UNIVERSITY OF WOLLONGONG IN DUBAI

ECTE250
ENGINEERING DESIGN AND MANAGEMENT 2

Winter 2025 / Spring 2025

Practical Electronics 4

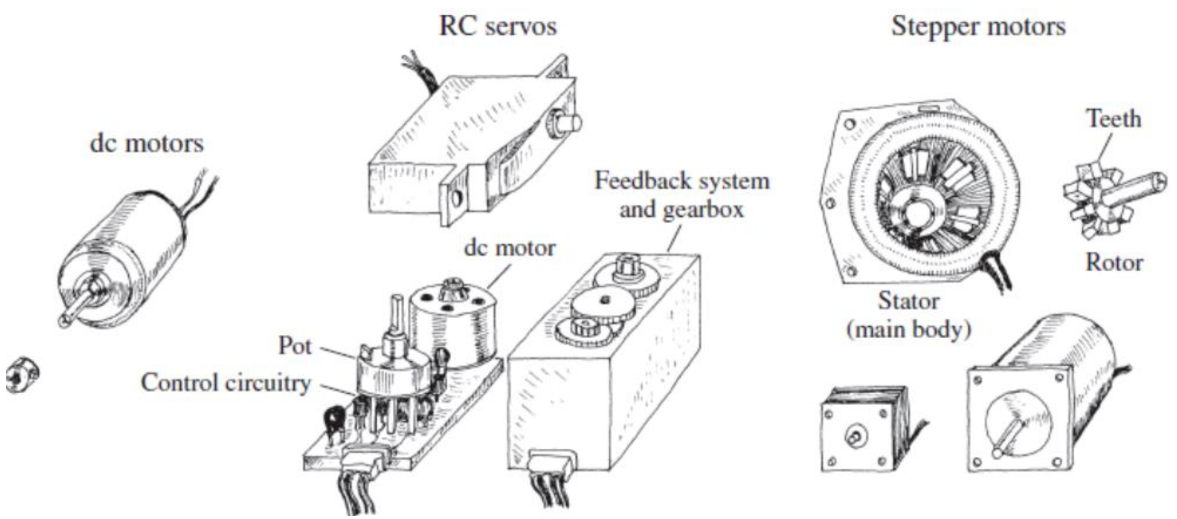
Outline

- H-bridge
- RC Servos
- Stepper motors
- Motors and Arduino

Motors

Motors

- Perhaps one of the most entertaining things to do with electronics is make some mechanical device move
- Three very popular devices used to "make things move" include dc motors, RC servos, and stepper motors



DC Motors and H-bridge

- **A *dc motor* is a simple two–lead, electrically controlled device that comes with a rotary shaft on which wheels, gears, propellers, etc., can be mounted**
- A dc motor generates a considerable amount of revolutions per minute (rpm) for its size and can be made to rotate clockwise or counter-clockwise by **reversing the polarity applied to the leads**
- At low speeds, dc motors provide little torque and minimal position control, making them impractical for point like position–control applications
- Most dc motors provide rotational speeds anywhere between 3000 and 8000 rpm at a specific operating voltage typically set between 1.5 and 24 V
- The operating voltage provided by the manufacturer tells you at what voltage the motor runs most efficiently
  - the actual voltage applied to a motor can be made slightly lower to make the motor slower or can be elevated to make the motor faster
  - when the applied voltage **drops to below around 50 percent of the specified operating voltage,** the motor usually will **cease to rotate**
  - if the applied voltage **exceeds the operating voltage by around 30 percent,** there is a chance that the motor will **overheat and become damaged**
- **the speed of a dc motor is most efficiently controlled by means of PWM** (pulse–width modulation), whereby the motor is rapidly turned on and off
  - The width of the applied pulse, as well as the period between pulses, controls the speed of the motor

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DC Motors and H-bridge

- it is worth noting that a freely running dc motor (no load) may draw little current (power).
- But, if a load is applied, the amount of current drawn by the motor's inner coils goes up immensely (up to 1000% or more {10 times!}).
- Manufacturers usually will provide what is called a ***stall current*** rating for their motors
  - This rating specifies the amount of current drawn at the moment the motor stalls
- If your motor's stall current rating is not listed, it is possible to determine it by using an ammeter
  - slowly apply a force to the motor's shaft, and note the current level at the point when the motor stalls.

DC Motors and H-bridge

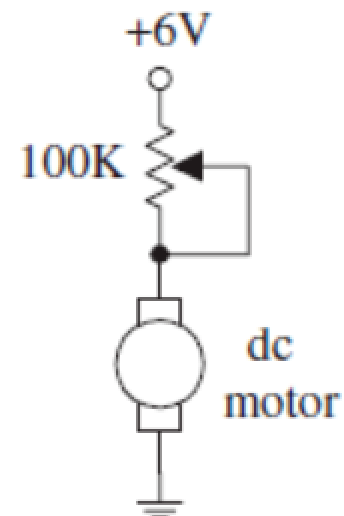
- Another specification given to dc motors is a **torque rating.**
- This rating represents the amount of force the motor can exert on a load.
- A motor with a high torque rating will exert a larger force on a load placed at a **tangent to its rotational arm** than a motor with a lower torque rating
- The torque rating of a motor is usually given in lb/ft, g/cm, or oz/in.

DC Motors and H-bridge

Speed control of small DC motors

Approach 1: Variable resistor

- seemingly obvious approach to control the speed of a dc motor would be simply to limit the current flow by using a potentiometer
- According to Ohm's law, as the resistance of the pot increases, the current decreases, and the motor will slow down
- However, using a pot to control the current flow is inefficient:
  - As the pot's resistance increases, the amount of current energy that must be converted into heat increases
  - *Producing heat in order to slow a motor down is not good: it consumes supply power and may lead to potentiometer meltdown (or will need some seriously large heat sinks)*

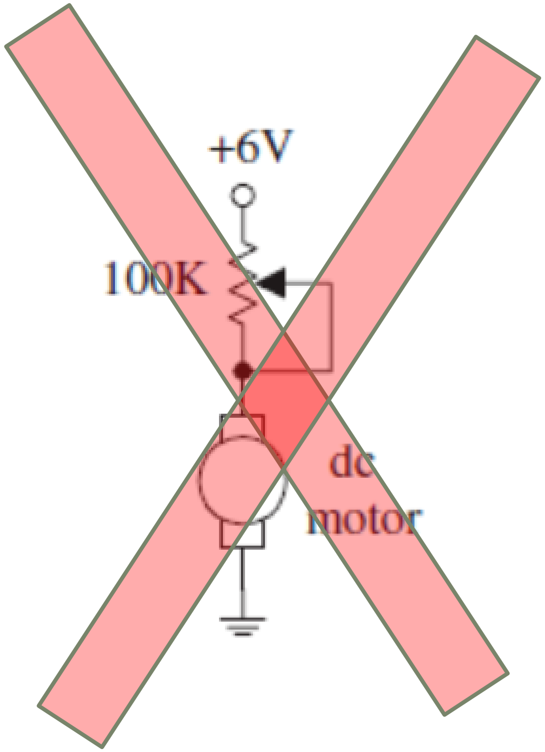


DC Motors and H-bridge

Speed control of small DC motors

Approach 1: Variable resistor

- Don’t use this Approach!!!!

