2.017 DESIGN OF ELECTROMECHANICAL ROBOTIC SYSTEMS

Fall 2009 Lab 4: Motor Control

October 5, 2009

Dr. Harrison H. Chin

Formal Labs

1. Microcontrollers
- Introduction to microcontrollers
- Arduino microcontroller kit

2. Sensors and Signals
- Analog / Digital sensors
- Data acquisition
- Data processing and visualization

3. GPS and Data Logging
- GPS receiver and shield
- Data logging
- Visualization of data

4. Motor Control
- Motors
- Encoders
- Position control

Fall 2009 Calendar

MITMECHE

Formal labs: 4 weeks
Term project: 8 weeks

SEPTEMBER 2009

	Su	Mo	Tu	We	Th	Fr	Sa
			1	2	3	4	5
W1	6	7	8	9	10	11	12
W2	13	14	15	16	17	18	19
W3	20	21	22	23	24	25	26
W4	27	28	29	30			

9/9: First day of classes

Lab 1: Lab Intro, Arduino microcontroller

Lab 2: Sensors & signals, A/D, D/A, PWM

Lab 3: GPS & data logging

Term project proposal (W4)

OCTOBER 2009

	Su	Mo	Tu	We	Th	Fr	Sa
					1	2	3
W5	4	5	6	7	8	9	10
W6	11	12	13	14	15	16	17
W7	18	19	20	21	22	23	24
W8	25	26	27	28	29	30	31

Lab 4: Motor control

10/12: Columbus Day—Holiday
10/13: Monday schedule

Term project starts (W6)

Fall 2009 Calendar (Cont.)

MITMECHE

NOVEMBER 2009

	Su	Mo	Tu	We	Th	Fr	Sa
W9	1	2	3	4	5	6	7
W10	8	9	10	11	12	13	14
W11	15	16	17	18	19	20	21
W12	22	23	24	25	26	27	28
	29	30					

Term project milestone presentation (11/5)

11/11: Veteran's Day—Holiday

11/26-27: Thanksgiving Vacation

DECEMBER 2009

	Su	Mo	Tu	We	Th	Fr	Sa
W13			1	2	3	4	5
W14	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
	27	28	29	30	31		

Term project draft (12/1)

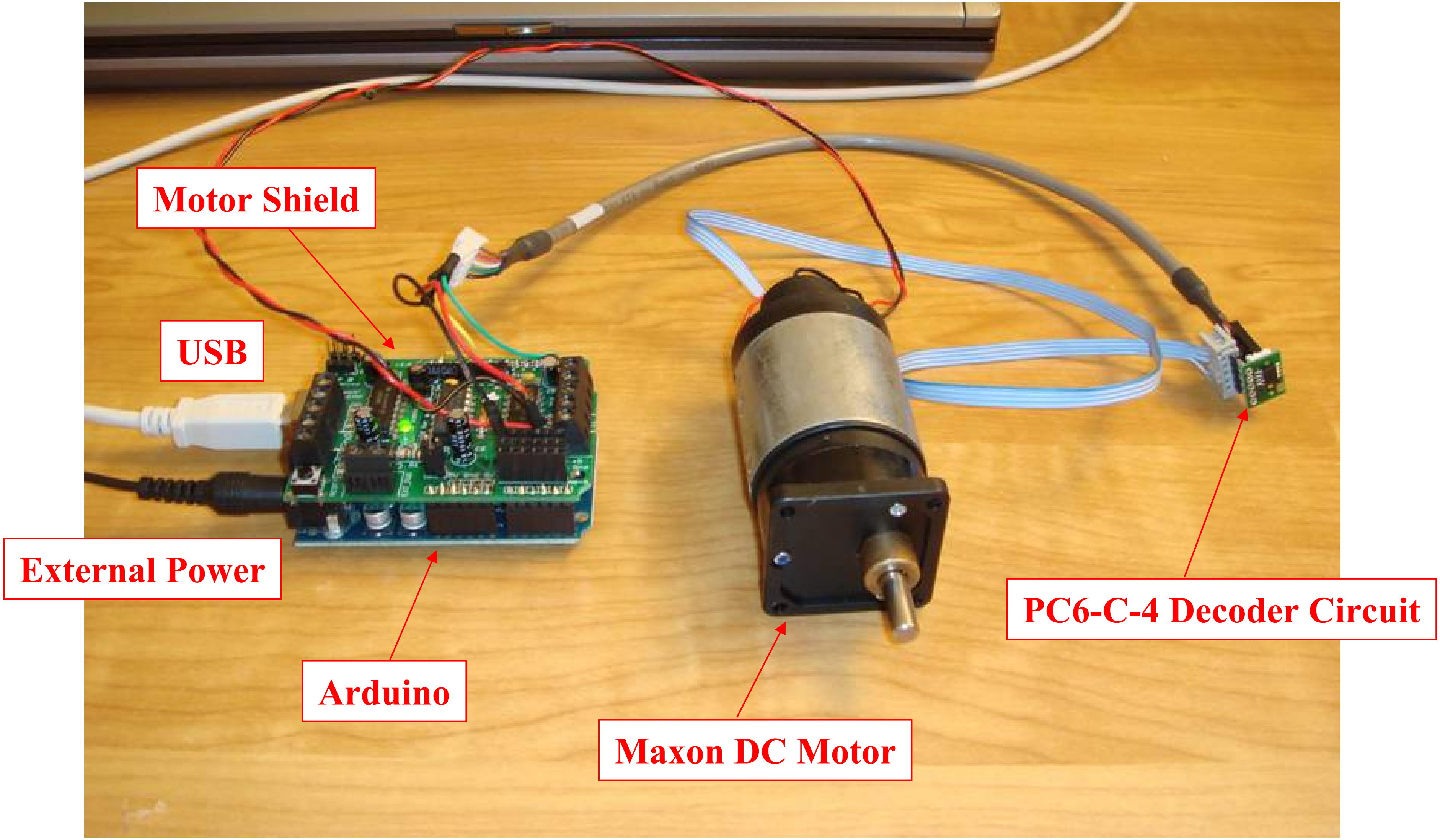
Term project presentation (12/8 & 12/10)

