6.270 Lecture

Sensors, Motors, Gear Ratios, & Motor DC Theory

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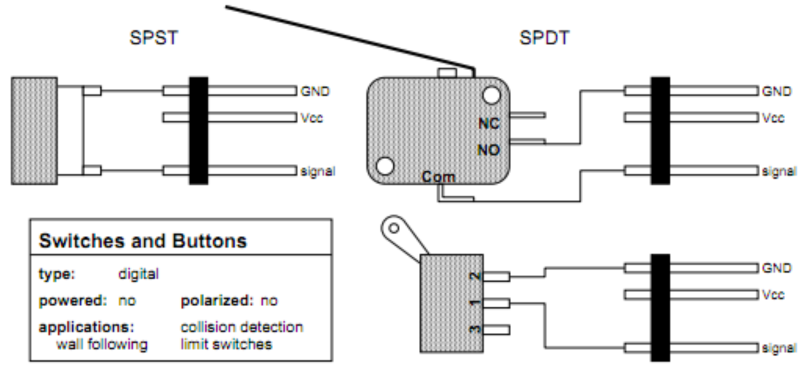
Overview of Lecture

- Sensors
  - Switches, Breakbeam/Optical Encoders, GyroScopes,
  - Pull-up/Down Resistors

  IR-LED & Phototransistor, & Sharp IR Distance Sensor
- Motors
  - 6.270 DC Motor
  - Servo Motor
  - Continuous Servo Motor
- Gear Ratios
  - Torque and Speed Tradeoff
  - Sample Calculation/s
- DC Motor Theory
  - PWM / H-bridge
  - Torque vs Speed, Current, Power, and Efficiency Curves
  - Sample Calculation/s

Sensors - Switches



- Digital Input – Only Binary outputs (1 or 0)

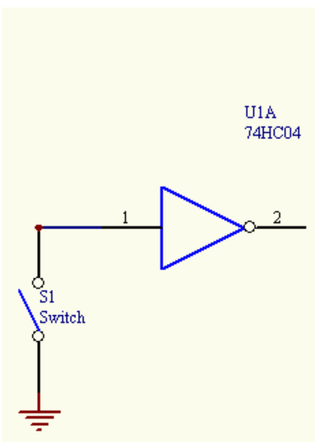
Wiring (Pins 0-23); Pins(0-7 recommended)

  - Single Pole Single Throw (SPST) Single Pole Double Throw (SPDT)
  - Normally Open (NO or digital output is 0 unless switch is pressed) vs. Normally Close (NC or digital output is 1 unless switch is pressed)
- Applications Wall Following, Alignment, Logic Stop
- Note about Pull-Up/Pull-Down Resistors
- Example on HappyBoard
  - digital_read(Port #)

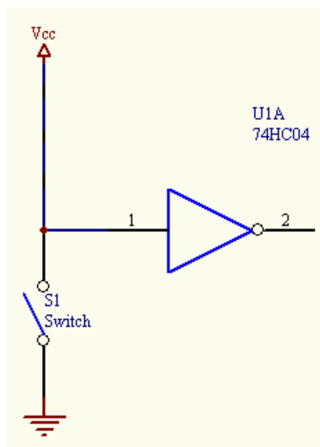
- For Digital Inputs: Always have Pull-up Resistors ON

Pull-Up, Pull-Down Resistors

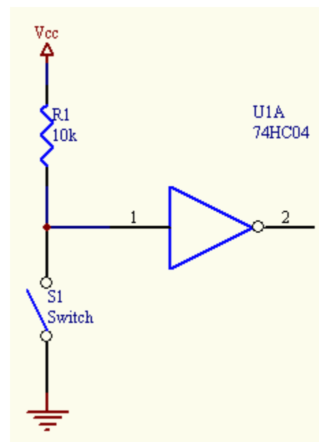
- Logic gates can have floating values (1 or 0).
  - Susceptible to Electrical Noise
- Pull-up/down Resistors always gives a definite value to logic.



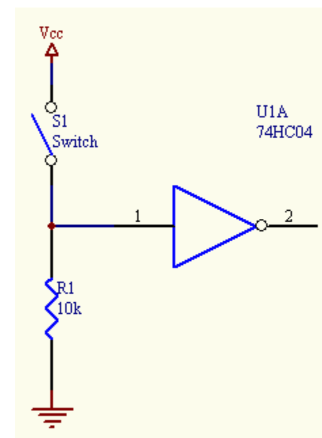
BAD: Floating Logic Gate Susceptible to Electrical Noise