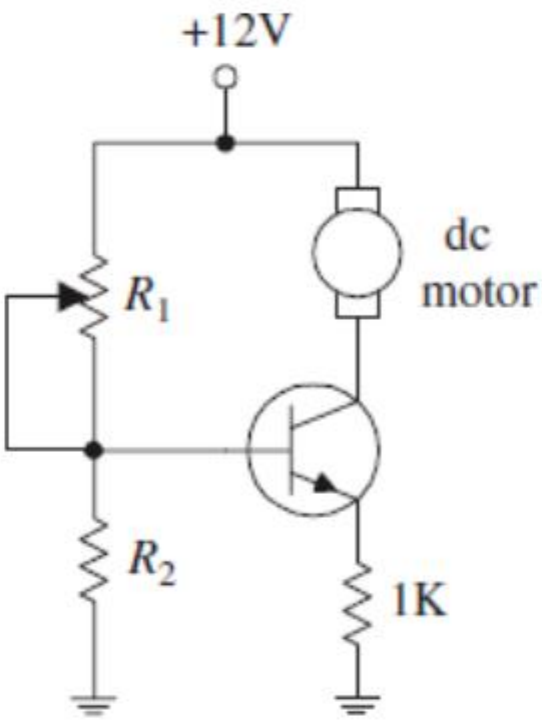


DC Motors and H-bridge

Speed control of small DC motors

Approach 2: Transistor amplifier

- Another seemingly good but inefficient approach to control the speed of a motor is to use a transistor amplifier arrangement
- As the collector-to-emitter resistance increases with varying base voltage/current, the transistor must dissipate a considerable amount of heat
  - This can lead to the transistor melting down (getting very hot, emitting smoke and that distinctive carbon based smell!)



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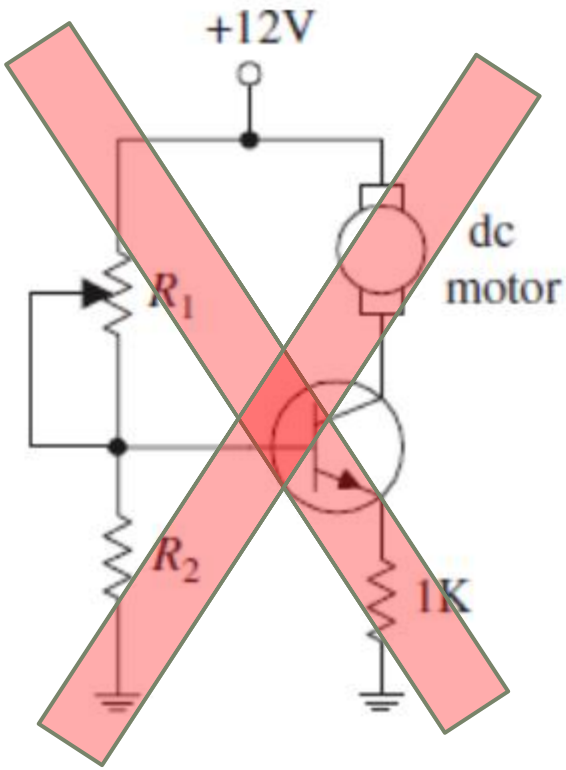
DC Motors and H-bridge

Speed control of small DC motors

Approach 2: Transistor amplifier

- Don’t use this Approach!!!!



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DC Motors and H-bridge

Speed control of small DC motors

- Successful small dc motor speed control which conserves energy and prevents electronic component meltdown involves simply using dc pulses of varying width and frequency (called Pulse Width Modulation PWM)
- These varying width and frequency pulses can control the speed of the motor while **preventing** any particular electronic component from experiencing **continuous current stress**
- So three better circuit ideas is to use
  - Unipolar Junction Transistor (UJT) with an SCR (Silicon Controlled Rectifier) – this will probably covered in power engineering specialisation subjects – we don't normally use them in small projects.
  - NAND gates with MOSFET
  - 555 timer IC with MOSFET

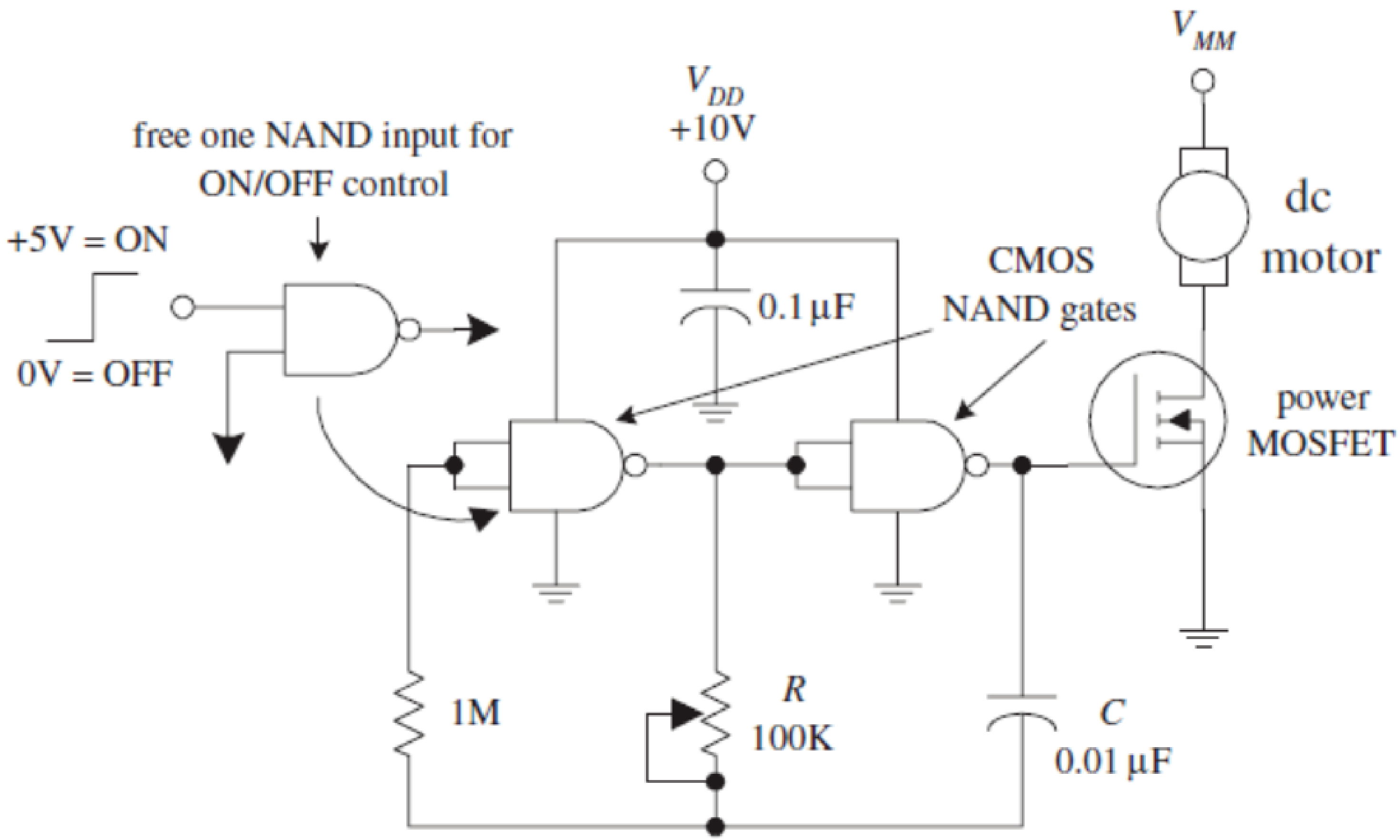
DC Motors and H-bridge

Speed control of small DC motors (circuit on next slide)

