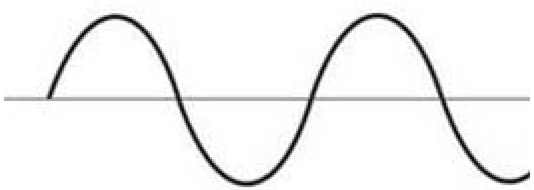
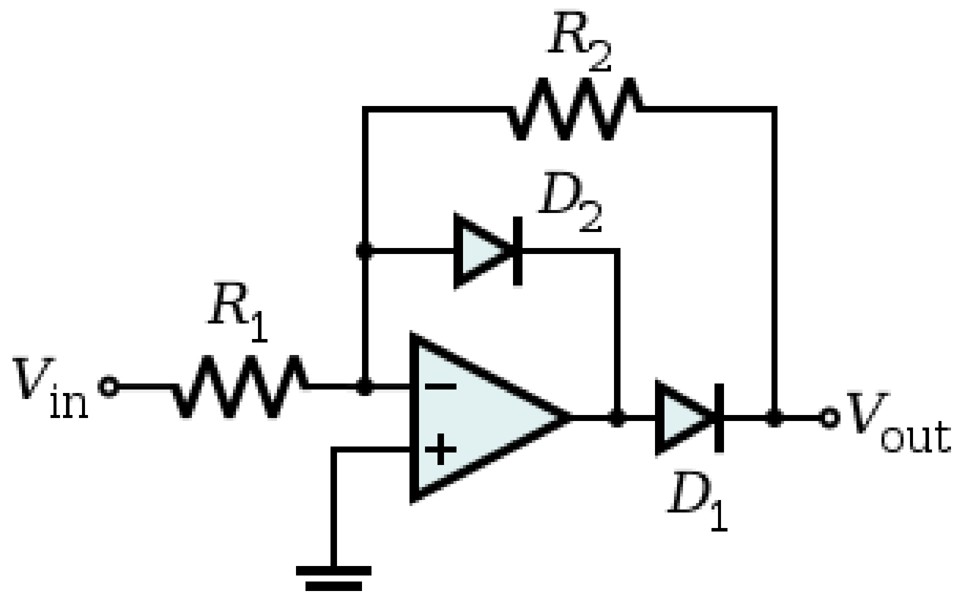
Lab 2 recap: Superdiode

• Frequency response limited by op-amp being driven to saturation. TL082CP seemed to handle this more poorly than TL0821P

• Improved circuit:





ENPH 253 - Lecture 3

- Power circuits – how to control your motors
- Noise and Shielding (if we can fit it in today)

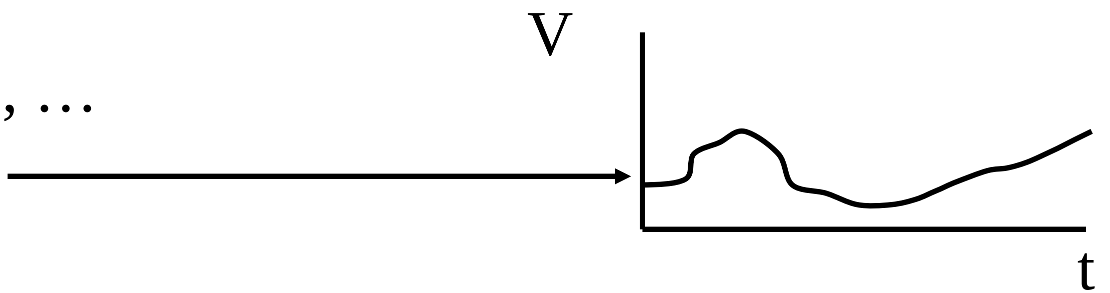
Digital-to-Analog Conversion
PWM

D/A Conversion and power circuits

When would you like to produce an output signal that is more than just on or off? (e.g. brightness of light, speed of a motor, current through electric heater, etc….) → **Analog Outputs**

Digital-to-Analog Conversion (DAC):

10110011, 01010101, …



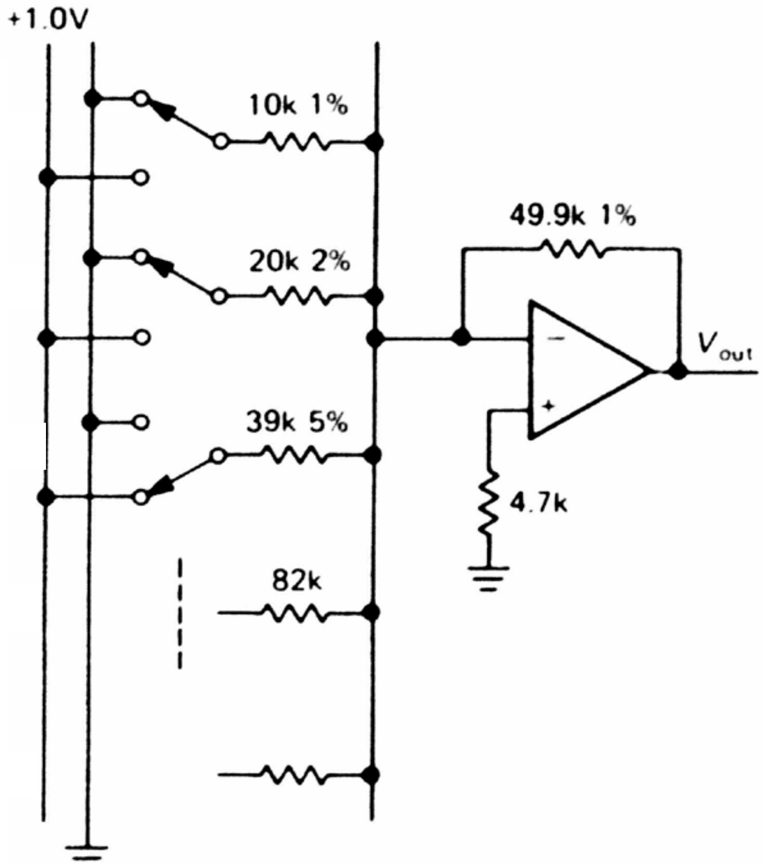
Two simple schemes we will use in 253 (of many possible schemes)

1. **Resistor ladders** (combine multiple digital outputs into one analog output)

2. **Pulse Width Modulation** (turn one digital output on and off at high frequency)

D/A conversion: Resistor ladders

(binary weighted DAC)



An op-amp summing circuit

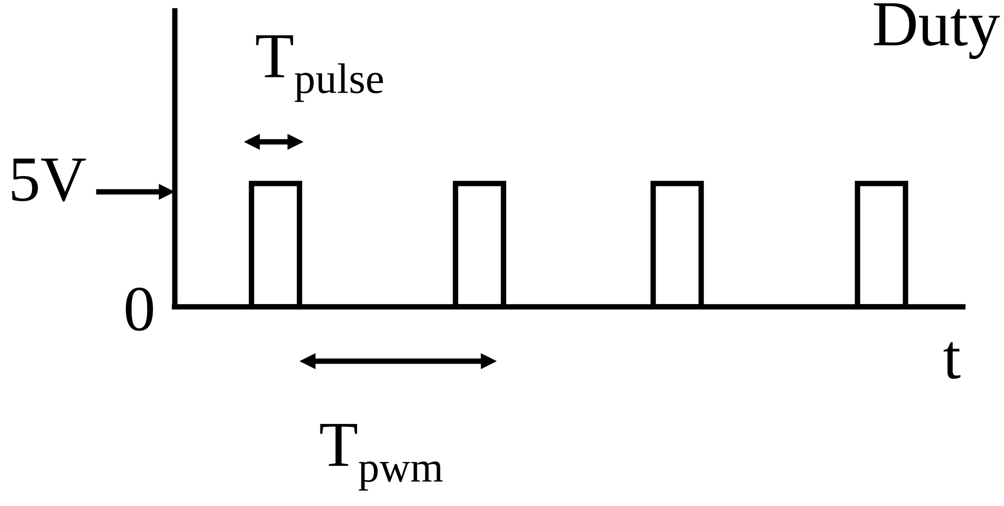
$$V_{out} = -(50k / R) * 1.0V$$

D/A conversion: Pulse Width Modulation (PWM)

• This scheme uses a digital output to produce an analog voltage by digitally controlling the % of time that the output is high.

• The TIME AVERAGED voltage produced can therefore be almost continuously variable.

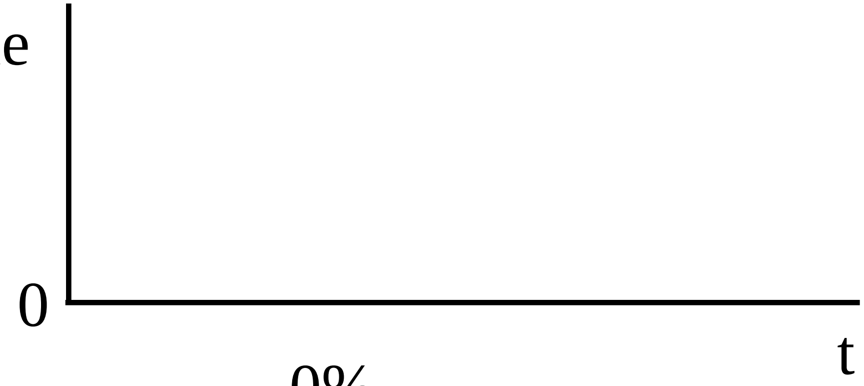
Duty cycle = T_{pulse}/T_{pwm}



D/A conversion: PWM

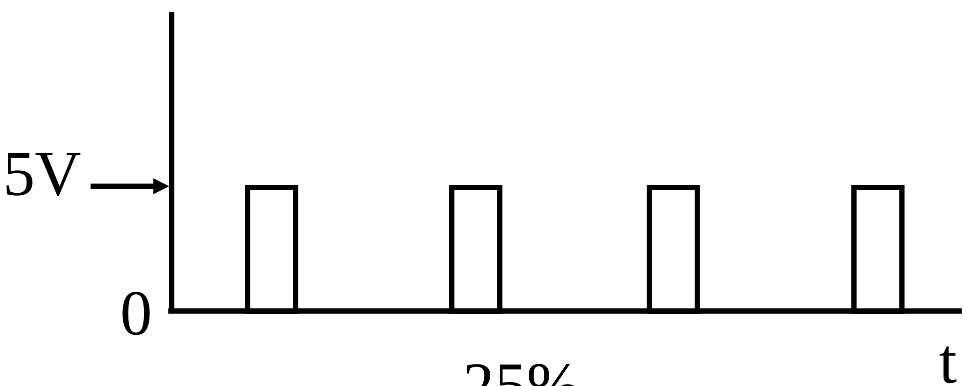
PWM Duty Cycle

Average voltage:



