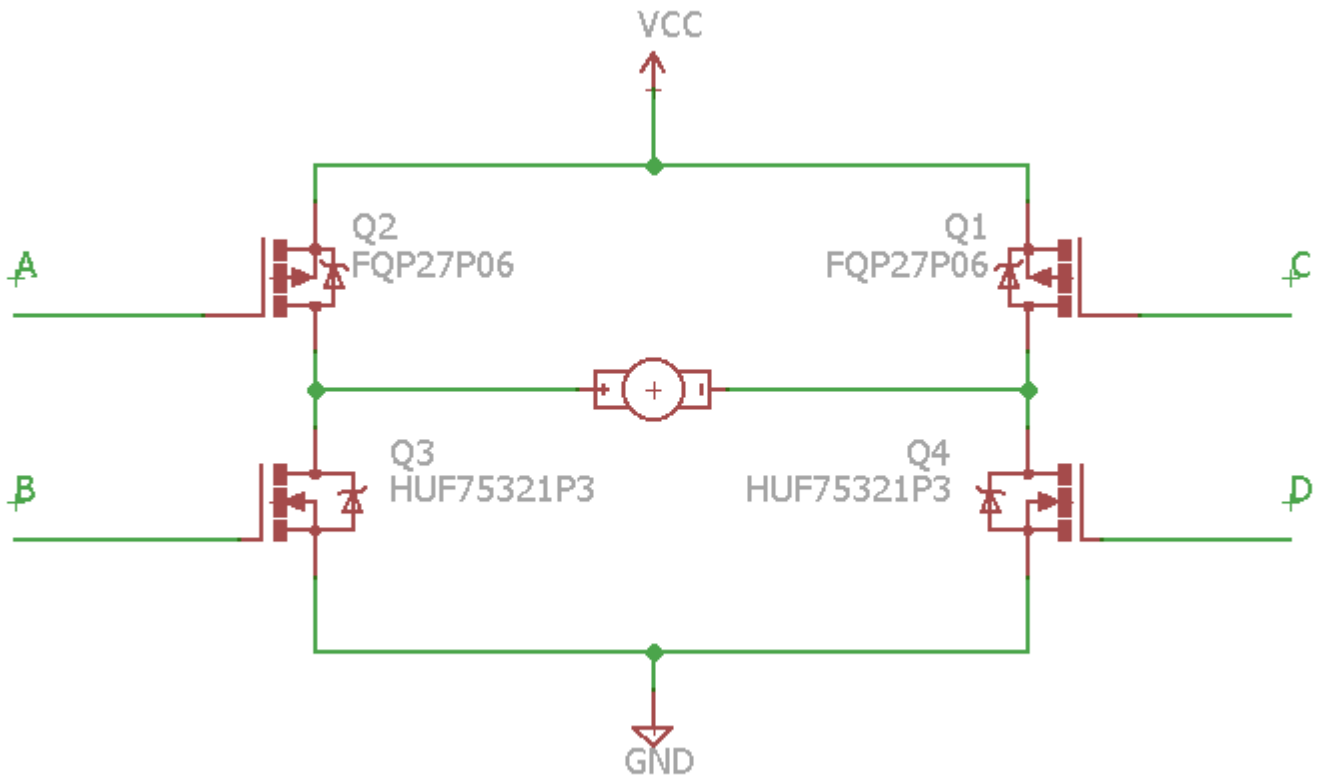
MOSFET Switching Speed



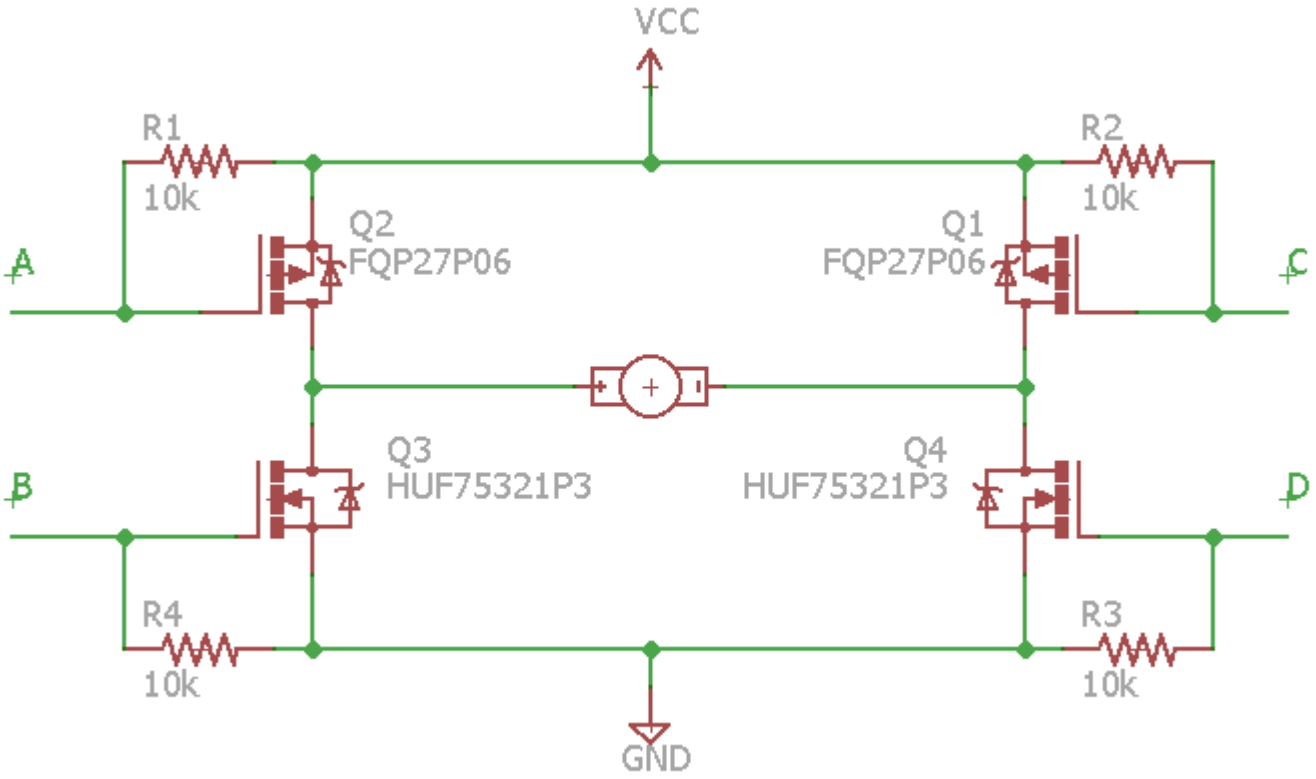
Slow Slew Rate



H-Bridge – Basics (for Lab)



Avoid smoke…


VCC
R1
10k
R2
10k
Q2
FQP27P06
Q1
FQP27P06
A
C
Q3
HUF75321P3
Q4
HUF75321P3
B
D
R4
10k
R3
10k
GND

Your Robot

5-A H-Bridge for DC-Motor Applications **TLE 5205-2**

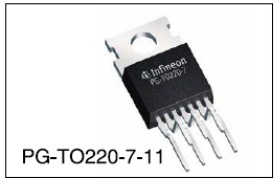
AEC Qualified RoHS

1 Overview

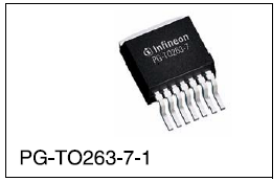
1.1 Features

- Delivers up to 5 A continuous 6 A peak current
- Optimized for DC motor management applications
- Operates at supply voltages up to 40 V
- Very low $R_{DS\,ON}$; typ. 200 mΩ @ 25 °C per switch
- Output full short circuit protected
- Overtemperature protection with hysteresis and diagnosis
- Short circuit and open load diagnosis with open drain error flag
- Undervoltage lockout
- CMOS/TTL compatible inputs with hysteresis
- No crossover current
- Internal freewheeling diodes
- Wide temperature range; – 40 °C < T_j < 150 °C
- Green Product (RoHS compliant)
- AEC Qualified