- a pair of NAND gates make up the relaxation oscillator section generating a series of pulses while an enhancement type MOSFET is used to drive the motor
- the speed of the motor is controlled by the relaxation oscillator's RC time constant
- Notice that if one of the input leads of the left NAND gate is pulled out, it is possible to create an extra terminal that can be used to provide on/off controls that can be interfaced with CMOS logic circuits

DC Motors and H-bridge

CMOS/MOSFET Control Circuit



DC Motors and H-bridge

Speed control of small DC motors (circuit on next slide)

- A 555 timer (NE555) is used to generate pulses that drive a power enhancement mode MOSFET

- Note this is the circuit version which allows for duty cycles less than 50% (note diode across R_2) and we can use the formulas seen last week and in this figure for this circuit to work out the frequency and duty cycles that's applied as pulses to the power FET

DC Motors and H-bridge

555 Timer/MOSFET Control Circuit

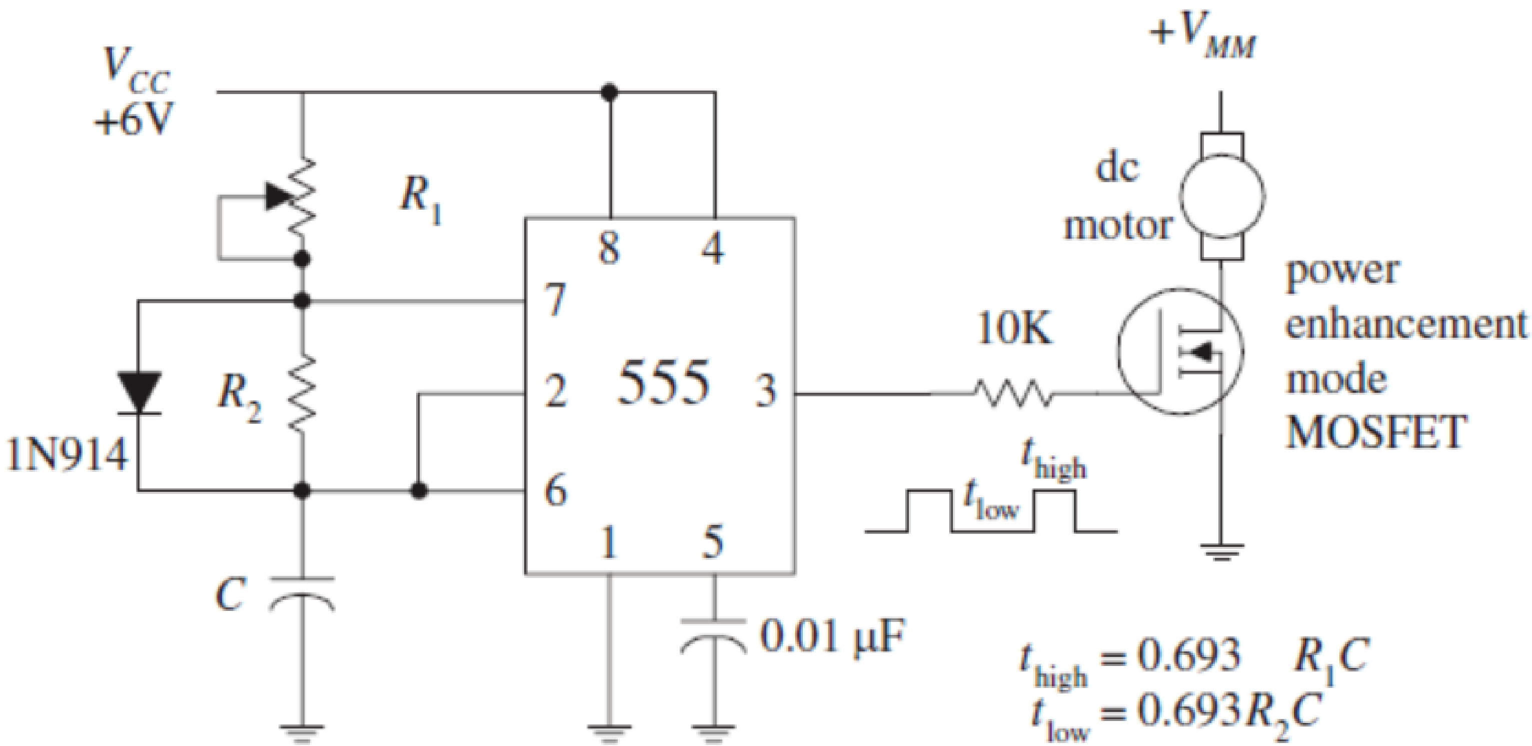


Figure 14.3.

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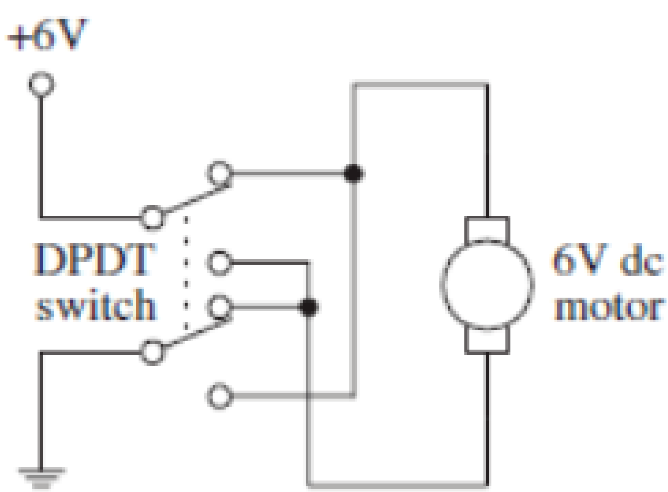
DC Motors and H-bridge

Directional Control of DC motors

- To control the direction of a motor, the polarity applied to the motor's leads must be reversed
- A simple manual–control approach is to use a DPDT switch:



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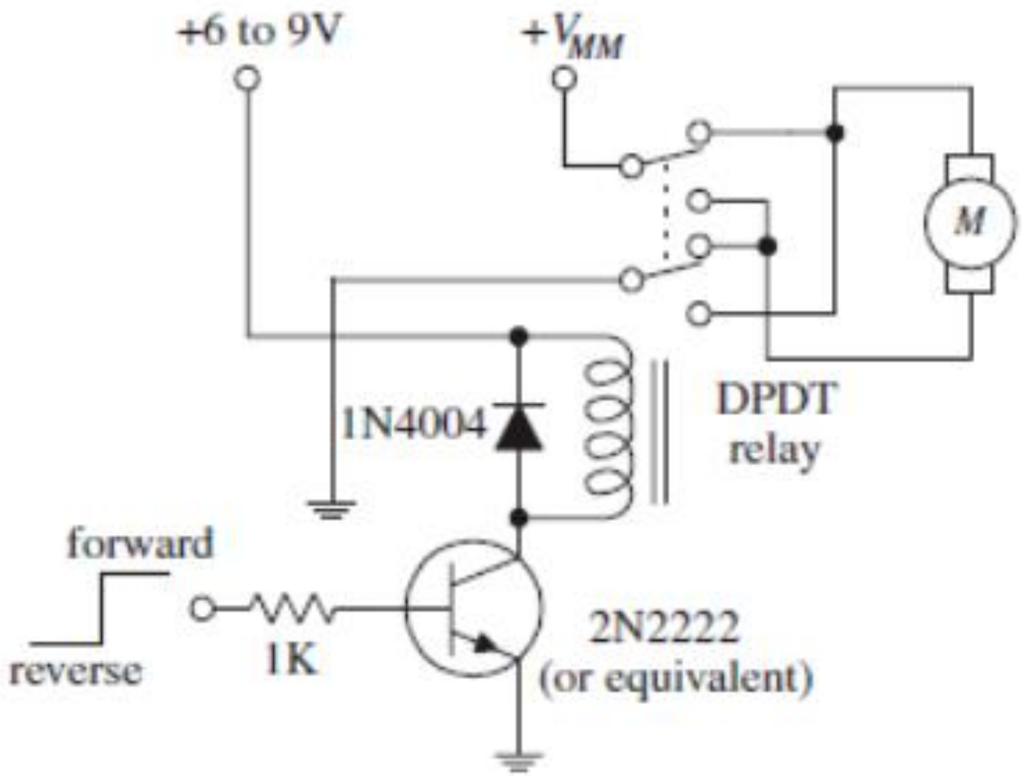
DC Motors and H-bridge

Directional Control of DC motors

- Or a transistor–driven DPDT relay can be used:



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DC Motors and H-bridge

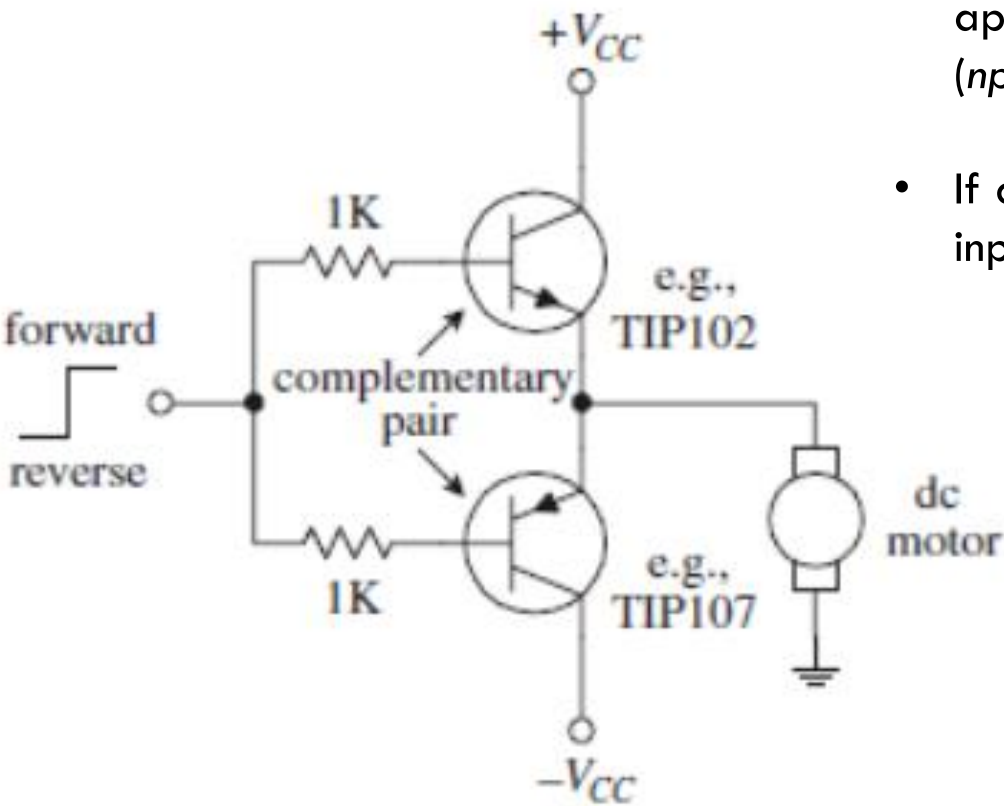
Directional Control of DC motors (circuit on next slide)

- Or you can use a **push-pull circuit**:
  This circuit uses a complementary pair of transistors (similar betas and power rating)—one is an *npn* power Darlington, and the other is a *pnp* power Darlington.

- When a high voltage (e.g., +5 V) is applied to the input, the upper transistor (*npn*) conducts, allowing current to pass from the positive supply through the motor and into ground.

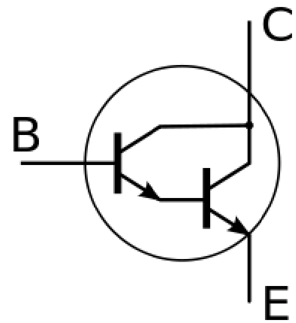
- If a low voltage (0 V) is applied to the input, the lower transistor (*pnp*) conducts, allowing current to pass through the motor from ground into the negative supply terminal

DC Motors and H-bridge



- When a high voltage (e.g., +5 V) is applied to the input, the upper transistor (*npn*) conducts.
- If a low voltage (0 V) is applied to the input, the lower transistor (*pnp*) conducts.

Darlington Pair



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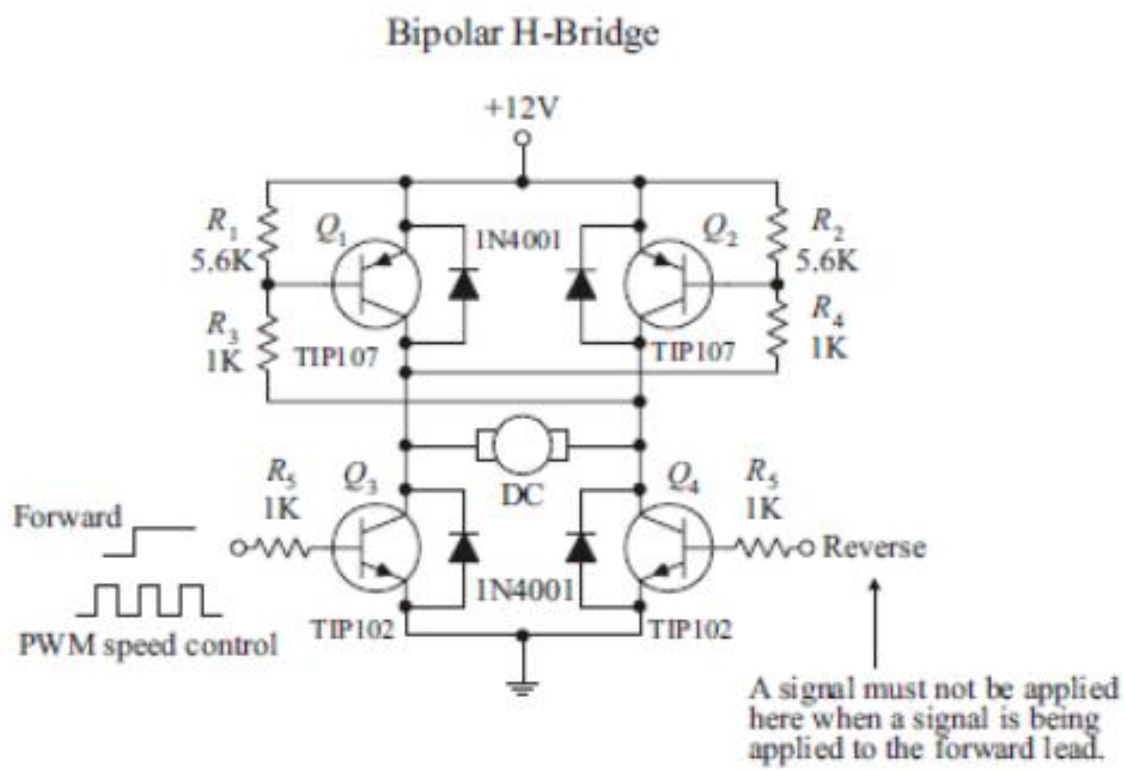
DC Motors and H-bridge