0%

0 V



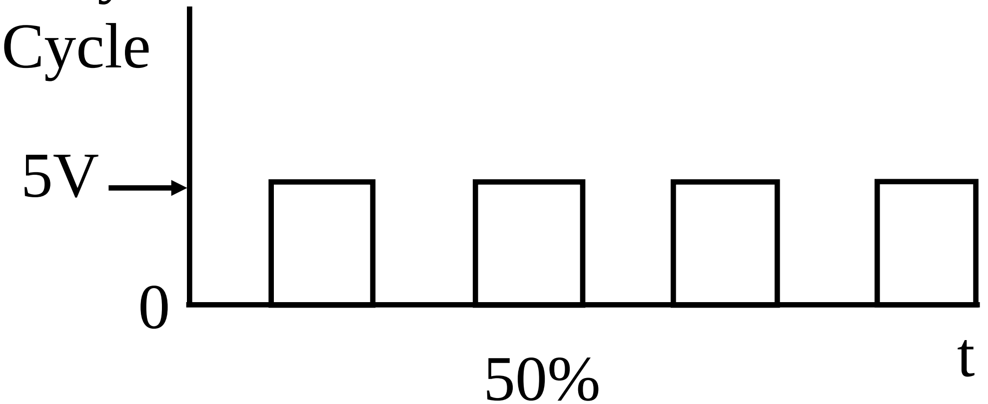
25%

0.25 * 5 V = 1.25 V

D/A conversion: PWM

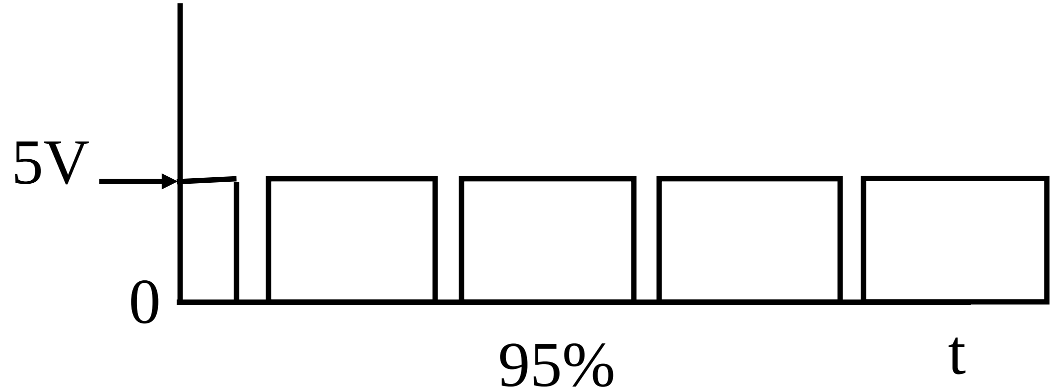
PWM
Duty
Cycle

Average voltage:



50%

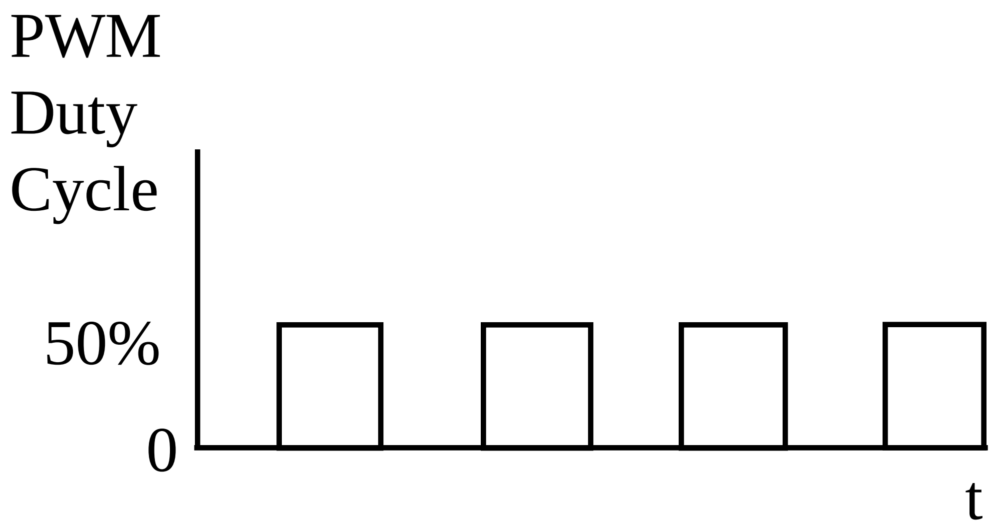
2.5 V



95%

4.75 V

D/A conversion: PWM



Average voltage:

2.5 V

• Must be low-pass filtered to be used as an analog output
• To avoid ripple, low-pass filter at $f << f_{pwm}$. Note that this can place a severe limit on the output bandwidth.
• Resolution is limited by minimum switching time of the digital output.

High-Current Circuits and Motor Control

Discrete devices: Transistors

Transistors are semiconductor devices used to **amplify** a signal (e.g. small current/voltage to large current/voltage).

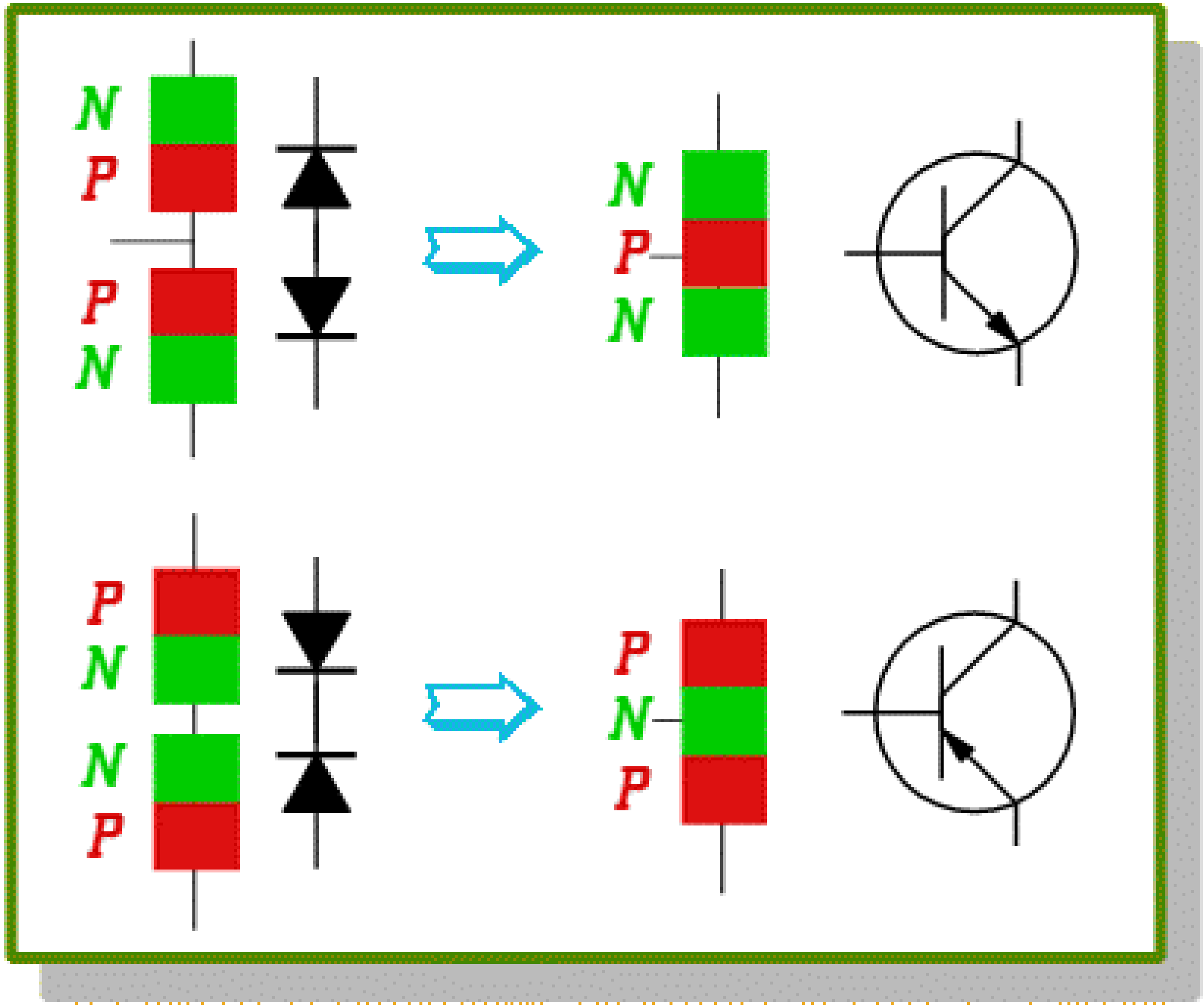
In ENPH253, we use transistors as **switches** to turn on and off larger amounts of current.

Two major types of transistors:

Bipolar Junction Transistors
MOSFETs

Discrete devices: BJT

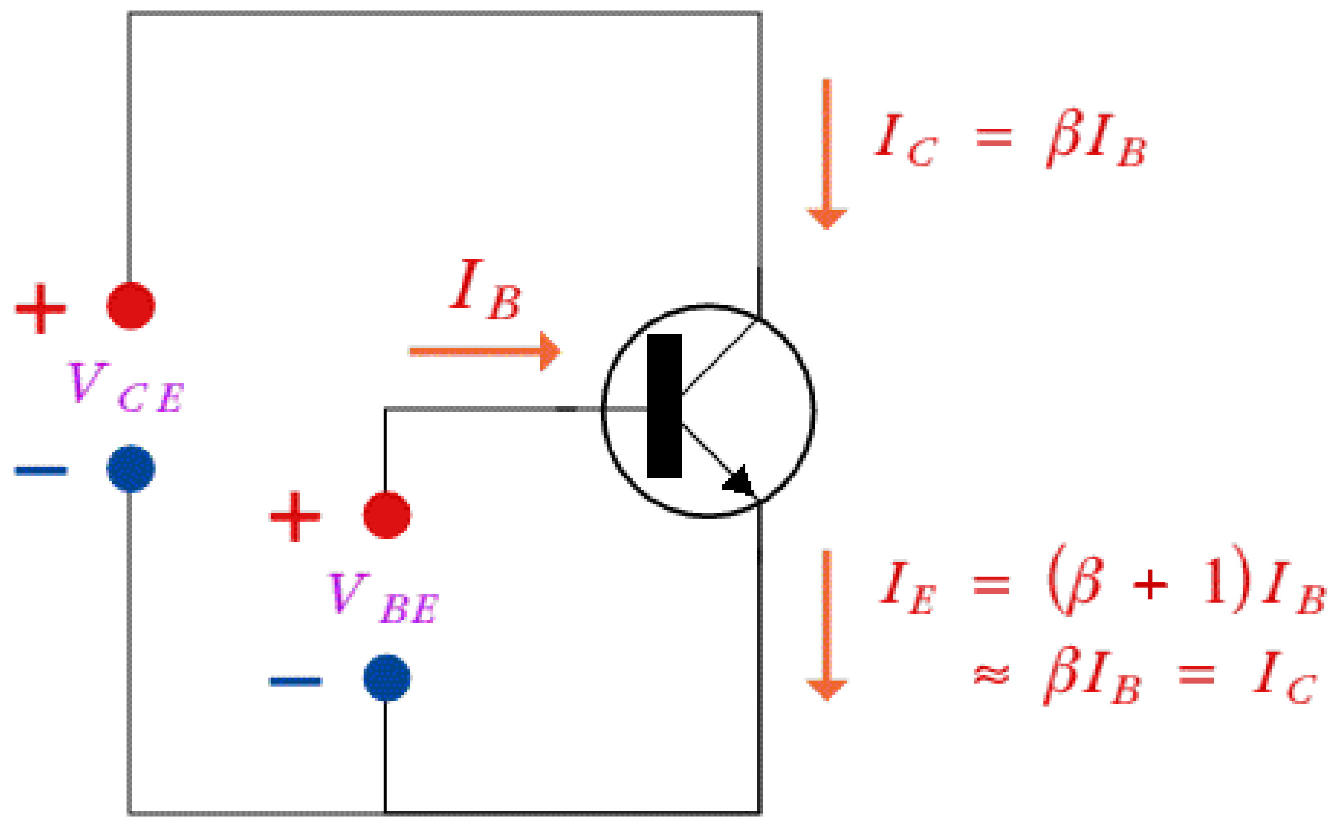
Bipolar Junction Transistors



Diagrams courtesy of: University of St. Andrews, St Andrews, Fife KY16 9SS, Scotland

Discrete devices: BJT

Bipolar Junction Transistors



'Conventional' view of the NPN Bipolar Transistor

Diagrams courtesy of: University of St. Andrews, St Andrews, Fife KY16 9SS, Scotland

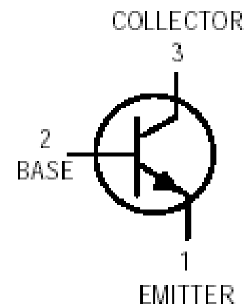
Discrete devices: BJT

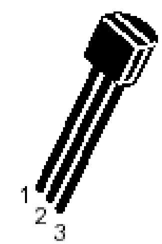
General Purpose Transistors

NPN Silicon

2N3903
2N3904*

*Motorola Preferred Device





CASE 29–04, STYLE 1
TO–92 (TO–226AA)

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Collector–Emitter Voltage	V_{CEO}	40	Vdc
Collector–Base Voltage	V_{CBO}	60	Vdc
Emitter–Base Voltage	V_{EBO}	6.0	Vdc
Collector Current — Continuous	I_C	200	mAdc
Total Device Dissipation @ T_A = 25°C Derate above 25°C	P_D	625 5.0	mW mW/°C
Total Device Dissipation @ T_C = 25°C Derate above 25°C	P_D	1.5 12	Watts mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

Discrete devices: BJT

Bipolar Junction Transistors

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted) (Continued)

Characteristic		Symbol	Min	Max	Unit
ON CHARACTERISTICS					
DC Current Gain(1)		h_{FE}			—
(I_C = 0.1 mAdc, V_{CE} = 1.0 Vdc)	2N3903		20	—	
	2N3904		40	—	
(I_C = 1.0 mAdc, V_{CE} = 1.0 Vdc)	2N3903		35	—	
	2N3904		70	—	
(I_C = 10 mAdc, V_{CE} = 1.0 Vdc)	2N3903		50	150	
	2N3904		100	300	
(I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	2N3903		30	—	
	2N3904		60	—	
(I_C = 100 mAdc, V_{CE} = 1.0 Vdc)	2N3903		15	—	
	2N3904		30	—	
Collector–Emitter Saturation Voltage(1)		$V_{CE(sat)}$			Vdc
(I_C = 10 mAdc, I_B = 1.0 mAdc)			—	0.2	
(I_C = 50 mAdc, I_B = 5.0 mAdc			—	0.3	
Base–Emitter Saturation Voltage(1)		$V_{BE(sat)}$			Vdc
(I_C = 10 mAdc, I_B = 1.0 mAdc)			0.65	0.85	
(I_C = 50 mAdc, I_B = 5.0 mAdc)			—	0.95	

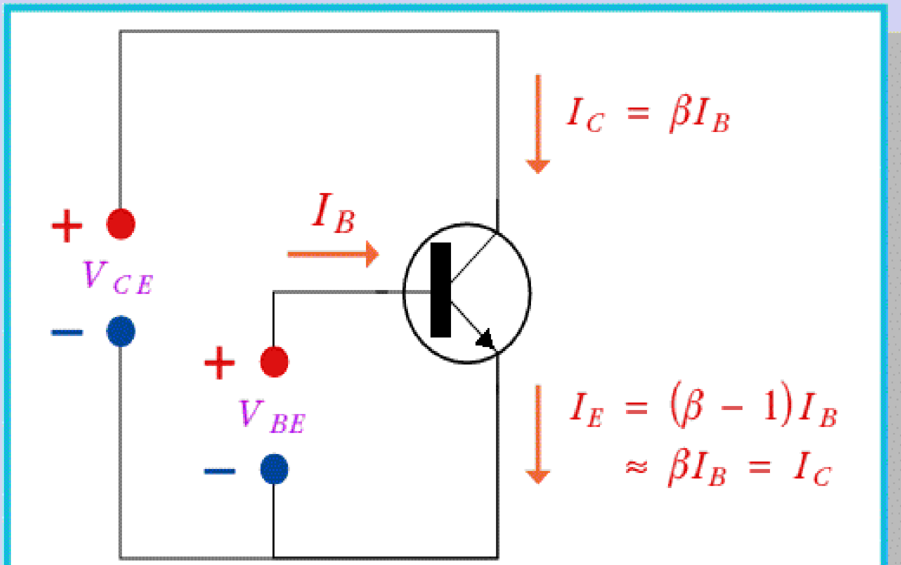
Discrete devices: Transistors (NPN)

Build a circuit that :

Uses a 3904 (NPN) transistor to light a lamp

- ❖ Check: when the 3904 is turned on, the Base-Emitter voltage should be ~ 0.7V
- ❖ Limit the current into the base!!

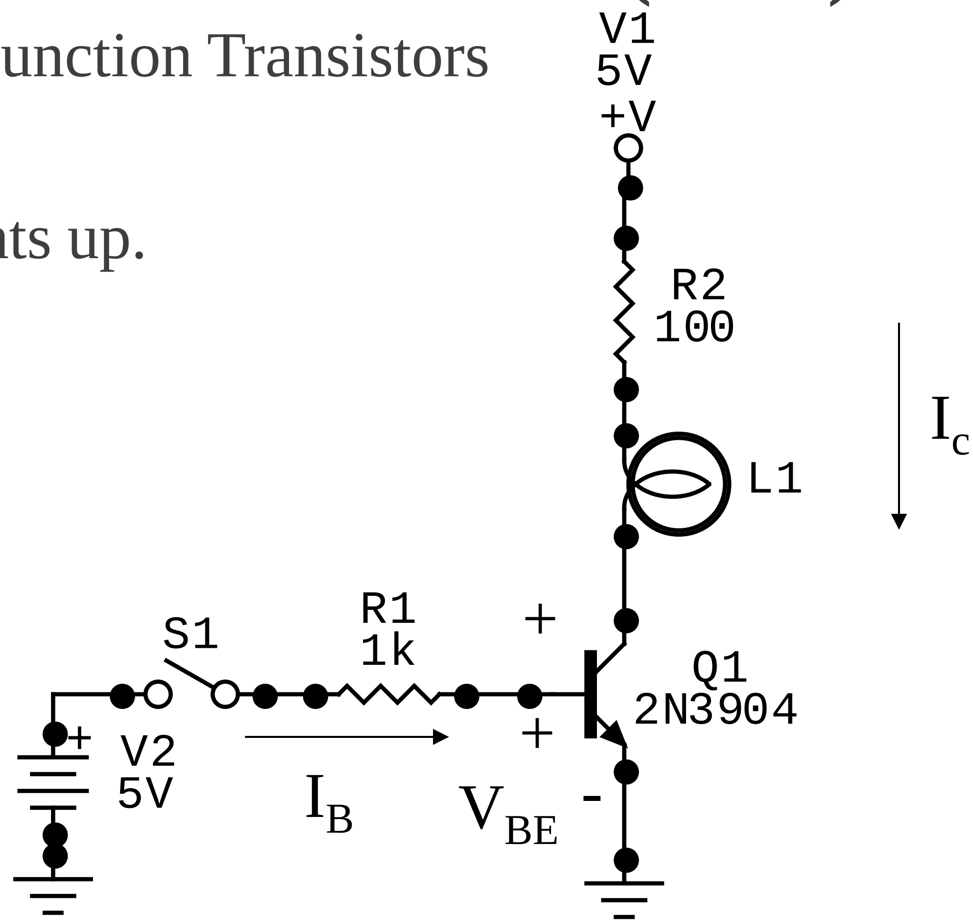
Note: arrange the 3904 so the emitter voltage to ground does not change when the lamp is lit (it needs to be stable as a reference for the base voltage)



'Conventional' view of the NPN Bipolar Transistor

Discrete devices: Transistors (NPN)

Bipolar Junction Transistors



Typical circuit (NPN):

When S1 is closed, lamp lights up.

I_B = (5-0.7)/1k = 4.3 mA

β= 30

I_c = (30)4.3 mA = 130 mA

V_{BE} = 0.7 V

V_{CE} = 0.3 V

Checking V_{BE} is a quick way to test a transistor.
If V_{BE} >> 0.7 V, the transistor is dead.