BAD: Solves Problem until switch is closed leading to a short



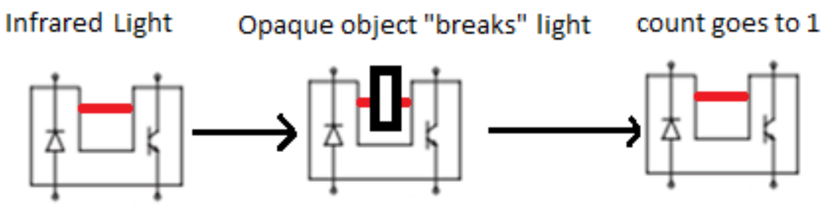
GOOD – Pull-up - When Switch is OFF, Logic is set to HIGH

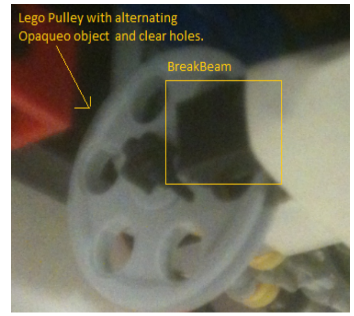


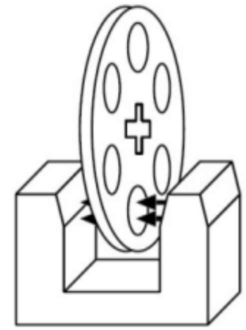
GOOD –Pull-down. When switch is OFF, Logic is set to LOW.

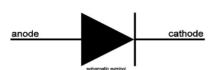
- Images from: http://www.seattlerobotics.org/encoder/mar97/basics.html

Sensors:
BreakBeam/Optical Shaft Encoders



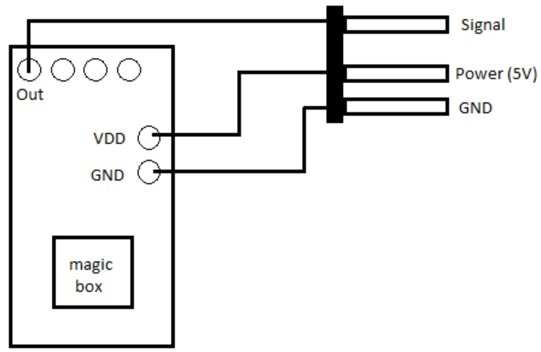




- Encoder Input (24-27): Transitive analog/Digital
  - IR-LED on Left, Photo*transistor* on right
- Wiring Tips
  - Look for Diode Symbol 

  - GNDs are Diagonal from each other.
- Applications – Track # of Wheel Rotations. Distance Calculation
- Happy Test Example
  - encoder_read(port#) and encoder_reset(port#)

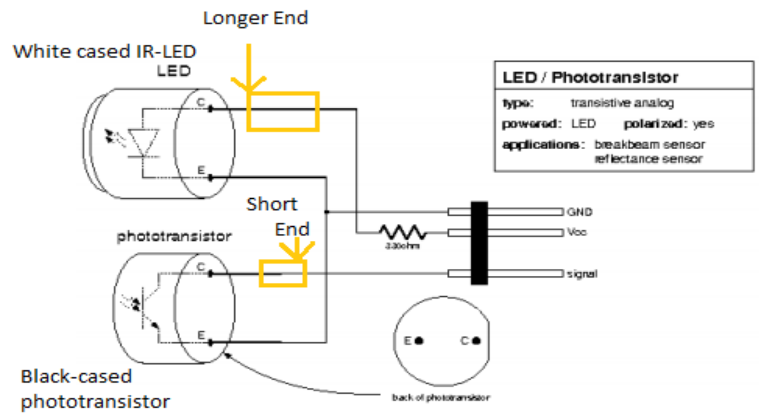
Sensors: Gyroscopes



- Analog (8-23)
  - Recommended (20-23) with Pull-Up resistors to OFF
- Application: Measures the *perpendicular Axis of Rotation* using Velocity Integration:
  - Constant of Integration builds up error over time $x = \int v\,dt + C$

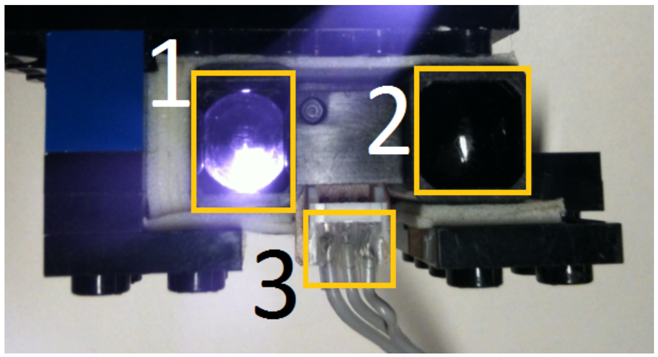
- Needs Calibration of Rotation Angle Multiplier
- HappyBoard Example
  - gyro_init (GYRO_PORT, LSB_US_PER_DEG, 500L);
    - Robot should be stationary during calibration
  - gyro_get_degrees() returns float