12/10: Last day of classes

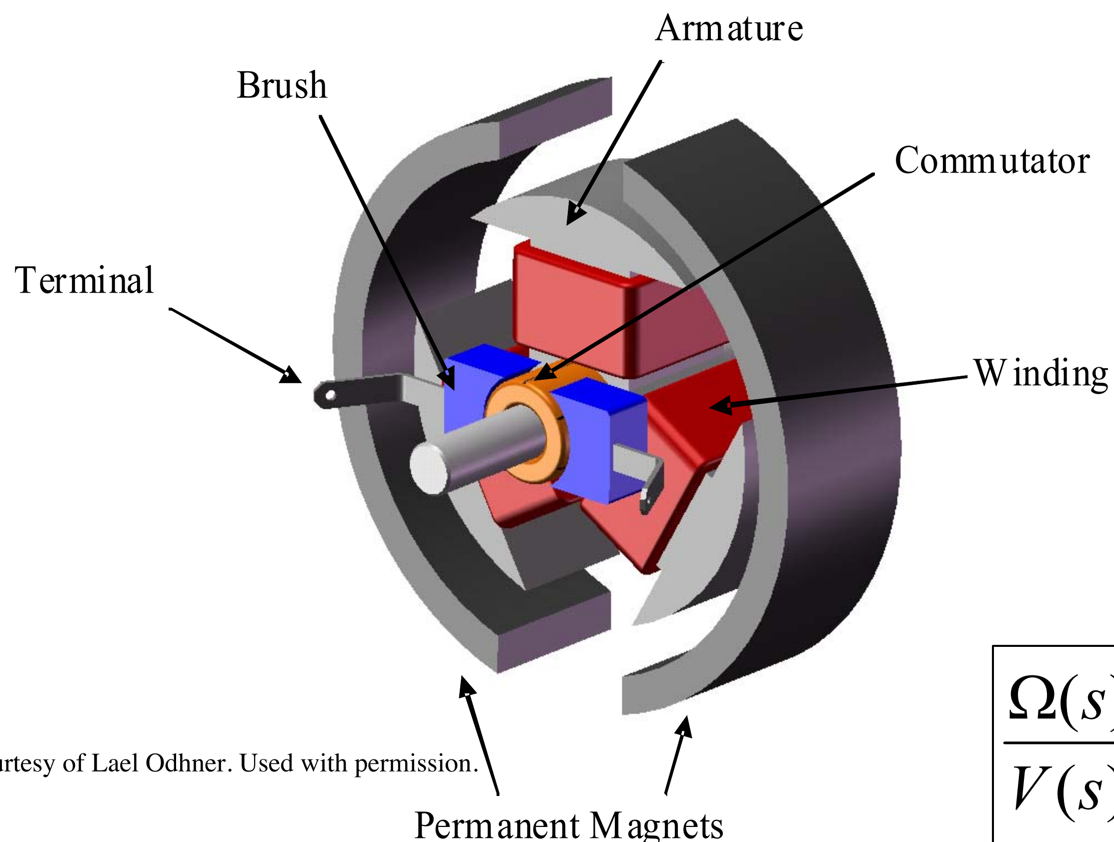
Lab 4: Motor Control

- **DC motor experiments (1:30 – 3:30)**
  - Processing Encoder Signals
  - Implementing Closed-Loop Position Control
  - Higher Performance from the Control System