Discrete devices: Transistors (PNP)

Build a circuit that :

- Uses a 3906 (PNP) transistor to light a lamp

❖ Check: when the 3906 is turned on, the Base-Emitter voltage should be ~ 0.7V

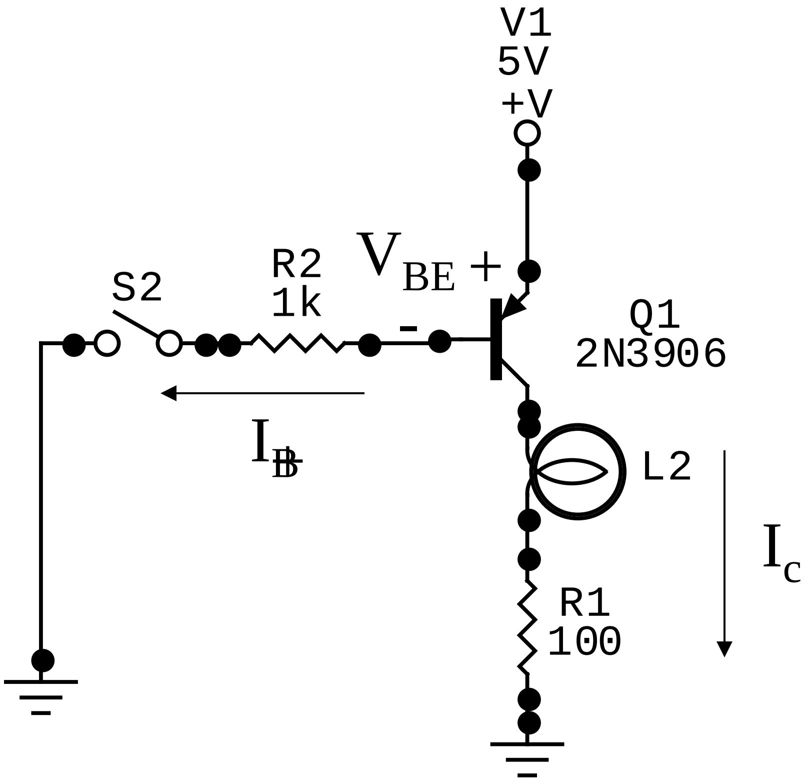
❖ Note: arrange the 3906 so the emitter voltage does not change when the lamp is lit (it needs to be stable as a reference for the base voltage)

Discrete devices: Transistors (PNP)

Bipolar Junction Transistors

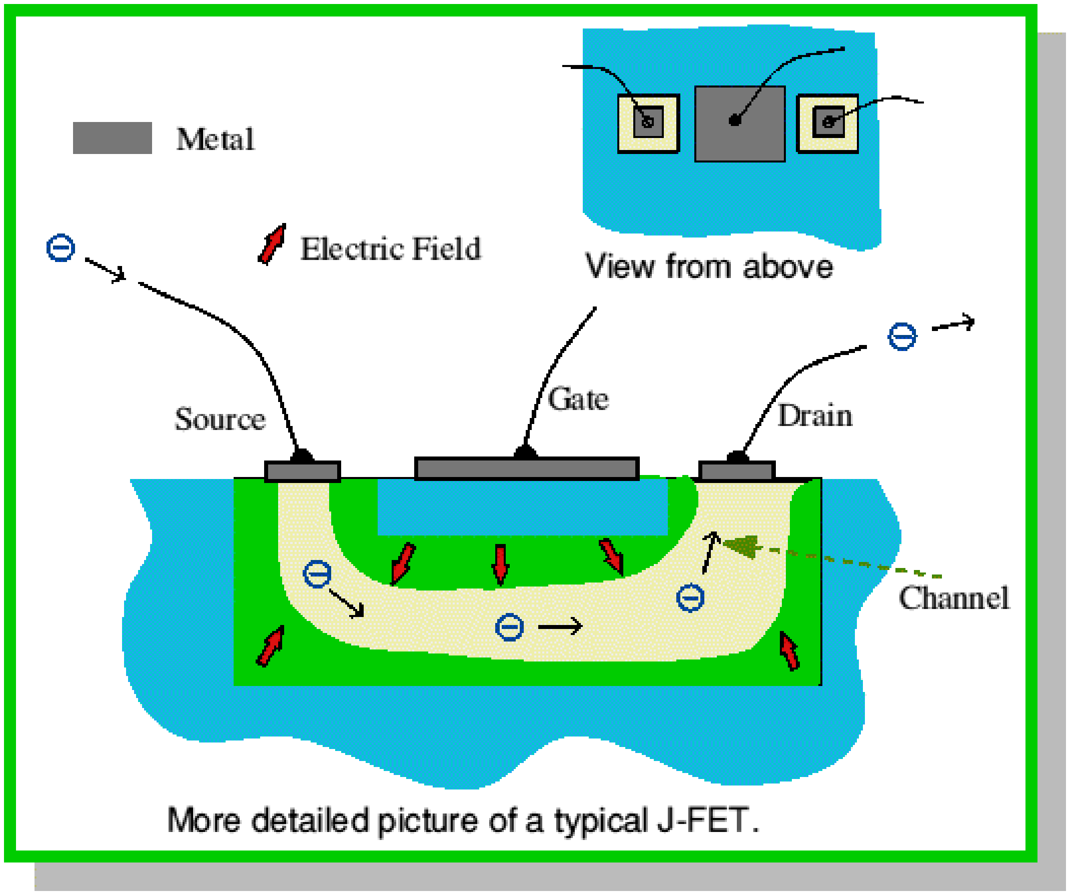
Typical circuit (PNP):

When S2 is closed, lamp lights up.



Discrete devices: FETs

Field Effect Transistors



Gate voltage either ENHANCES or DEPLETES the conduction channel.

JFET = Junction FET
MOSFET = Metal Oxide Semiconductor FET

MOSFETS have an insulating layer at gate so draw less current.

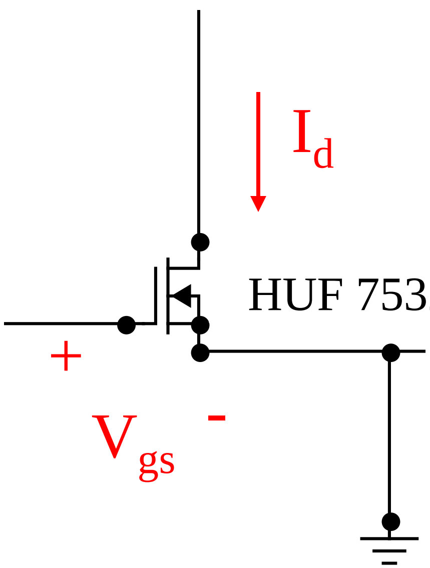
Current passing from source to drain now controlled by VOLTAGE at the gate
(rather than by CURRENT into the base as in a BJT).

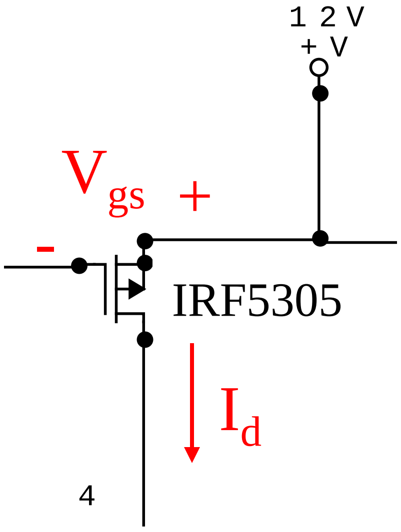
Discrete devices: FETs

Field Effect Transistors

There are FOUR kinds of MOSFETs:

Enhancement Mode: N type P type





Increasing V_{gs} increases I_d.

Depletion : Increasing V_{gs} decreases I_d

35A, 55V, 0.034 Ohm, N-Channel UltraFET Power MOSFETs

These N-Channel power MOSFETs are manufactured using the innovative UltraFET® process. This advanced process technology achieves the lowest possible on-resistance per silicon area, resulting in outstanding performance. This device is capable of withstanding high energy in the avalanche mode and the diode exhibits very low reverse recovery time and stored charge. It was designed for use in applications where power efficiency is important, such as switching regulators, switching converters, motor drivers, relay drivers, low-voltage bus switches, and power management in portable and battery-operated products.

Formerly developmental type TA75321.

Ordering Information

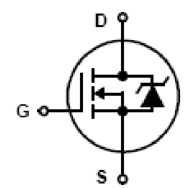
PART NUMBER	PACKAGE	BRAND
HUFA75321P3	TO-220AB	75321P
HUFA75321S3S	TO-263AB	75321S

NOTE: When ordering, use the entire part number. Add the suffix T to obtain the TO-263AB variant in tape and reel, e.g., HUFA75321S3ST.

Features

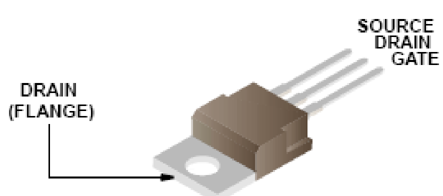
- 35A, 55V
- Simulation Models
  - Temperature Compensated PSPICE® and SABER™ Models
  - Thermal Impedance SPICE and SABER Models Available on the WEB at: www.fairchildsemi.com
- Peak Current vs Pulse Width Curve
- UIS Rating Curve
- Related Literature
  - TB334, "Guidelines for Soldering Surface Mount Components to PC Boards"

Symbol

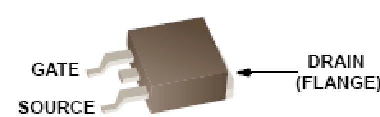


Packaging

JEDEC TO-220AB



JEDEC TO-263AB



Discrete devices: MOSFETS

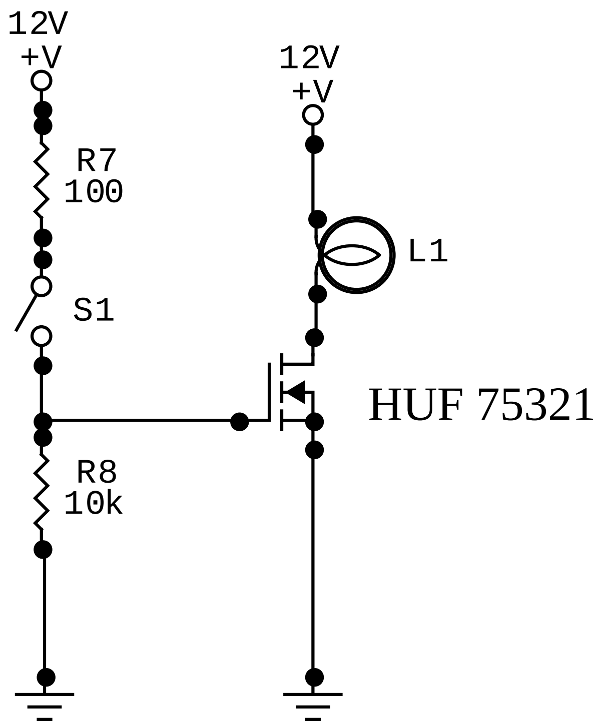
Build a circuit that :