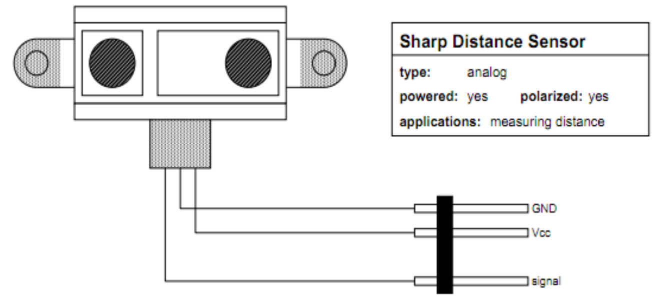
Sensors: IR-LED + Phototransistor



- Analog Input(0-23): For 20-23, have the Pull-ups ON
- InfraRed is emmited from LED. Photo*transistor* Receives light.
  - More Light = Lower Resistance = Lower analog Value
- Applications: BreakBeam, Line Follower, Light Follower
- HappyTest Example:
  - analog_read(port#)

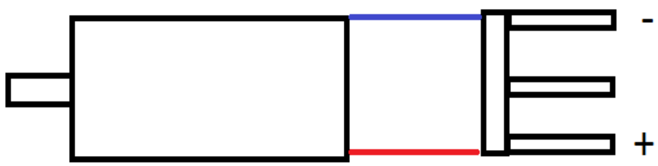
IR + Sharp Distance Sensor

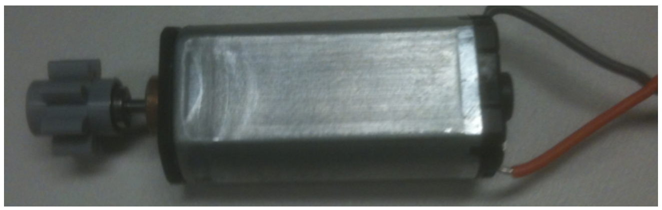




- Applications – measures distances from 8”-60”
  - Doesn’t have to be perpendicular.
- Analog Input, pins **20-23 only**. Pull-Up Resistors are OFF. (See HappyLab for ‘loophole’)
  - Sensor provides its own analog input.
- Near-Infrared is emitted from #1; #2 Measures Angle.
- Needs Calibration
  - Non-linear method of measuring distances
- HappyBoard Example: irdist_read(Port#) returns float in cm

Motors: DC Motor





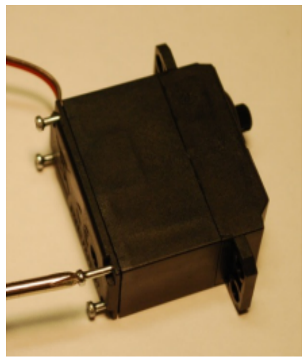
	Reflected Values	
Free Speed	14292	RPM
Free Current	0.39	Amps
Stall Current	2.2	Amps
Stall Torque	0.00587	N-m
Internal R	3.181818182	

Motor Operating V:	7

Kt(Torque Constant)	0.003241	Nm/A
Kv (Velocity Constant)	1938.6	RPM/V
ke(Back emf)	0.003241	V/rad/s

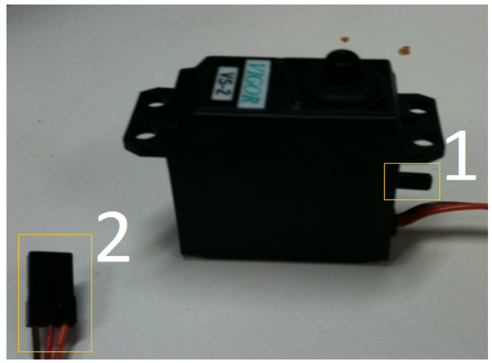
- Motor Pins 0-5 – Ask Organizers for extra Motor Drivers
- Must have 8-tooth Gear Connected
- Very High RPM, Very Low Torque
  - Useless **unless** Gear Ratios are used to Increase Torque and Decrease Speed.
- POS, NEG terminals no distinct PWR/GND
  - Note: Flipping Connection flips Motor Direction
- HappyBoard Example: motor_set_vel(Port#, Speed)
  - Speed Ranges from -255 to 255. 0 is stop.

Motors- Positional Servos



- Servo Pins 0-5. Three Cables: GND, PWR, SIG
- Precise Actuator limited to 0-180 degrees.
  - Actively set angular position of servo
  - No gear ratios
- Low RPM, Very High Torque
- Applications – Slow & powerful arms, precise open-loop motions
- HappyBoard Example: servo_set_pos(port#, pos). Pos ranges from 0-511. CAREFUL with Extreme Positions.