- Another very popular circuit used to control the direction of a motor (as well as the speed) is the **H–bridge**

Here is a H-bridge constructed from bipolar transistors:



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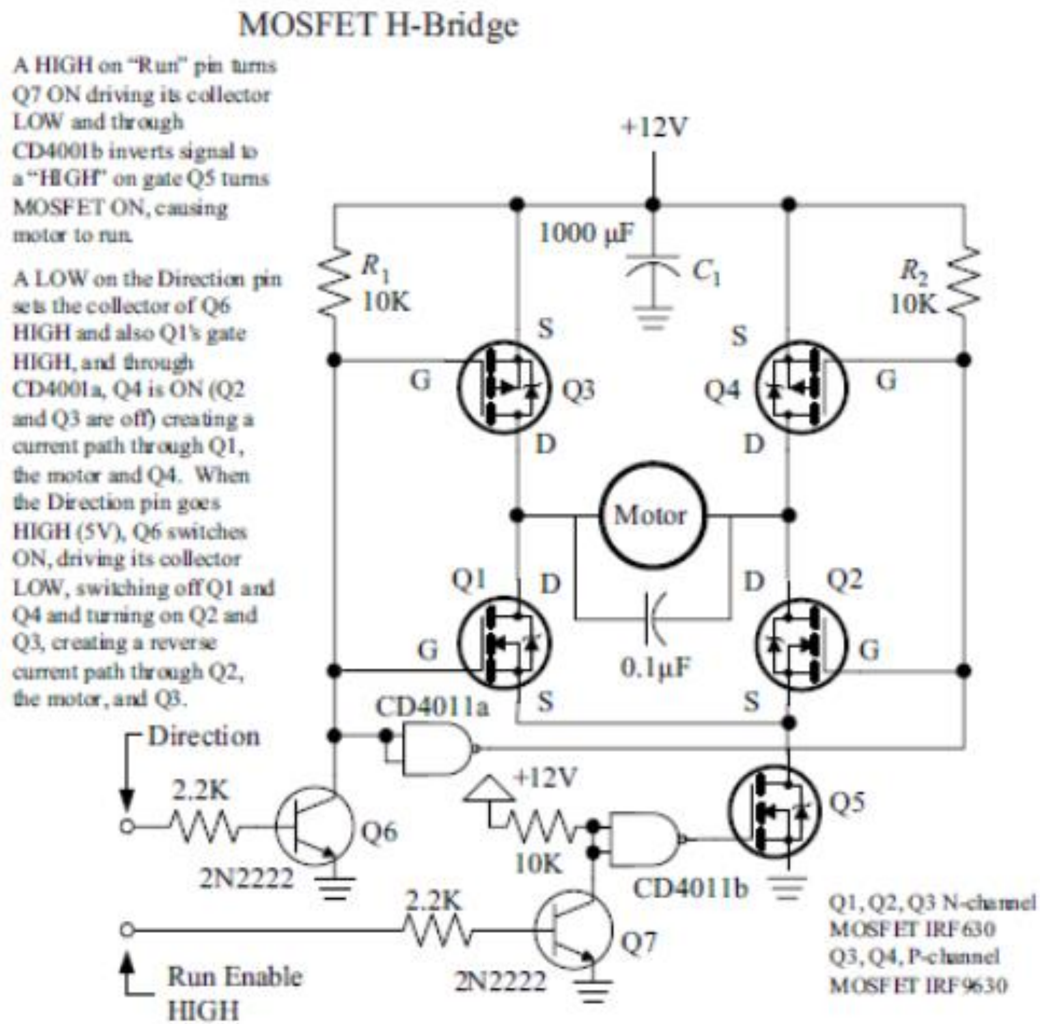
DC Motors and H-bridge

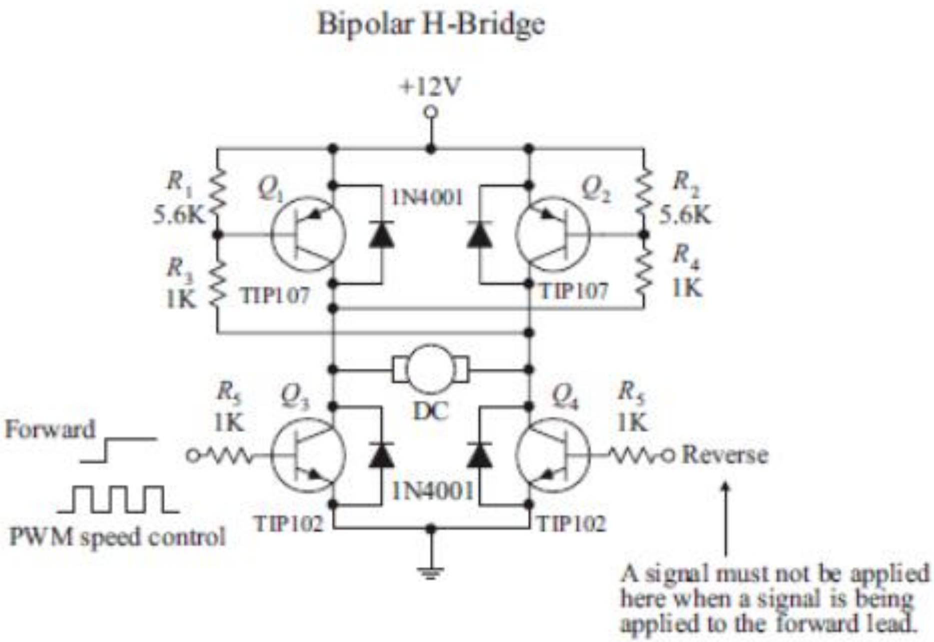
- Here is a H-bridge constructed from MOSFETS:



DC Motors and H-bridge

- To make the motor rotate in the forward direction, a high (+5V) signal is applied to the forward input, while no signal is applied to the reverse input (applying a voltage to both inputs at the same time is not allowed)