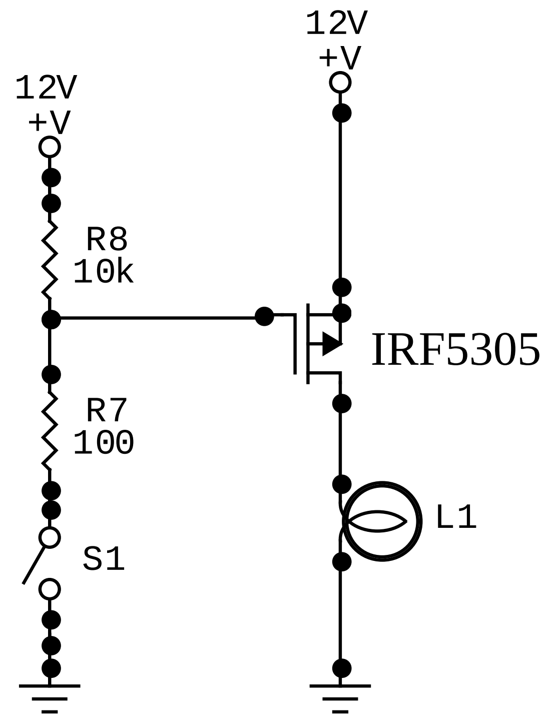
- Uses a MOSFET to light a lamp

❖ Note: no current is required to flow into the gate to switch on or off the MOSFET

Discrete devices: MOSFETs

Enhancement: N type P type



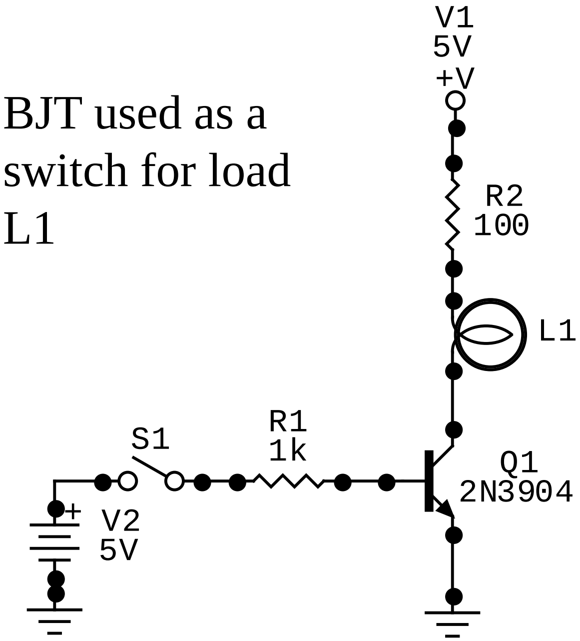


High current and inductive loads

Digital Outputs do not provide sufficient current to drive anything other than output signals to other electronics.

Digital outputs can be "amplified" to turn on devices that require high currents. Mechanical/solid-state relays or Transistors can be used as electrically-controlled switches…

BJT used as a switch for load L1



Electromechanical relay

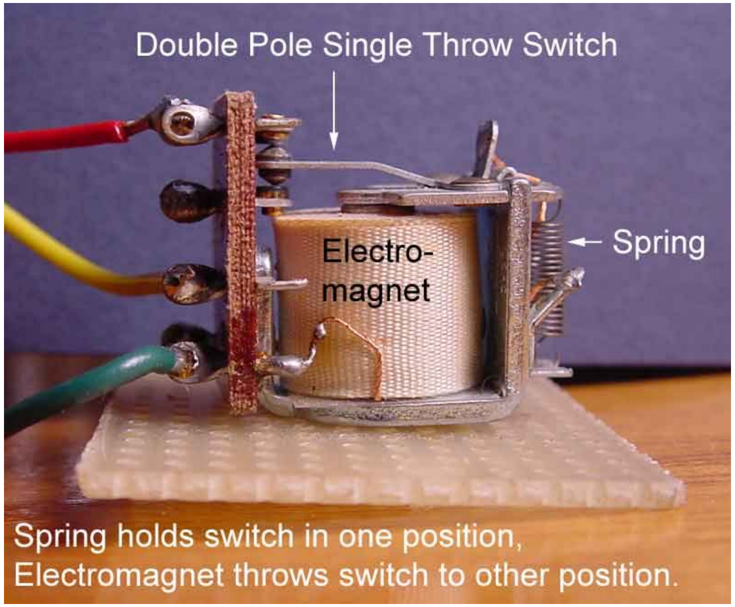
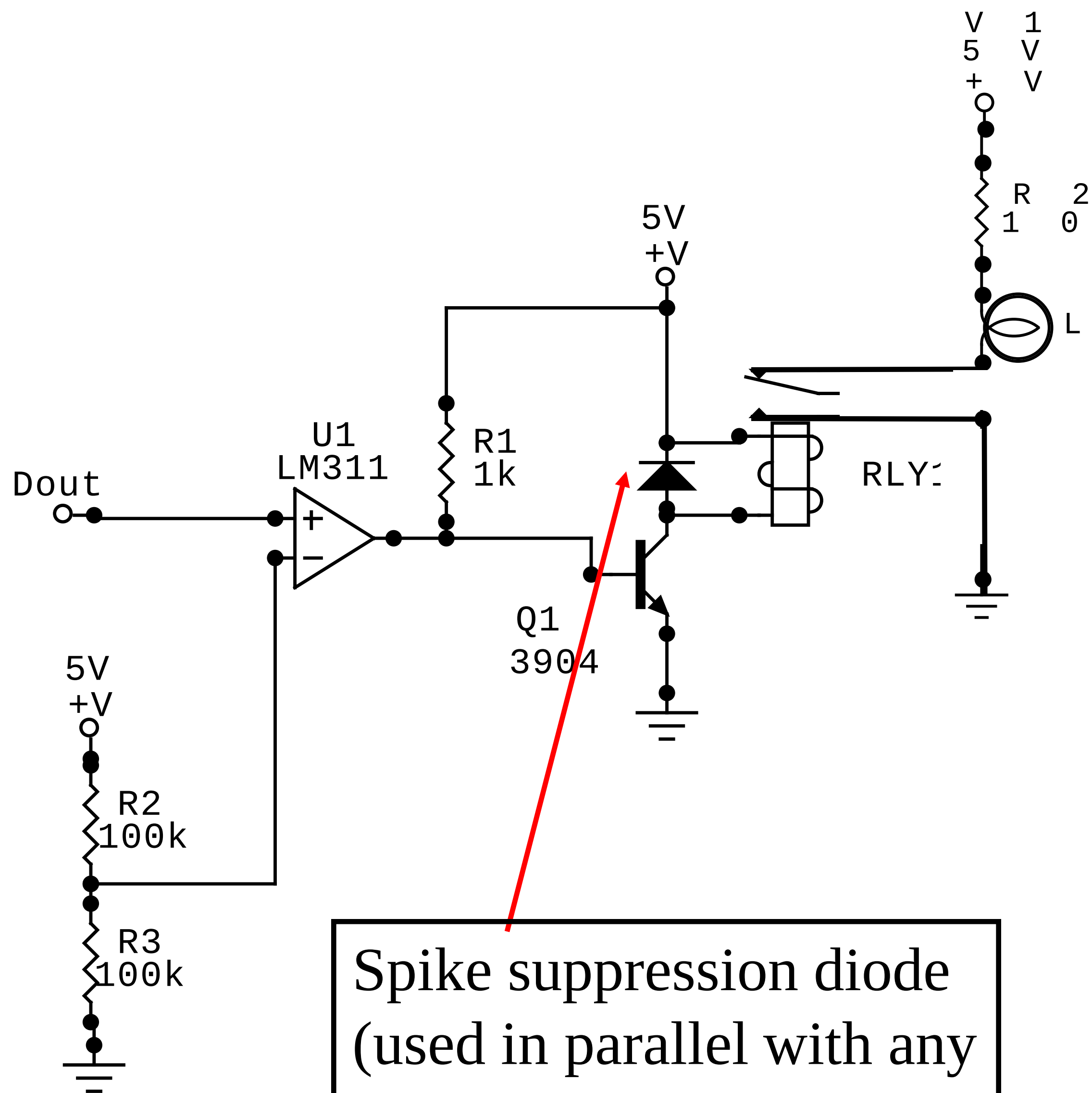


Image from CMU - http://www.vialab.org/Bioe_1010

Example - High current and inductive loads

Eg. Load with 4 stages Electromechanical Relay

- Relay coil current at 5 V ~ 80 mA
- LM311 sinks up to 50mA
- 3904 rated to 200 mA



Spike suppression diode (used in parallel with any inductive loads)

Power output: H-bridges

The above circuits work for loads where current only travels in one direction – how to get current to travel FORWARDS and REVERSE?