Motors: Continuous Servos



- No longer restricted to 0-180deg, but no longer capable of precise motions.
  - Essentially a High Torque, Low RPM DC motor.
- NOT Recommended. Positional Servos are *beautiful!*
  - Permanent Change. Potential Screw-up
- Potentiometer Calibration is needed -> Servo's Center changes. Use HotGlue to find center
- HappyBoard Example:
  - Potentiometer's effect on: servo_set_pos(port#, pos) servo_disable(port#)

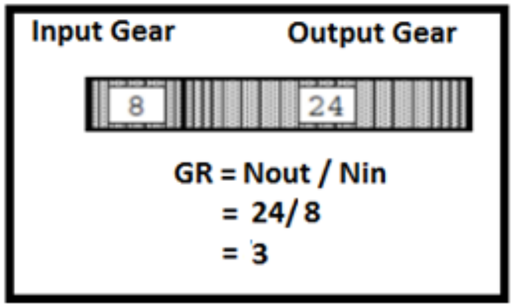
Gear Ratios

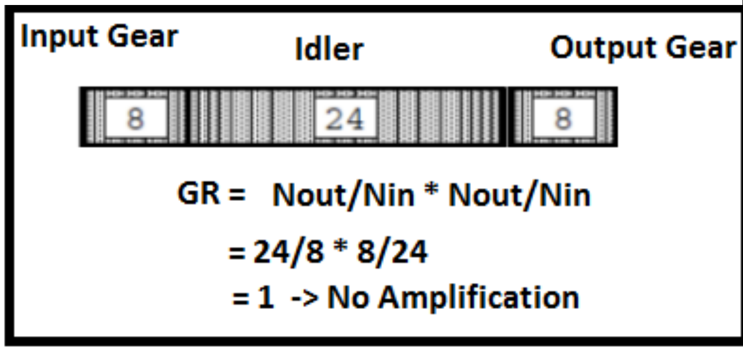
- Concept: Change output angular velocity & its Torque using gears
- Important Equation: $Gear\ Reduction = \frac{N_{out}}{N_{in}}$
  - Derivables: $Torque\ Ratio = G.R. = \frac{T_{out}}{T_{in}}$ $Speed\ Ratio = \frac{W_{in}}{W_{out}}$

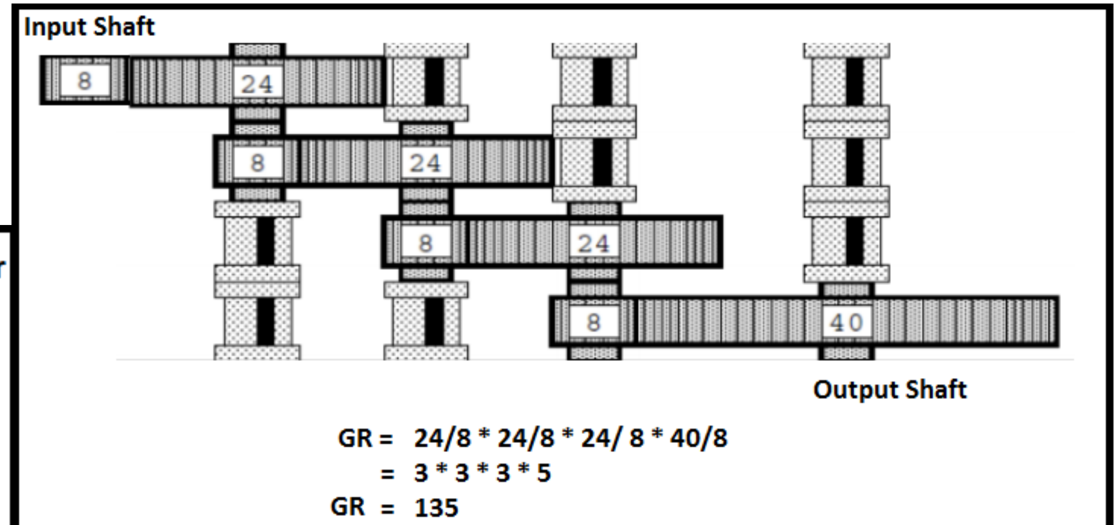
$$\frac{N_{out}}{N_{in}} = \frac{W_{in}}{W_{out}} = \frac{T_{out}}{T_{in}}$$

- Mechanical Advantage attained through conservation of Power $P = T_A\omega_A = T_B\omega_B,$ Which yields $MA = \frac{T_B}{T_A} = \frac{\omega_A}{\omega_B}.$
- Higher Gear Reduction amplifies torque, trading speed.
- Lower Gear Reduction amplifies speed, trading torque.