  - Velocity Control
- **Controlling a Servo (3:30 – 4:30)**
- **Project discussion (4:30 – 5:00)**

Hardware Setup



DC Motors



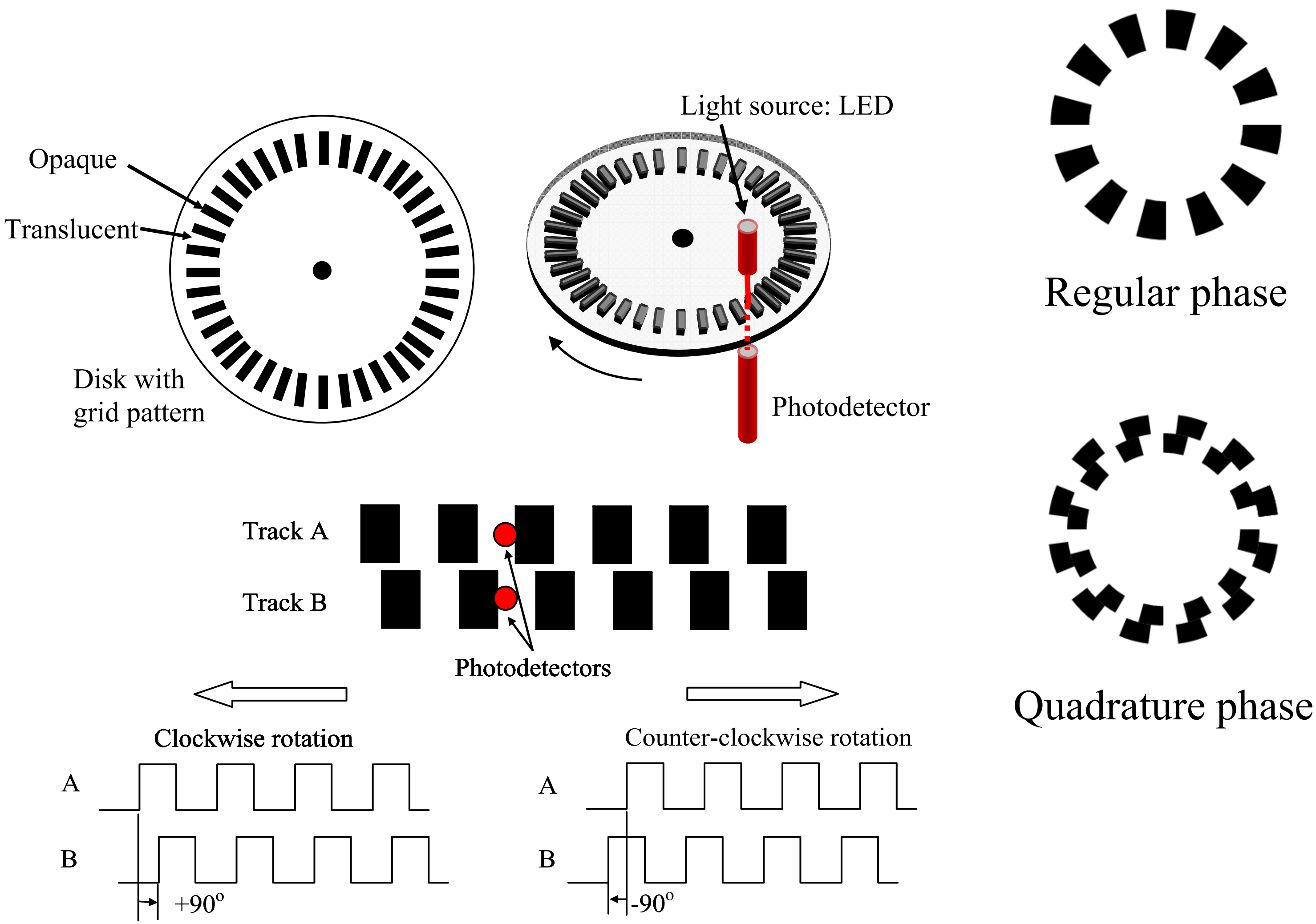
Courtesy of Lael Odhner. Used with permission.