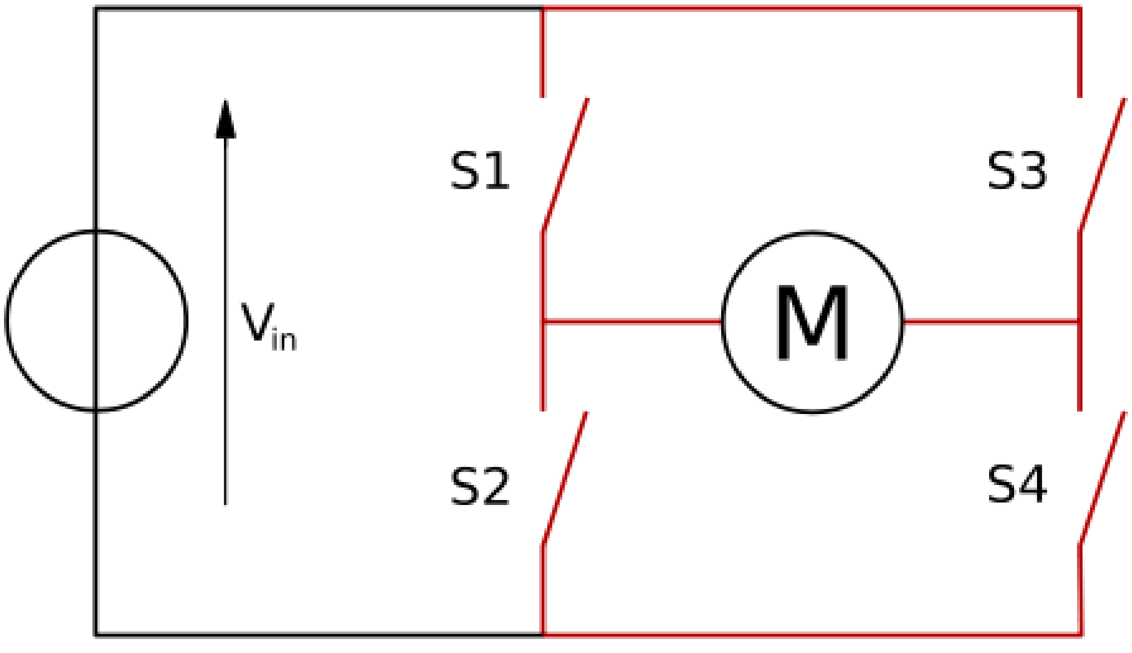
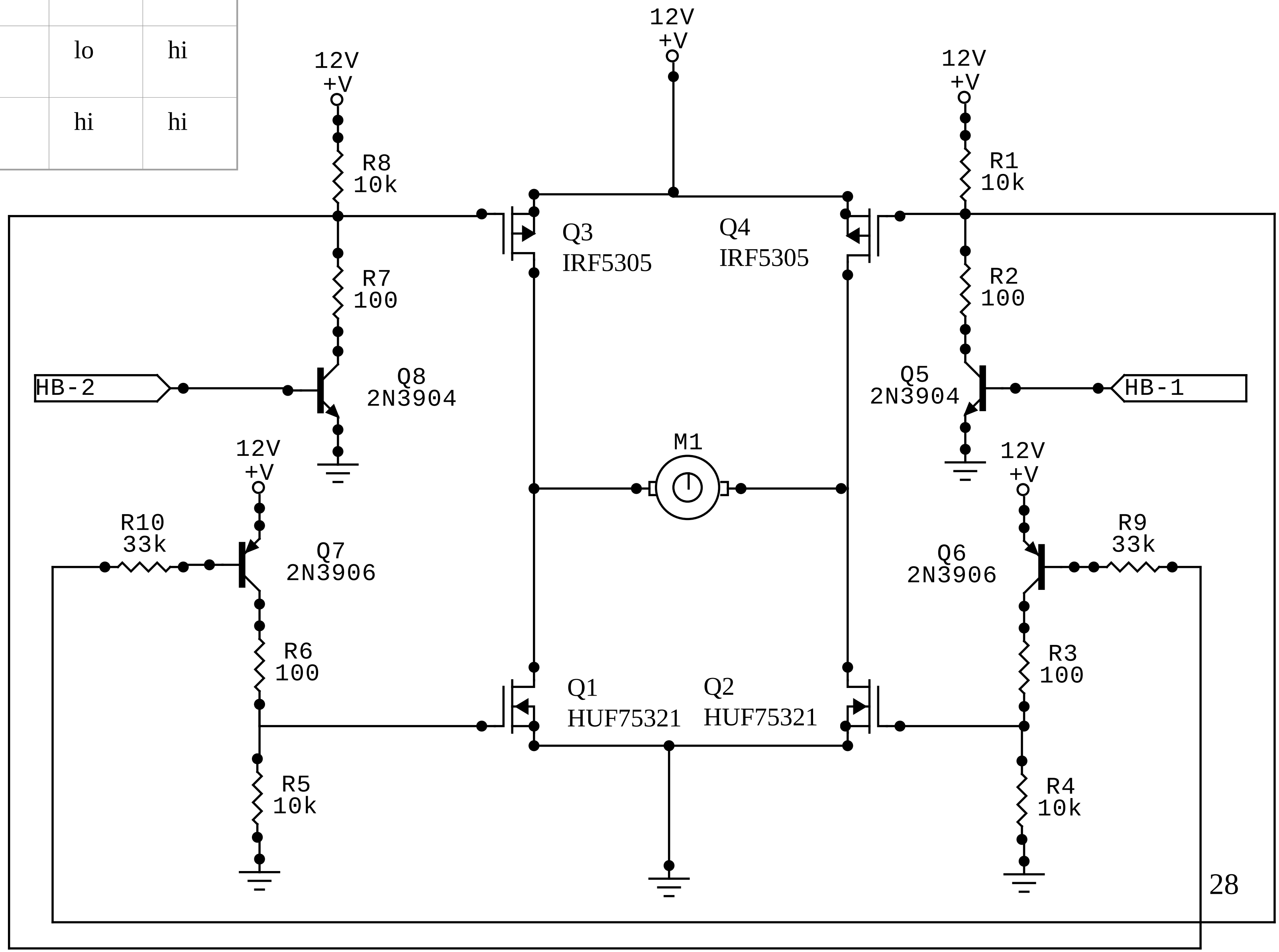


Image from wikipedia (H-Bridge)

Power output: H-bridges

	HB -1	HB -2
STOP	lo	lo
FORWARD	hi	lo
REVERSE	lo	hi
NOT ALLOWED	hi	hi

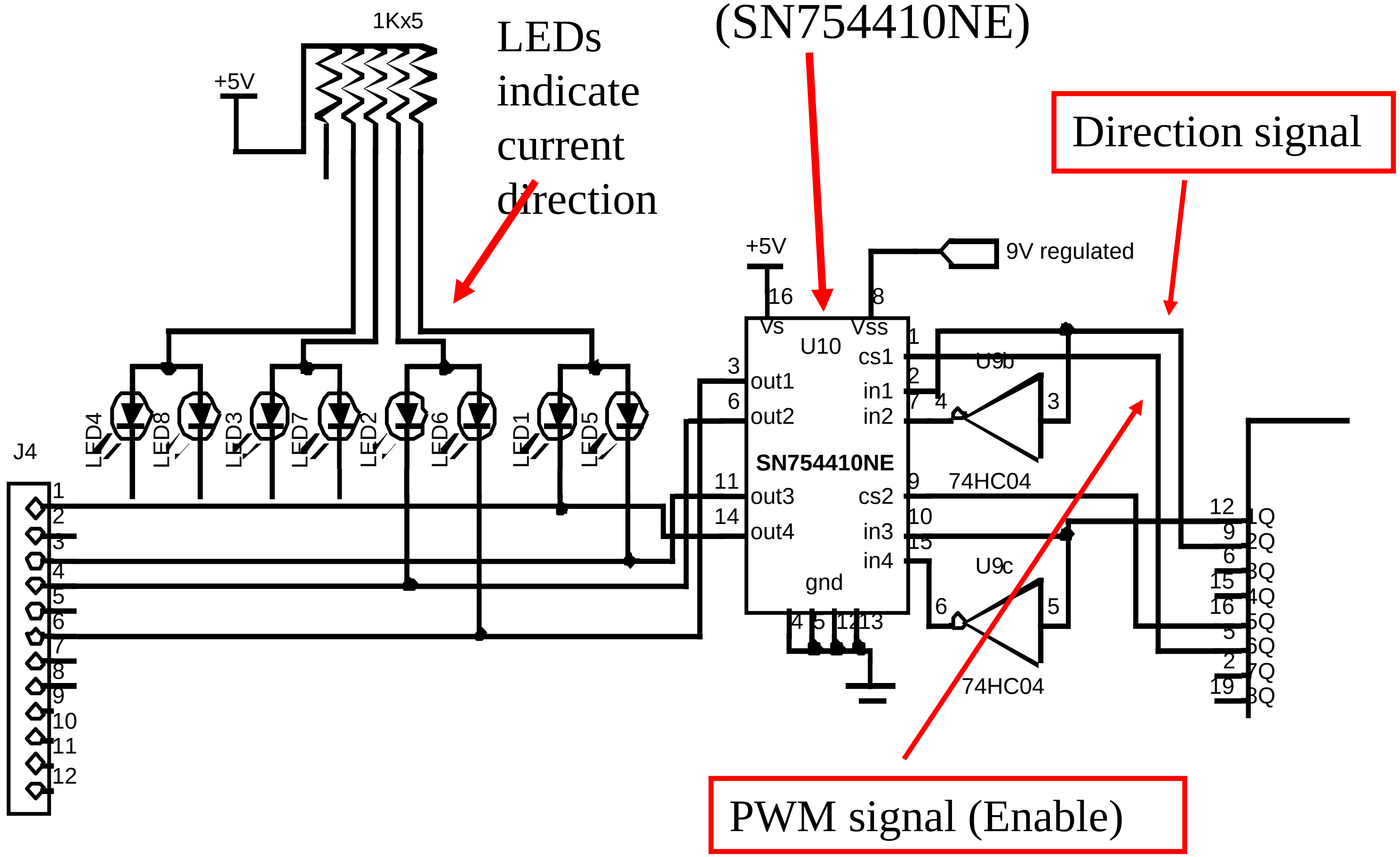


PWM on the TINAH Motor Outputs

The TINAH Board has a built-in software to generate a PWM signal, and hardware to use the PWM signal to power a small motor (max 9V, ~600 mA) either forward or reverse.

TINAH motor output schematic

H-Bridge Chip (SN754410NE)



Output header strip – note how the pins are grouped

TINAH motor outputs – from data sheet of on-board H-Bridge

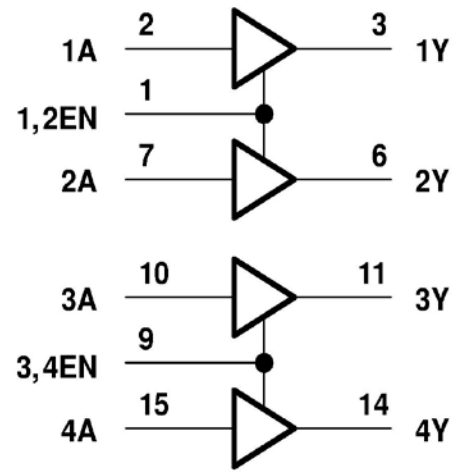
All inputs are TTL-compatible. Each output is a complete totem-pole drive circuit with a Darlington transistor sink and a pseudo-Darlington source. Drivers are enabled in pairs with drivers 1 and 2 enabled by 1,2EN and drivers 3 and 4 enabled by 3,4EN. When an enable input is high, the associated drivers are enabled, and their outputs are active and in phase with their inputs. External high-speed output clamp diodes should be used for inductive transient suppression. When the enable input is low, those drivers are disabled, and their outputs are off and in a high-impedance state. With the proper data inputs, each pair of drivers form a full-H (or bridge) reversible drive suitable for solenoid or motor applications.

A V_{CC1} terminal, separate from V_{CC2}, is provided for the logic inputs to minimize device power dissipation.