Gear Ratios – 10% Loss each Stage



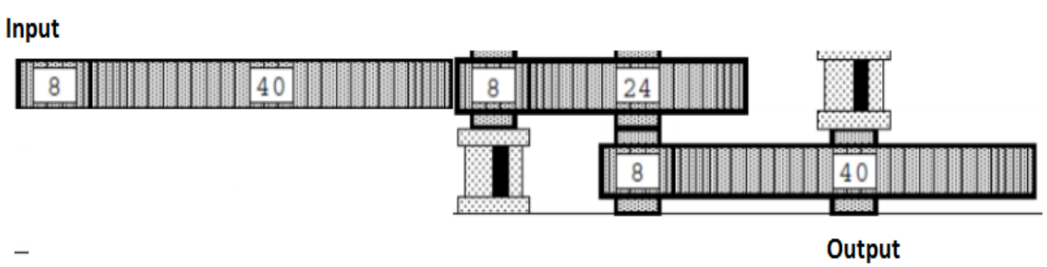


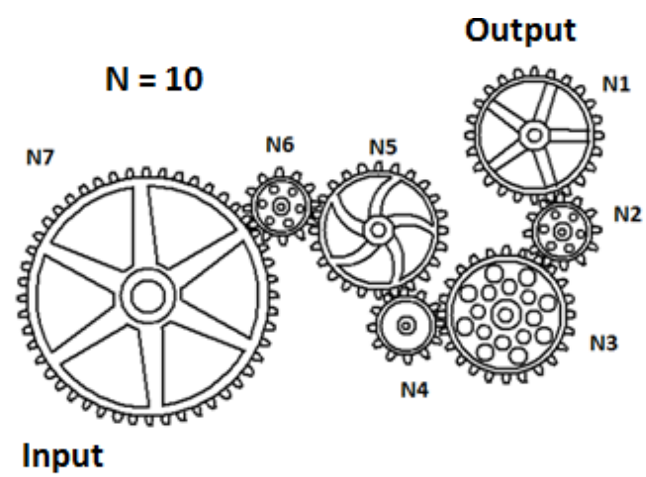


- Simplest Case use: Nout/Nin
- Compound Gearing requires Repeated Multiplication of Gear Ratios at Every Stage
- Idler Gears – Intermediate Gear does not contribute to ratio
  - Only Input and Output Matters
  - Useful for switching directions and Spacing

Gear Ratio Sample Calculations

- Given: Motor's Torque = 2N-m & RPM = 1000
- Calculate the Following Gear Ratios
- Which ones amplify torque and which amplifies speed?
  - By How Much?
- Remember: $\text{Gear Reduction} = \frac{N_{out}}{N_{in}}$ $\qquad \frac{N_{out}}{N_{in}} = \frac{W_{in}}{W_{out}} = \frac{T_{out}}{T_{in}}$



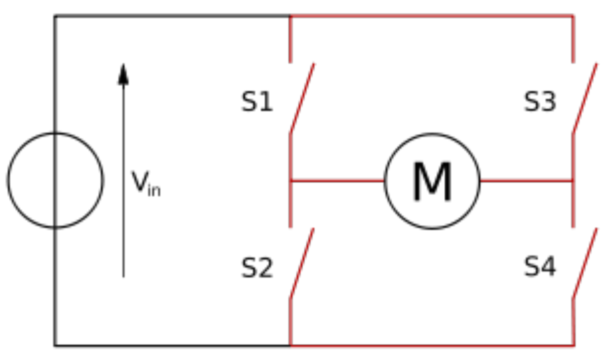


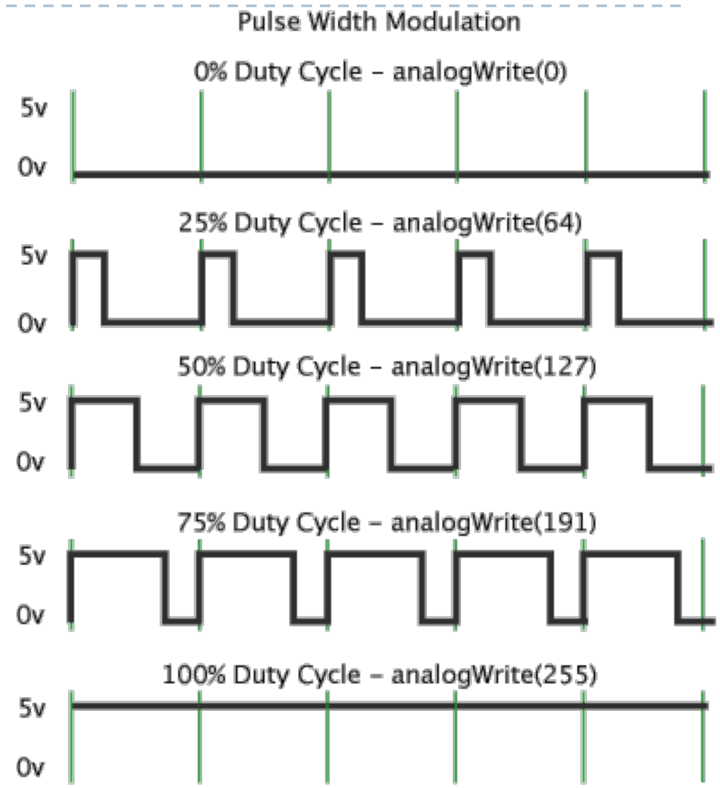
ANS: Left: GR = 15. Geared for Torque. Output RPM: 1000/15; Output Torque: 30Nm