The speed of the motor is can be controlled by PWM



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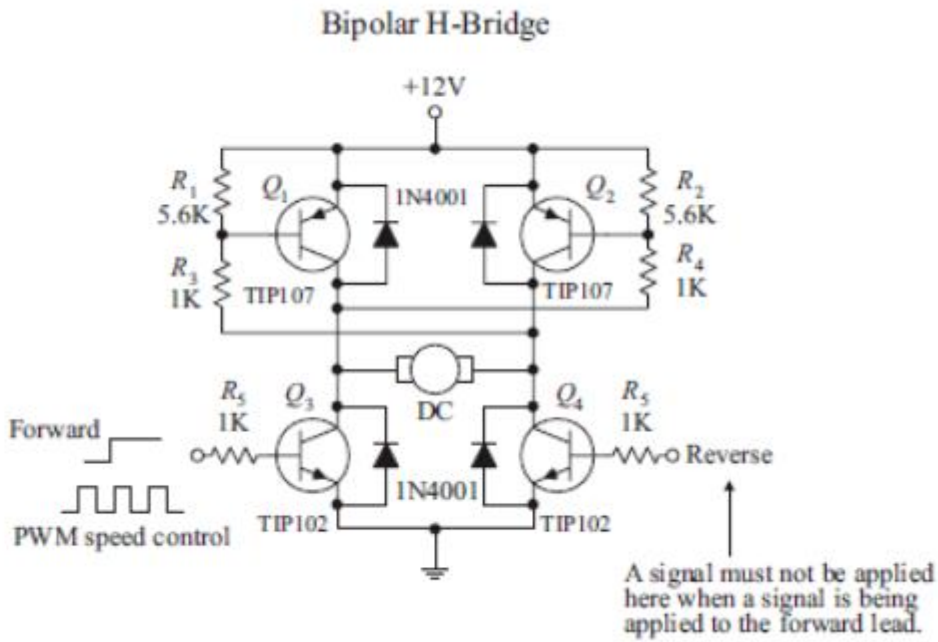
DC Motors and H-bridge

- When a high voltage is applied to Q_3's base, Q_3 conducts, which in turn allows the *pnp* transistor Q_2 to conduct. Current then flows from the positive supply terminal through the motor in the right–to–left direction (call it the *forward direction* if you like).

To reverse the motor's direction, the high voltage signal is removed from Q_3's base and placed on Q_4's base. This sets Q_4 and Q_1 into conduction, allowing current to pass through the motor in the opposite direction



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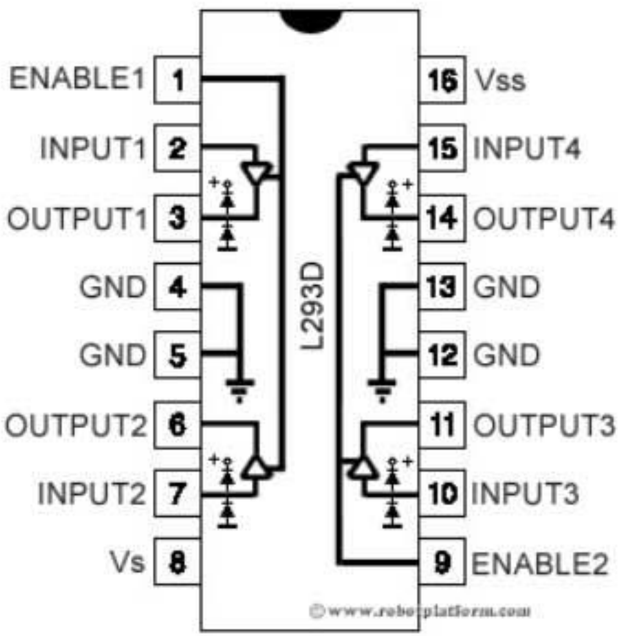
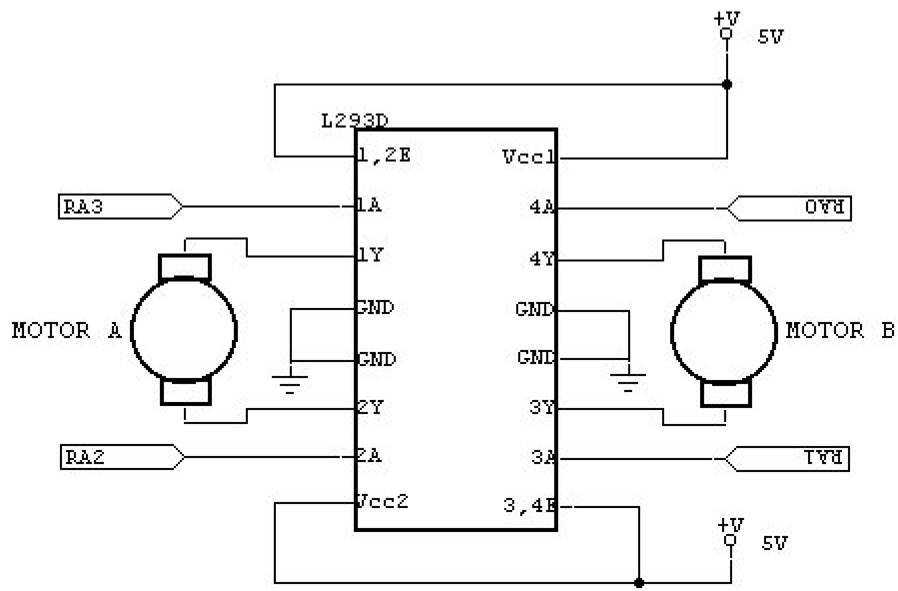
DC Motors and H-bridge

- it is possible to construct these H–bridge circuits from scratch, but it is far easier and usually cheaper to buy a motor–driven IC
- The Arduino Kit has the L293D which includes the diode protection shown in the bipolar H-bridge (if these were not in the IC package we would have to apply them externally to avoid causing damage to the Arduino or other device was generating the speed control pulses)
- The draw back of this H-bridge (not a problem for an ECTE250 project) is that the maximum current is about 600mA.

DC Motors and H-bridge

- The L293D can be used to drive two DC motors or 1 bipolar stepper motor.





DC Motors and H-bridge

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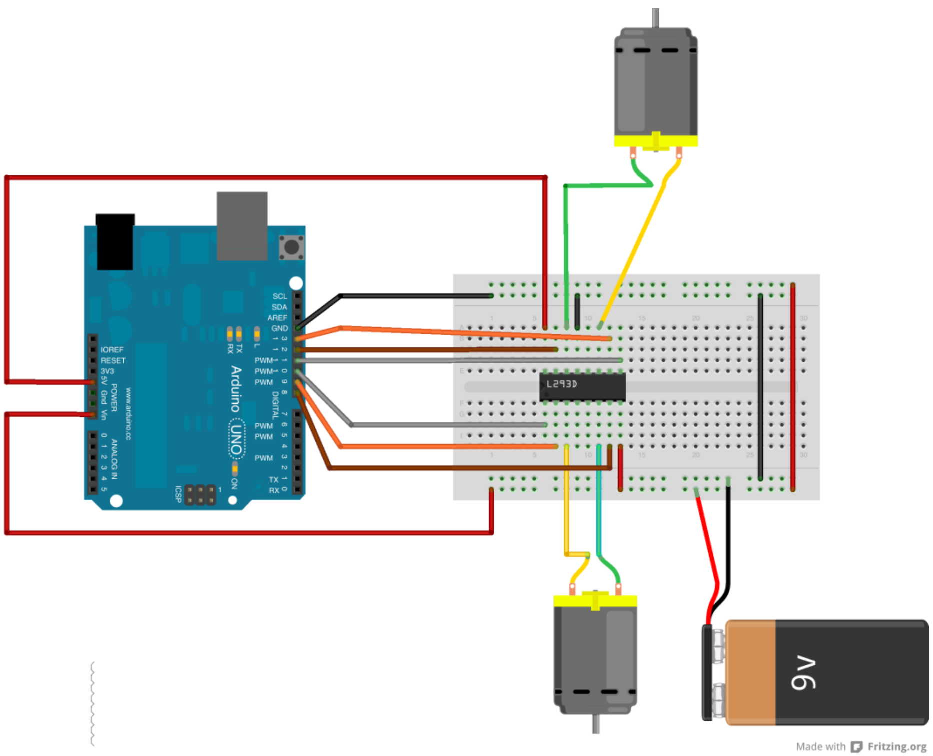