The L293D is designed for operation from 0°C to 70°C.

and IEC Publication 617-12.

logic diagram



FUNCTION TABLE
(each driver)

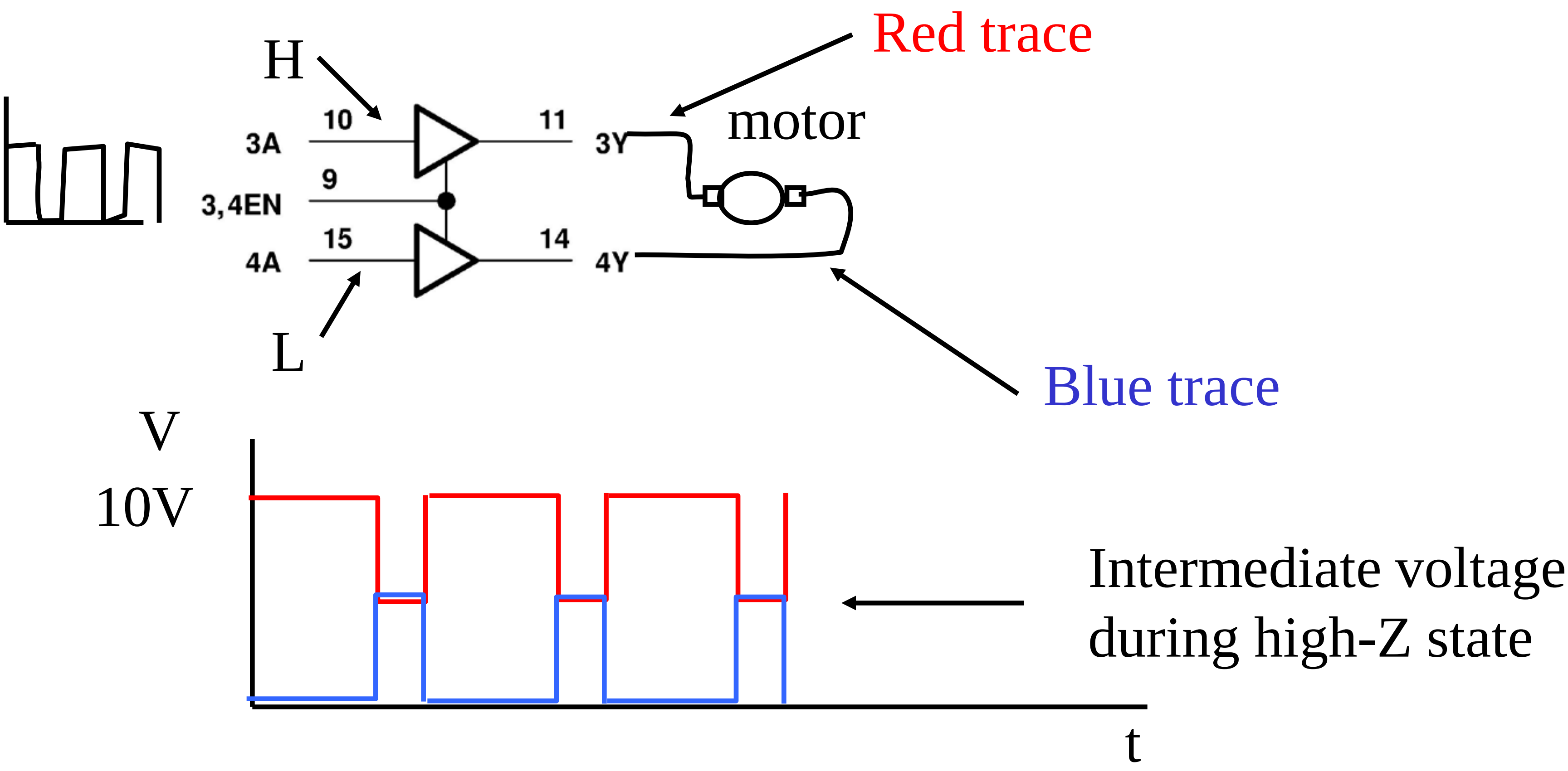
INPUTS‡		OUTPUT
A	**EN**	**Y**
H	H	H
L	H	L
X	L	Z

H = high-level, L = low level,
X = irrelevant, Z = high-impedance (off)
‡ In the thermal shutdown mode, the output is in the high-impedance state regardless of the input levels.

PWM: TINAH motor outputs

TINAH/Wiring : **motor.speed(0,700);**

→ **turn on motor 0 at ~70% duty cycle:**

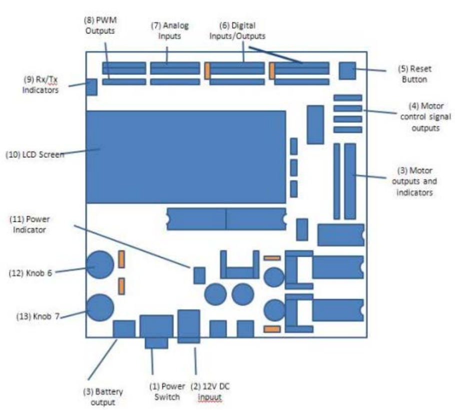


<u>PWM – regulated power vs. high-power</u>

TINAH board uses a regulated 9V for each H-bridge (L78S09CV), which remains constant under load → **increased repeatability.**

Some motors used in Phys 253 can use higher voltages and currents (e.g. 12V, 1.5 A) which cannot be achieved by the TINAH Board H-bridge chip outputs directly

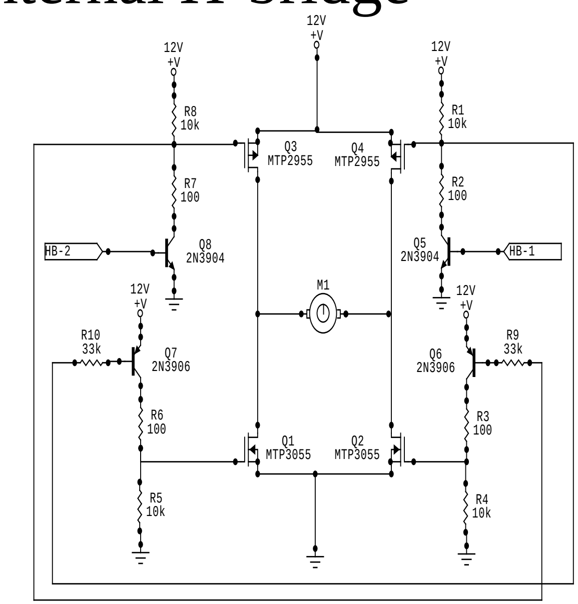
→ use **additional circuitry** to control an external H-bridge



TINAH Board

?

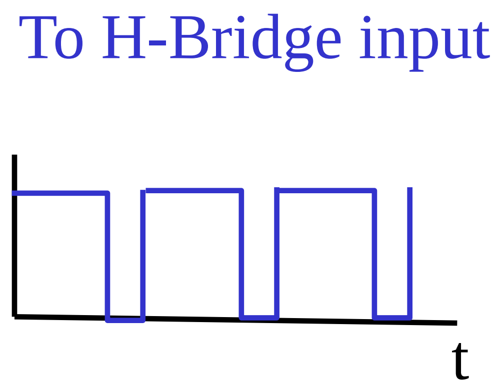
H-Bridge interface circuit

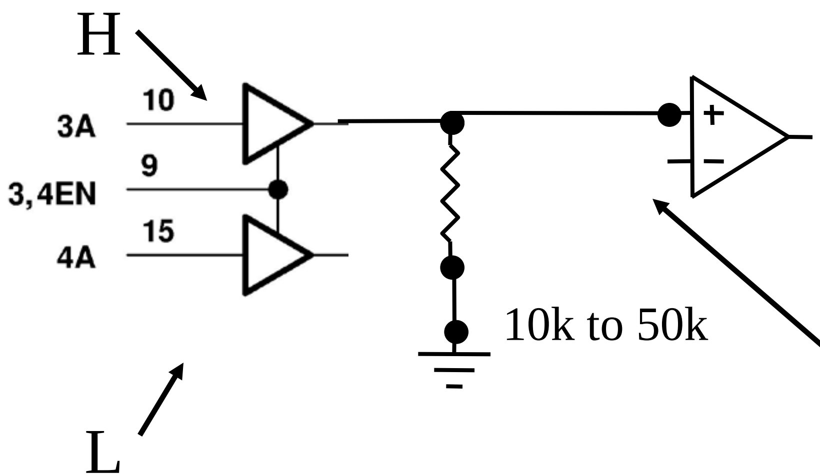


External H-Bridge

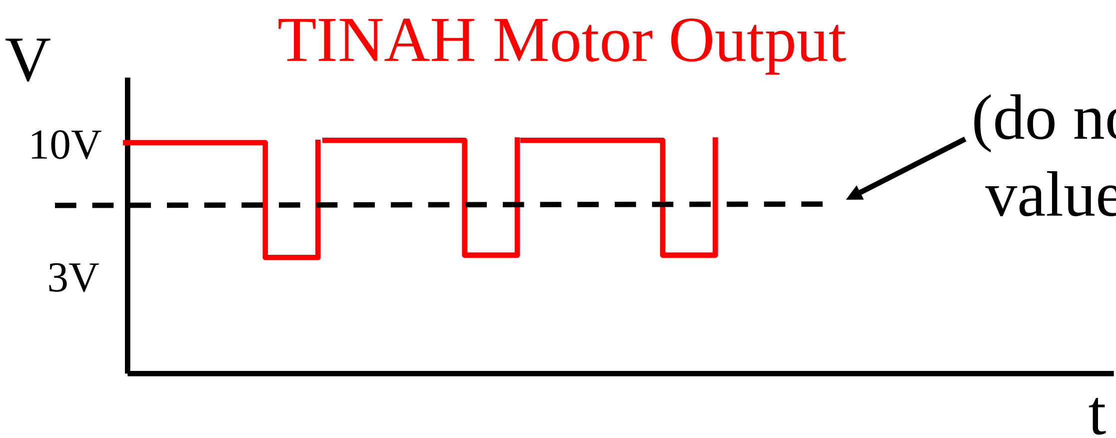
Power output: H-bridges

Need to connect TINAH motor outputs to H-bridge inputs:
Build an interface circuit for doing this