ANS: Right: GR = 1/7. Geared for Speed. Output RPM: 7000; Output Torque: 2/7Nm

DC Motor Theory – PWM and H-Bridges

- PWM – Pulse Width Modulation
- Changes Voltage across Battery
  - Scales RPM, Torque, Proportionally
  - No magical torque comes out when RPM goes down!
- H – Bridges – Directional Control
- of Motor





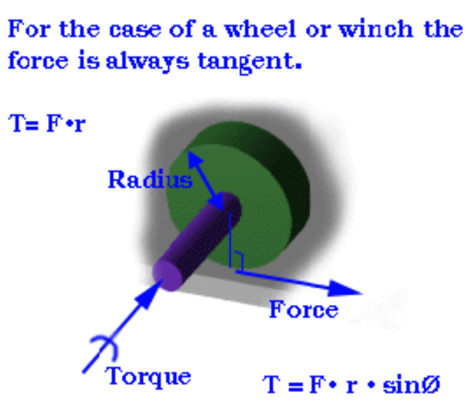
http://arduino.cc/it/Tutorial/PWM

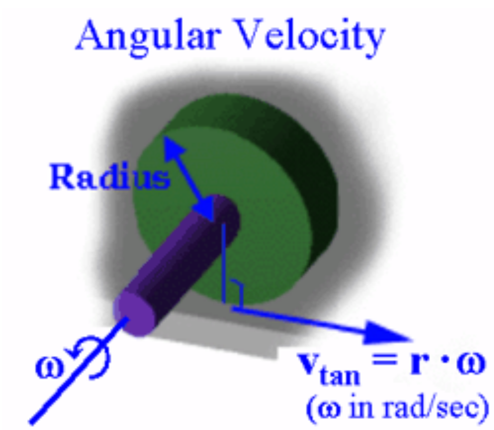
DC Motor Theory

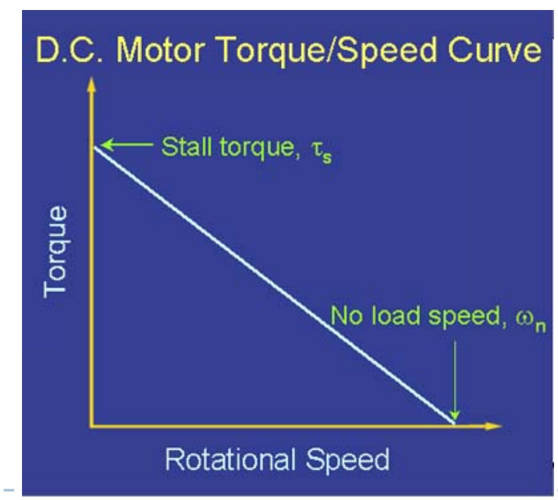
Gear Ratio:	3					
	Reflected Values	Effective Gear Ratio		Motor Operating V:	7	
Free Speed	14292	4764	RPM			
Free Current	0.39	0.39	Amps			
Stall Current	2.2	2.2	Amps			
Stall Torque	0.00587	0.01760	N-m	Kt(Torque Constant)	0.003241	Nm/A
Internal R	3.181818182			Kv (Velocity Constant)	1938.6	RPM/V
				ke(Back emf)	0.003241	V/rad/s

- Everything in DC Motor linearly Scales.
- Torque vs Speed Relationship

$$\tau_{motor} = \tau_s - \omega\tau_s/\omega_n$$
$$\omega_{motor} = (\tau_s - \tau)\omega_n/\tau_s$$