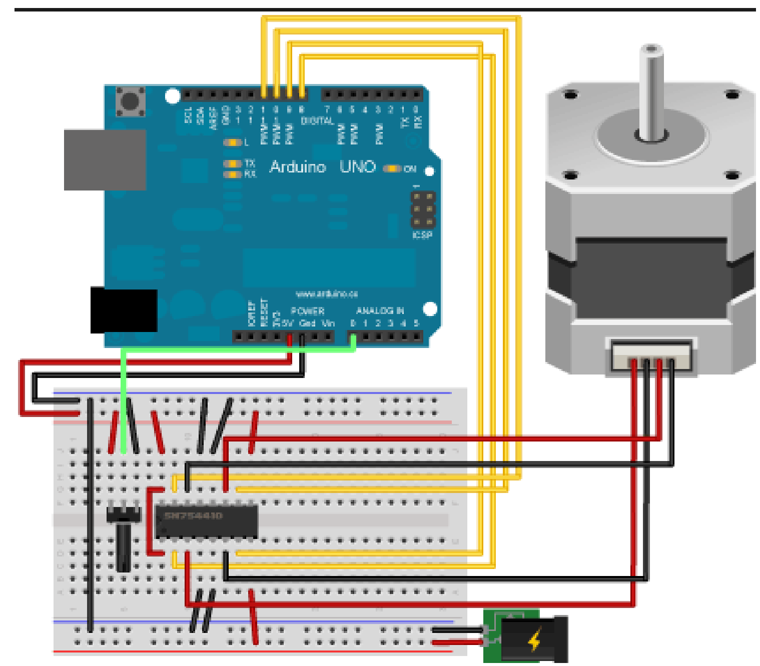

DC Motors and H-bridge

- The PWM frequency to drive motors (DC, Servo) quite low (usually 50Hz). Microcontrollers (including the AVR on the Arduino board) can synthesize a low frequency PWM on any output pin (i.e. you do not have to use the “~” output)

RC Servos

- Section 14.4 of “Practical Electronics for Inventors” covers Remote Control Servos and would be helpful if using the servo in your design

- *Remote Control* (*RC*) *Servos*, unlike dc motors, are motor-like devices designed specifically for pointer-like **position–control** applications (control in position instead of control in speed as DC motors).

- A small one included in the Arduino kit

RC Servos

- An RC servo uses an external pulse–width–modulated (PWM) signal to **control the position of its shaft to within a small fraction of its maximum range of rotation.**
  - used commonly in robotics as well as in many sensor–positioning applications
- To alter the position of the shaft, the pulse width of the modulated signal is varied
- The amount of angular rotation of an RC servo's shaft is limited to around 180 or 210° depending on the specific model of servo
  - The Arduino kits servo rotates over only 180 degrees
  - Also, the Arduino has a library specifically designed for Servos which you can use in your projects (no need to re-invent code – that's for ecte333 / ecte350 projects).
- These devices can provide a significant amount of low–speed torque (due to an internal gearing system) and provide moderate full–swing displacement switching speeds
  - RC servos frequently are used to control steering in model cars, boats, and airplanes

RC Servos

- The standard RC servo looks like a simple box with a drive shaft and **three wires coming** out of it
- The three wires consist of a power supply wire (usually black), a ground wire (usually red), and the shaft–positioning control wire (color varies based on manufacturer – in the one coming with the Arduino kits this control wire is 'white')
- Within the box there is a **dc motor, a feedback device, and a control circuit** (that's why its rectangular)
- The feedback device usually consists of a potentiometer whose control dial is mechanically linked to the motor through a series of gears
- When the motor is rotated, the potentiometer's control dial is rotated
- The shaft of the motor is usually limited to a rotation of 180° (or 210°)—a result of the potentiometer (pot) not being able to rotate indefinitely
- The ***pot*** acts as a position–monitoring device that tells the control circuit (by means of its resistance) exactly how far the shaft has been rotated
- The control circuit uses this resistance, along with a pulse–width–modulated input control signal, to drive the motor a specific number of degrees and then hold
  - The amount of holding torque varies from servo to servo
- **The width of the input signal determines how far the servo's shaft will be rotated**

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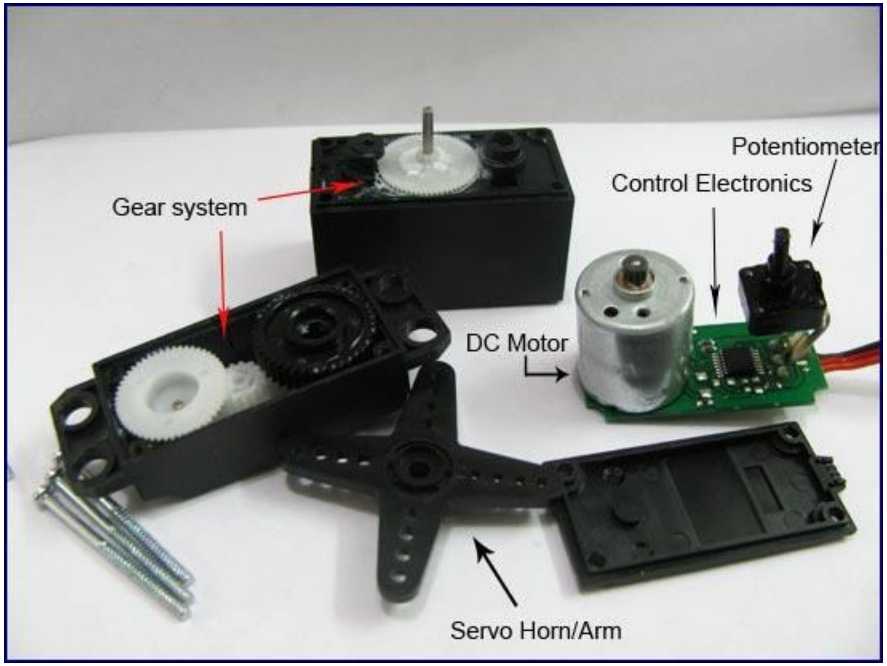
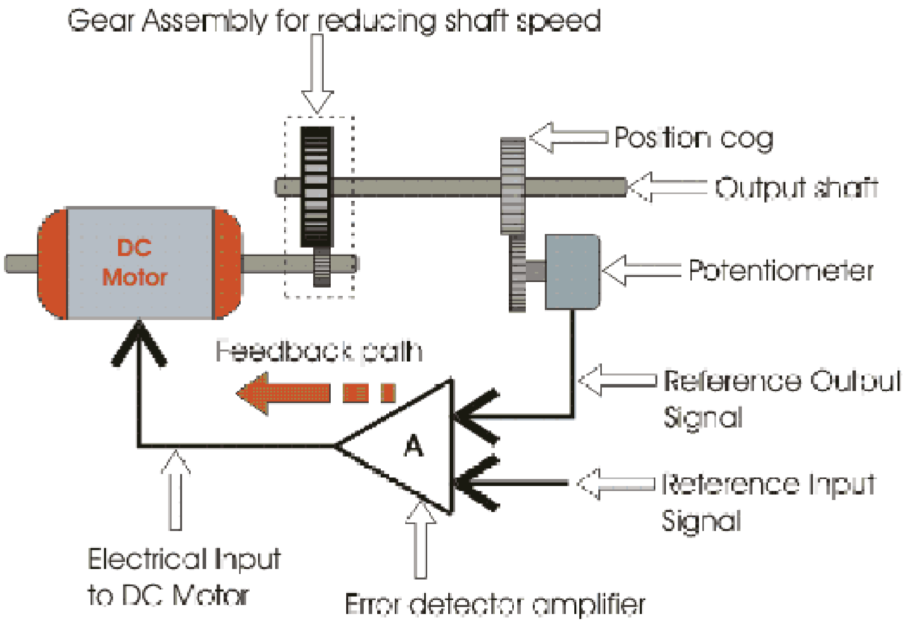
RC Servos