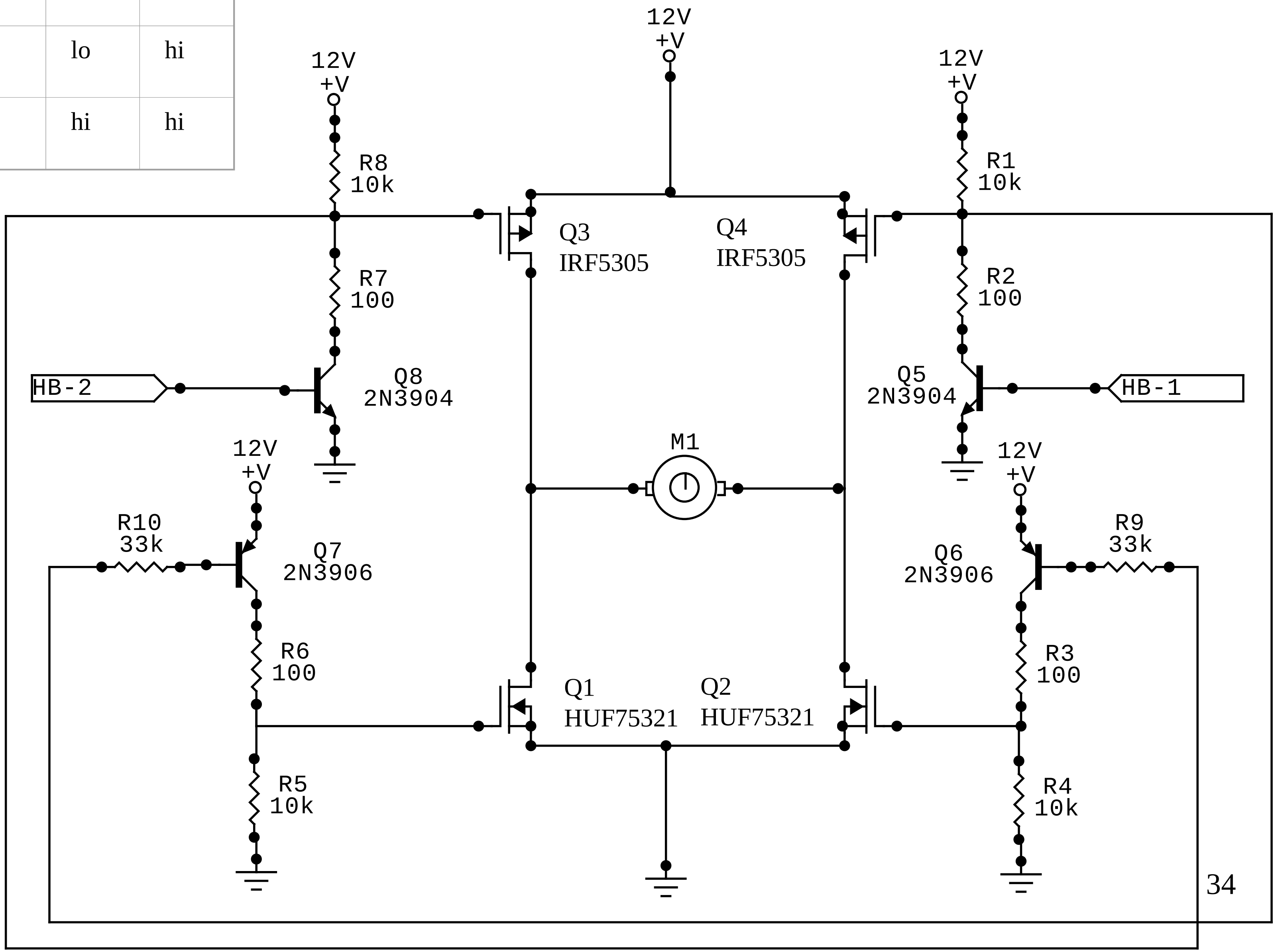
Comparator level – USE 5V FROM TINAH Board!!!

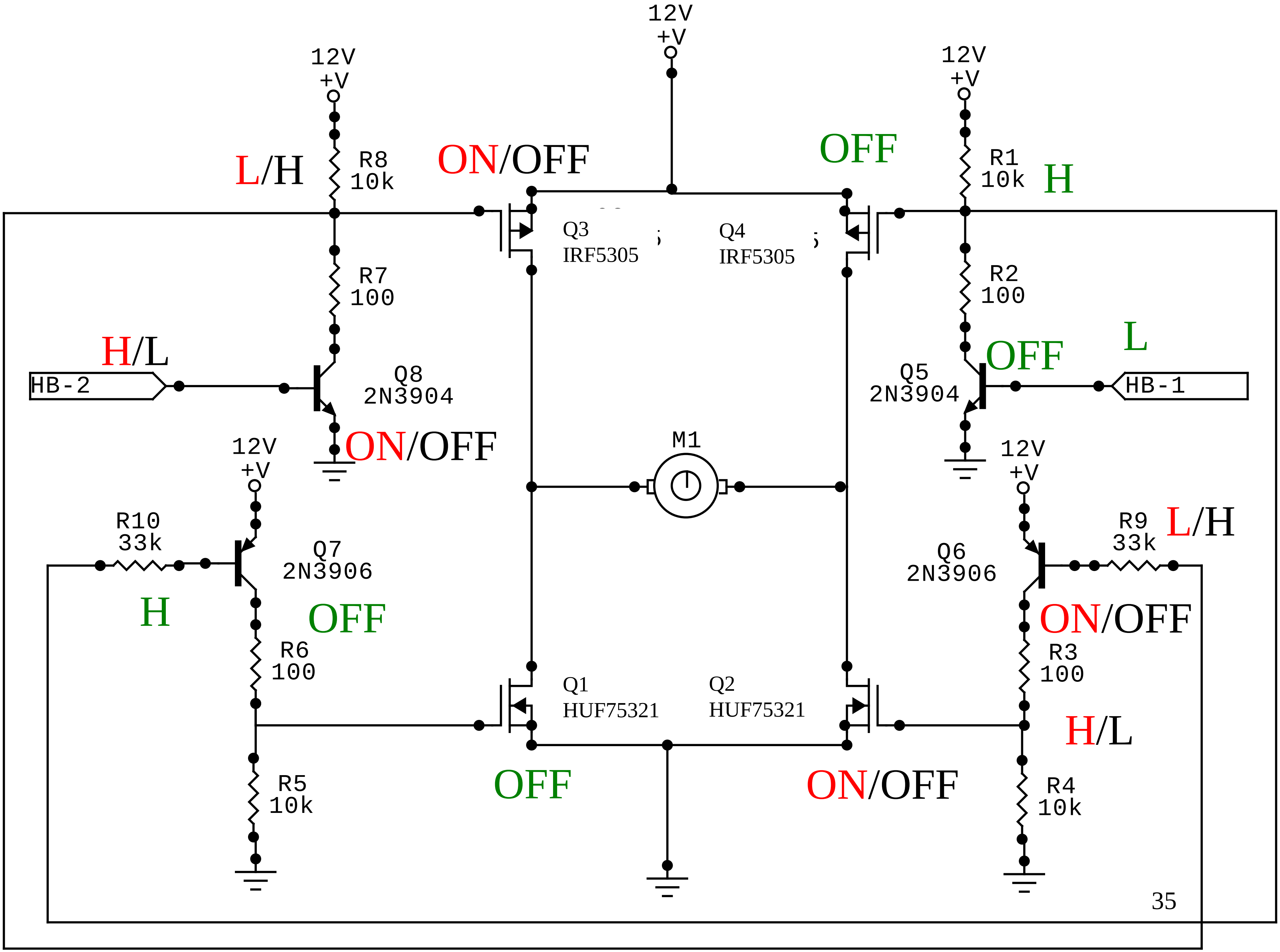


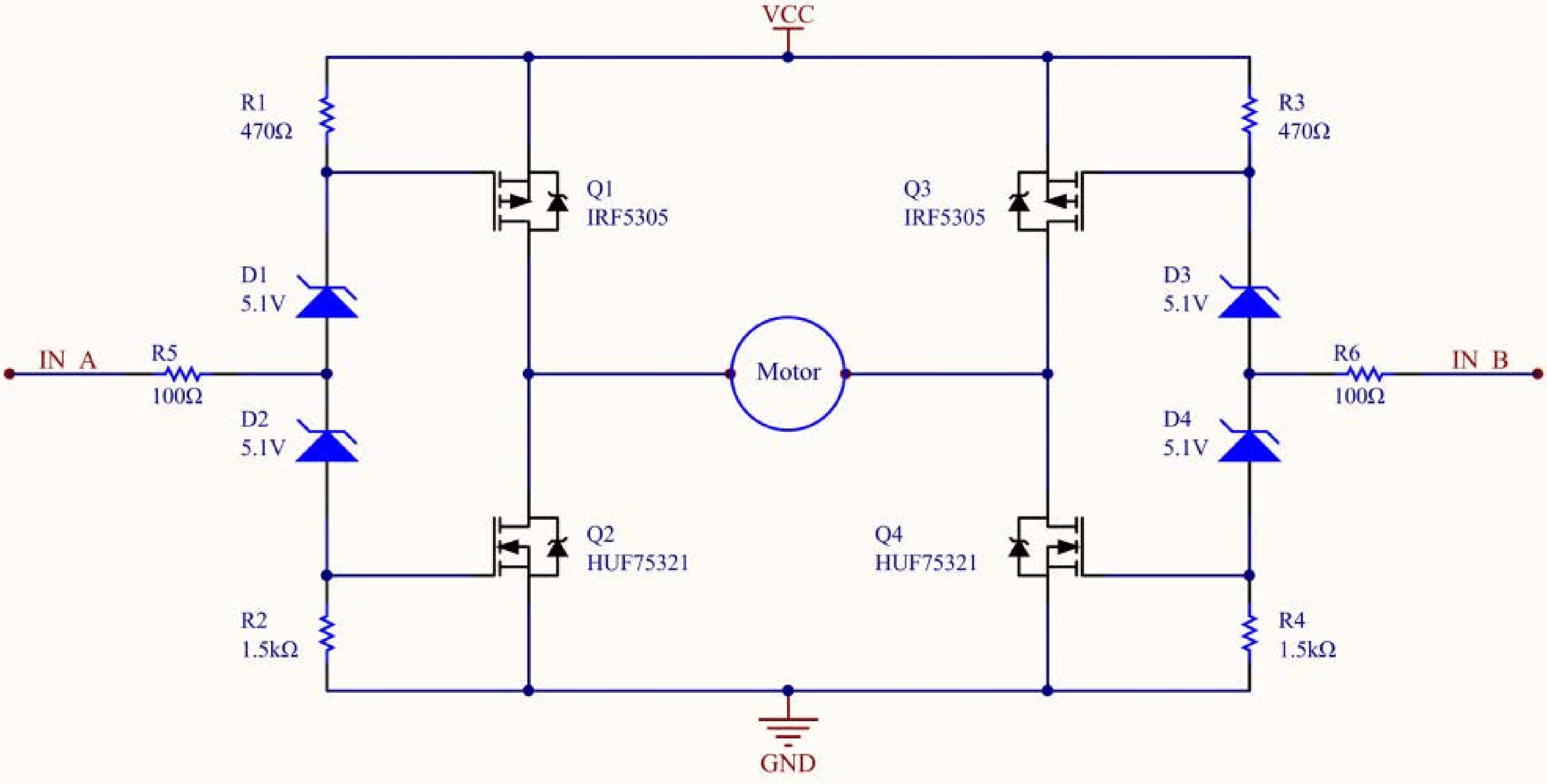
(do not use voltage divider, since value decreases with decreasing battery voltage)

Power output: H-bridges

	HB -1	HB -2
STOP	lo	lo
FORWARD	hi	lo
REVERSE	lo	hi
NOT ALLOWED	hi	hi




12V
+V
12V
+V
12V
+V
L/H
R8
10k
ON/OFF
OFF
R1
10k
H
Q3
IRF5305
Q4
IRF5305
R7
100
R2
100
H/L
HB-2
Q8
2N3904
OFF
L
Q5
2N3904
HB-1
ON/OFF
M1
12V
+V
12V
+V
R10
33k
Q7
2N3906
R9
33k
L/H
Q6
2N3906
H
OFF
ON/OFF
R6
100
R3
100
Q1
HUF75321
Q2
HUF75321
H/L
R5
10k
R4
10k
OFF
ON/OFF



Design credit: Scott Lawson