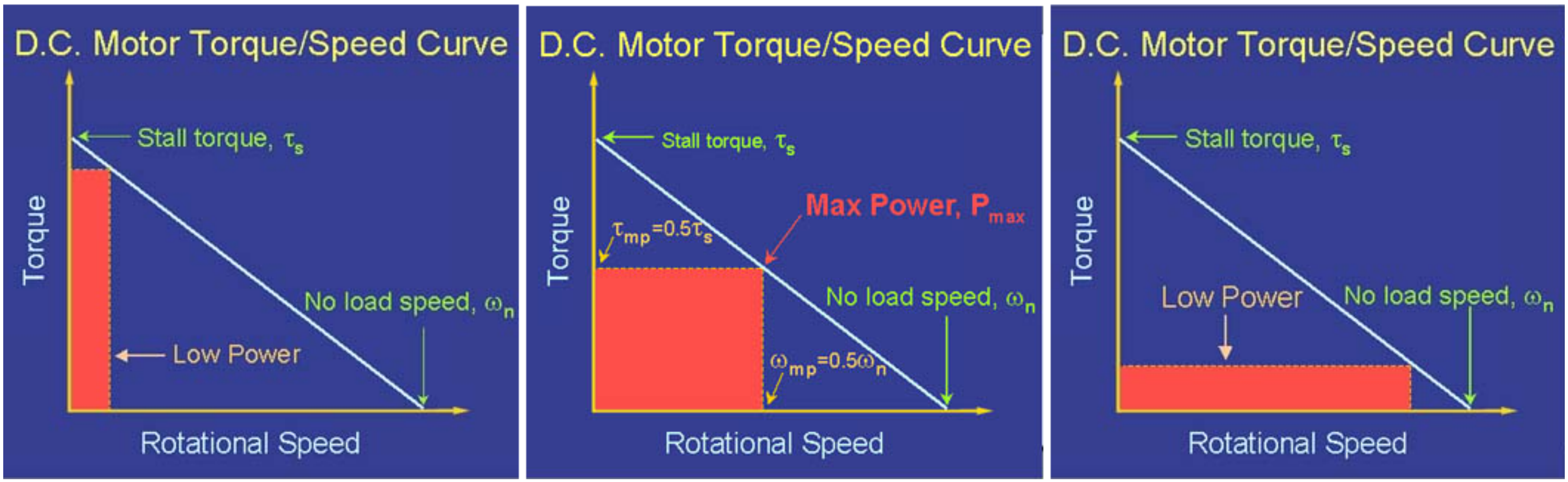




- http://lancet.mit.edu/motors/motors3.html

DC Motor Theory

- Power = Torque * Rotational Velocity (in radians)
- Max Power Occurs at ½ Stall Torque and ½ Rotational Speed



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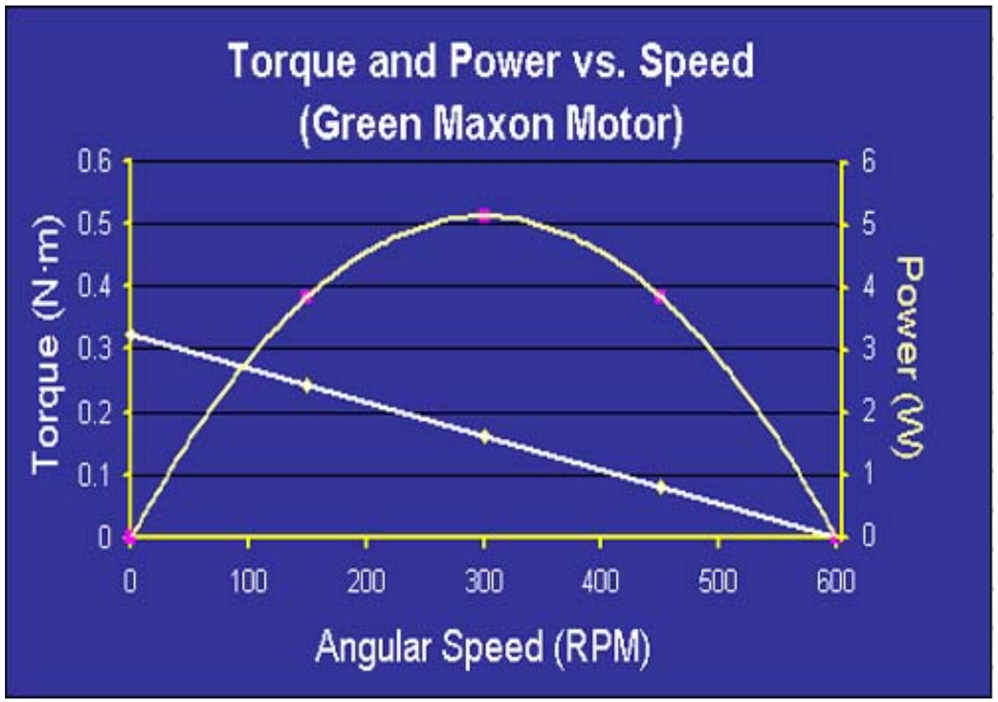
DC Motor Theory

- Plotting Torque & Power vs Speed
  - Further shows that Max Power occurs at ½ Torque and ½ Speed



- http://lancet.mit.edu/motors/motors3.html

DC Motor Theory – Usefulness?