$$\frac{\Omega(s)}{V(s)} = \frac{K_t^{-1}}{\left(R_m \cdot J_m \big/ K_t^2 \right) s + 1}$$

Time constant

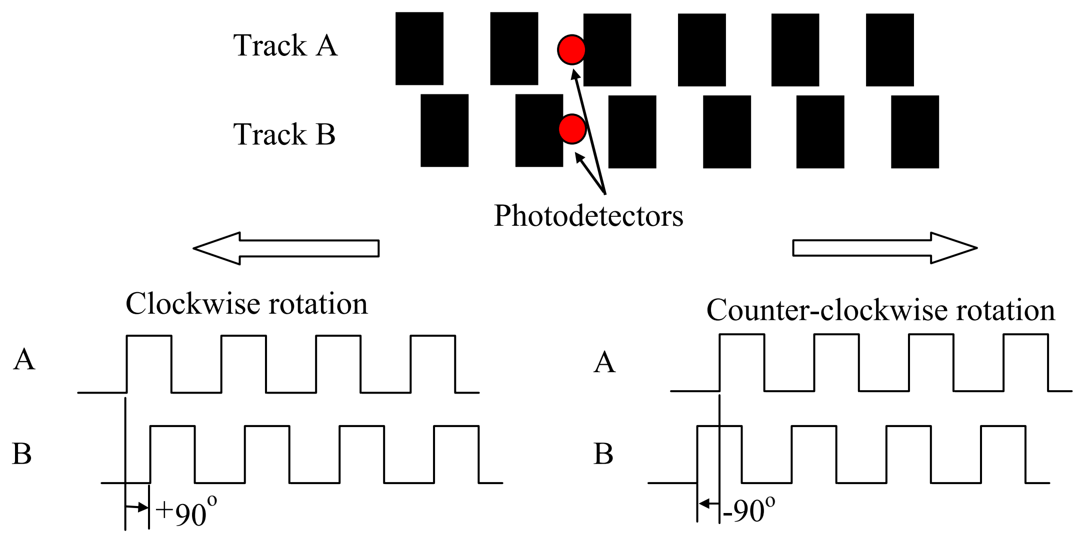
What is the time constant for our Maxon F2140.937 motor?

Optical Encoders



Quadrature Decoding

Courtesy of Harry Asada. Used with permission.



X (Ch A)	Y (Ch B)	F0	F1	F2	F3
0	0	1	0	0	0
1	0	0	1	0	0
1	1	0	0	1	0
0	1	0	0	0	1

Image by Deepak Kumar Tala, http://www.asic-world.com.

Decoder Circuit

- The PC6 decoder by US Digital decodes the quadrature outputs of an incremental shaft encoder. The circuit we use is the PC6-C-4, clock and direction version that provides 4x the encoder resolution.
- For the Maxon motor each encoder channel has 100 counts and through a 6:1 ratio gearhead we get 600 counts per channel (see Maxon motor specs).
- With the PC6-C-4 decoder circuit we get a total of 4x600 = 2,400 counts per shaft rotation.

Images removed due to copyright restrictions.
Please see any photo of the US Digital PC6 decoder,
such as http://usdigital.com/assets/images/galleries/take_2__0088.jpg,
and the pinout diagram for the LS7184 quadrature clock converter (datasheet).

Encoder Signals and Decoder Circuit Timing Diagram

- Check the following signals with an Oscilloscope

Image removed due to copyright restrictions.
Please see p. 4 in US Digital, "PC6 Encoder to Counter Interface Board."