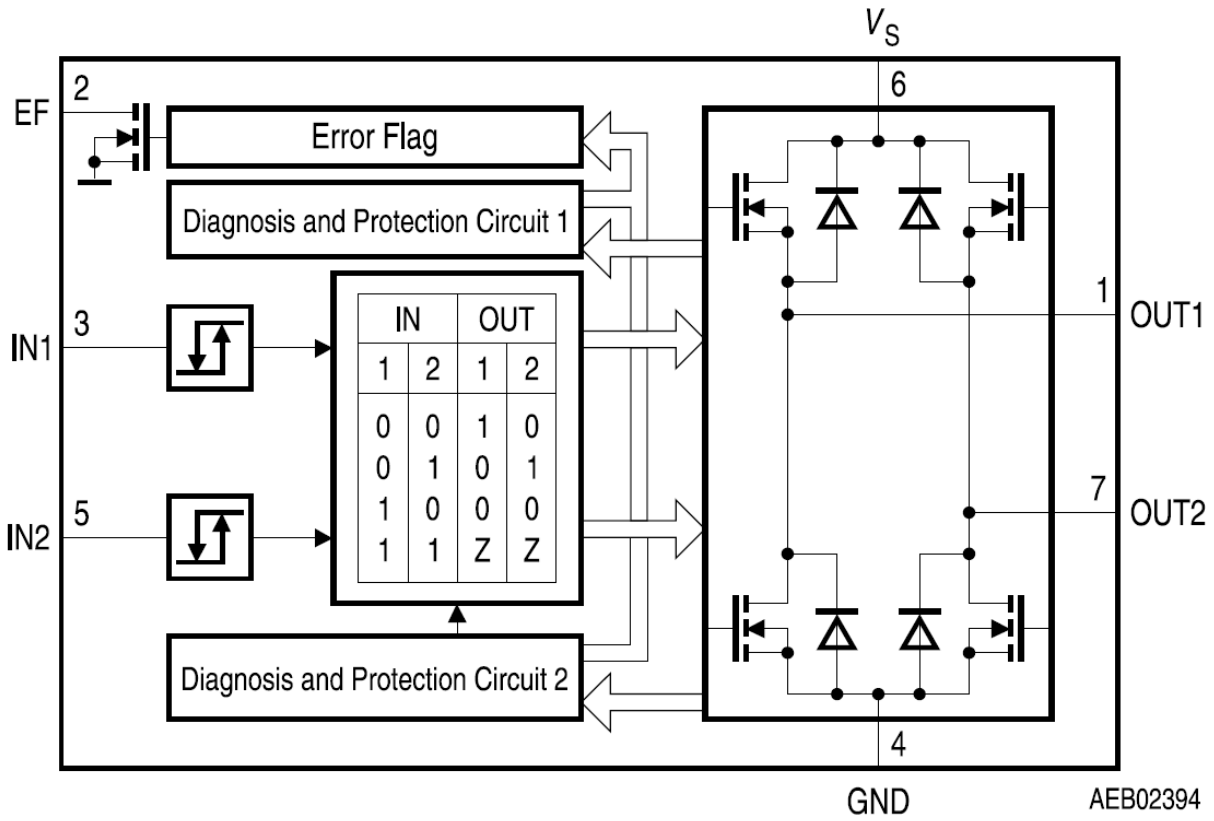
Type	Package
TLE 5205-2	PG-TO220-7-11


PG-TO220-7-11


PG-DSO-20-37


PG-TO263-7-1

Your Robot


V_S
6
EF
2
Error Flag
Diagnosis and Protection Circuit 1
IN1
3
IN2
5
IN
OUT
1 2 1 2
0 0 1 0
0 1 0 1
1 0 0 0
1 1 Z Z
1
OUT1
7
OUT2
Diagnosis and Protection Circuit 2
4
GND
AEB02394

Summary

- Brushed and Brushless DC Motors
- Motors characteristics give us some grief (turn-off spike, noise)
- Use transistors as switch for driving
- Careful design of both MOSFET and Bipolar circuits required