PARALLAX
www.parallaxinc.com

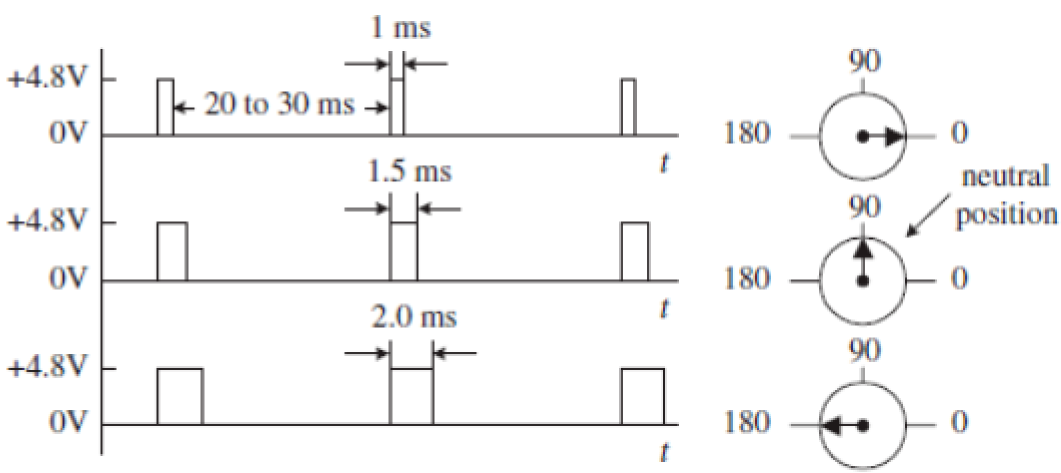

Gear system
Potentiometer
Control Electronics
DC Motor
Servo Horn/Arm


Gear Assembly for reducing shaft speed
Position cog
Output shaft
DC Motor
Potentiometer
Feedback path
Reference Output Signal
A
Reference Input Signal
Electrical Input to DC Motor
Error detector amplifier

RC Servos

- By convention, when the pulse width is set to 1.5 ms, the servo rotates its shaft to neutral position
  - e.g., 90° if the servo is constrained within a 0 to 180° range
- To rotate the shaft a certain number of degrees from neutral position, the pulse width of the control signal is varied
- To make the shaft go counter-clockwise from neutral, a pulse wider than 1.5 ms is applied to the control input
- Conversely, to make the shaft go clockwise from neutral, a pulse narrower than 1.5 ms is applied

A typical servo-control signal and shaft-position response



RC Servos

- Knowing exactly how much wider or narrower to make the pulse to achieve exact angular displacements depends largely on what model of servo you are using
  - example, one model of servo may provide maximum counter-clockwise rotation at 1 ms and maximum clockwise rotation at 2 ms,
  - whereas another may provide maximum counter-clockwise rotation at 1.25 ms and maximum clockwise rotation at 1.75 ms

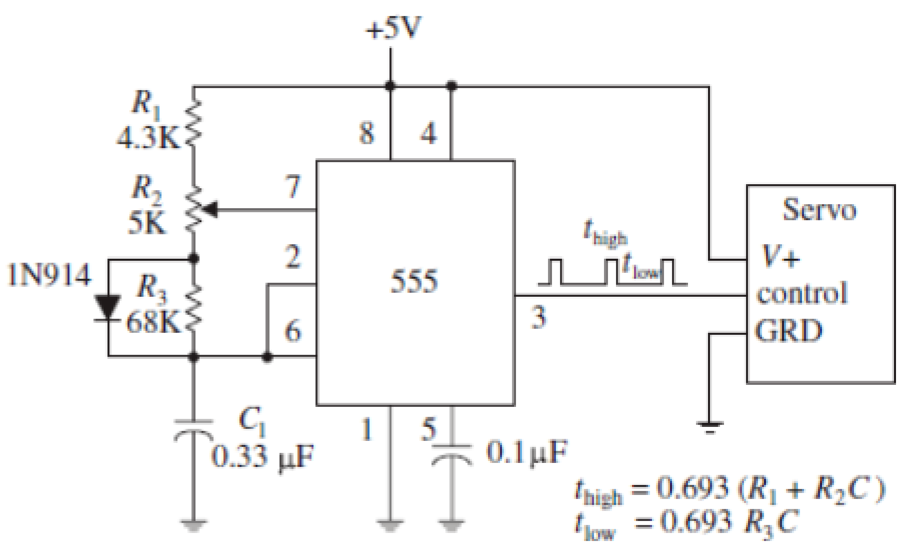
- The supply voltage used to power servos is commonly 4.8 V, can go up to 6.0 V depending on the specific model of servo

- Unlike the supply voltage, the supply current drawn by a servo varies greatly, depending on servo's power output

RC Servos

- A simple 555 timer circuit can be used to generate the servo control signal:

Simple servo driver



In this circuit, R_2 acts as the pulse–width control.

Stepper motors

- Stepper motors are covered in Sections 14.5 through to Section 14.8 (which includes using the ULN2003 Darlington transistor array which has been included in ECTE250 parts list) of "Practical Electronics for Inventors" , however there are no stepper motors in the Arduino kit

- Stepper motors have been used in the past in ECTE250 and ECTE350 projects and provided a case was properly made they could be ordered in ECTE250 (assuming within parts budget).

Motors and Arduino

- The Arduino project booklet has many activities that use Motors and H-bridges - Experiment 5 (Servo motor), 9 (dc permanent magnet motor), 10 (dc permanent magnet motor and H-bridge),12 (Servo motor and Arduino)

- Hopefully you have already done these experiments in the first weeks, but if not you can use these experiments if you need to use the DC motor or the RC servos motor that came with the kit

Bipolar Transistors

- https://www.youtube.com/watch?v=7ukDKVHnac4

Acknowledgement

- Peter Vial, UOW; Stefano Fasciani, Oslo University