- Remember Gear Ratios?
  - 6.270 DC Motors are very high RPM and very low Torque.
  - Gear Ratios scale
    - Use G.R. to amplify torque outputs
    - When Torque Increases, Velocity Decreases

Gear Ratio:	3					
	Reflected Values	Effective Gear Ratio		Motor Operating V:	7	
Free Speed	14292	4764	RPM			
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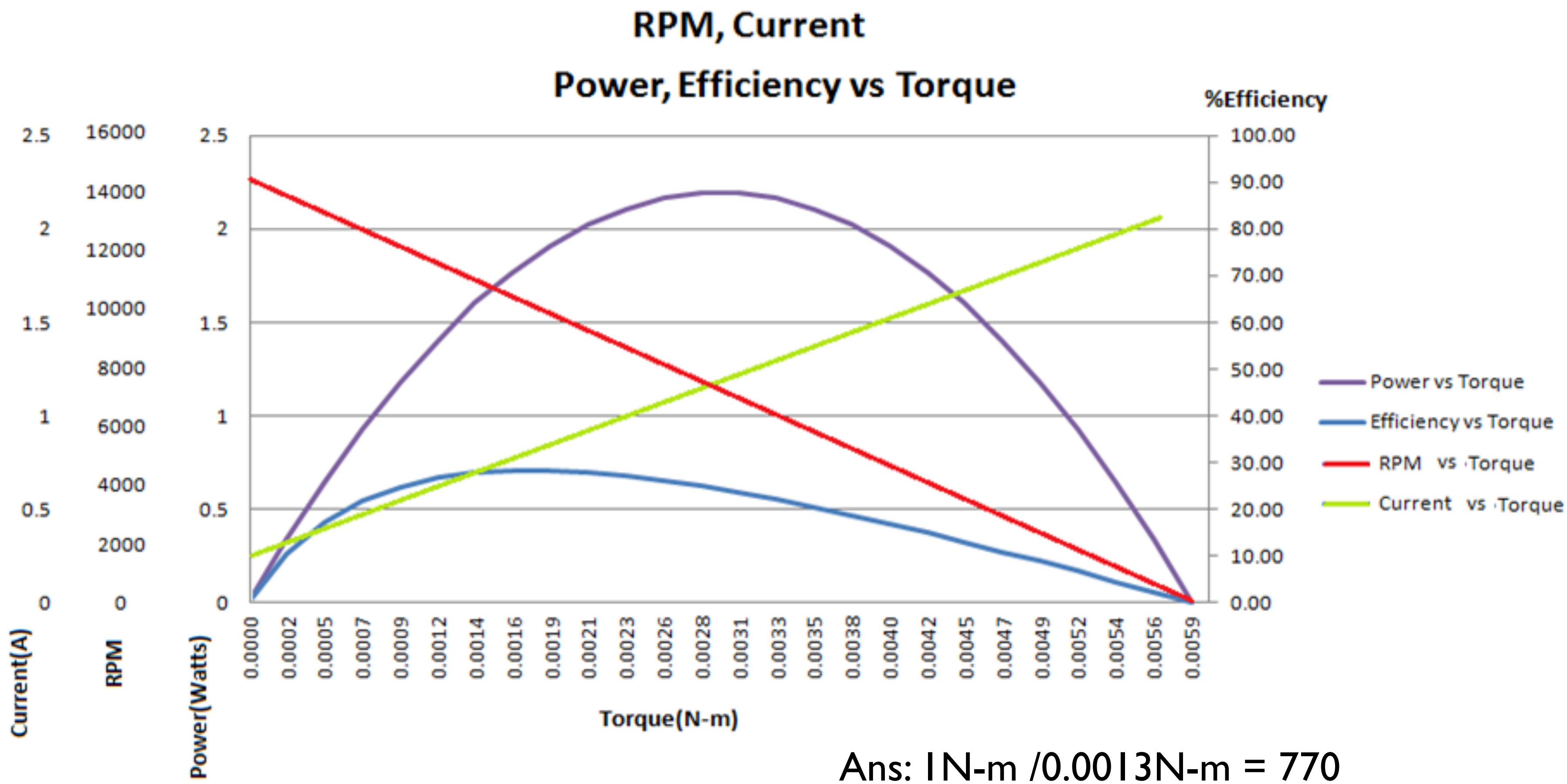
- Other Usefulness:
  - Kt : Nm/A : How much Torque is provided for a given current passing through Motor
  - Kv : RPM of motor for given V

DC Motor Theory

- Useful Visualization: Given a Required Torque of 1N-m, Find a Gear Ratio that operates near Efficiency



Ans: 1N-m /0.0013N-m = 770
Gear Ratio: 770:1 → A bit Ridiculous.

DC Motor Theory

Free Speed	14292
Free Current	0.39
Stall Current	2.2
Stall Torque	0.00587
Motor Operating V:	7

- Everything you need to know about a Motor's characteristics (Kt, Kv, Ke, Efficiency, Power, Graph, etc) can be derived from these scalar values
- Be sure to Download the 6.270 DC Motor Excel Graph to see how the math works.
- For the Lazy: Simply Input Torque and you Get Everything

	Torque Input(N-m)	vs RPM	vs Current(A)	vs Power(W)	vs %Efficiency
Input Torque	0.005	2110.7	1.9	1.1	8.2
At Max Power	0.00293	7146.0	1.3	2.2	24.2