Arduino Motor Shield

- 2 connections for 5V 'hobby' servos
- Up to 4 bi-directional DC motors
- Up to 2 stepper motors (unipolar or bipolar) with single coil, double coil, interleaved or micro-stepping.
- 4 H-Bridges: L293D chipset provides 0.6A per bridge (1.2A peak) with thermal shutdown protection, 4.5V to 36V
- Pull down resistors keep motors disabled during power-up
- Arduino reset button brought up top
- 2-pin terminal block to connect external power, for separate logic/motor supplies

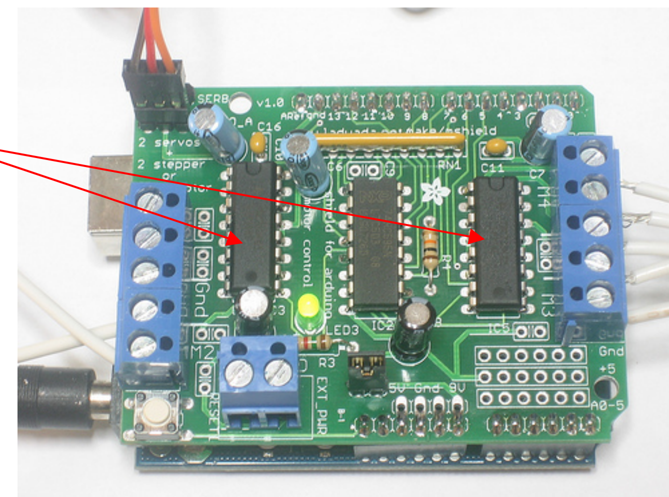


Photo by ladyada on Flickr.

L293D Quadruple Half-H Driver (H-Bridge)

- The L293D is a quadruple high-current half-H driver.
- The L293D is designed to provide bidirectional drive currents of up to 600-mA at voltages from 4.5 V to 36 V.
- It is designed to drive inductive loads such as relays, solenoids, dc and bipolar stepping motors, as well as other high-current/high-voltage loads in positive-supply applications.

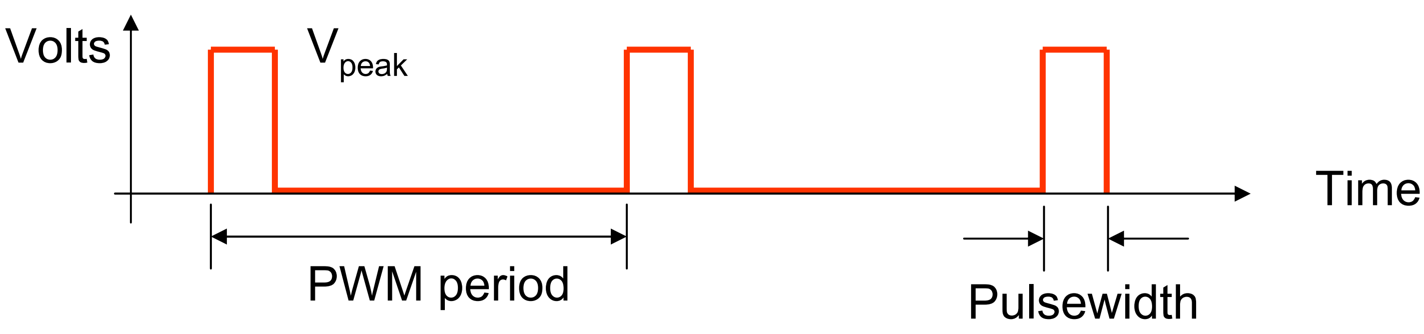
Image removed due to copyright restrictions.
Please see the pinout for L293D NE package
(datasheet).

An H-bridge enables a voltage to be applied across a load in either direction.

Pulse Width Modulation (PWM)

- PWM frequency (Hz) = 1 / PWM period
- Duty cycle = Pulsewidth / PWM period
- PWM frequencies typically range from 100Hz into MHz
- Duty cycles can be used from 0 – 100%, although some systems use much smaller ranges, e.g. 5-10% for hobby remote servos.
- The waveform has two pieces of information: Period and Pulsewidth, although they are usually not changed simultaneously.

Use a scope to look at the PWM signal if you can

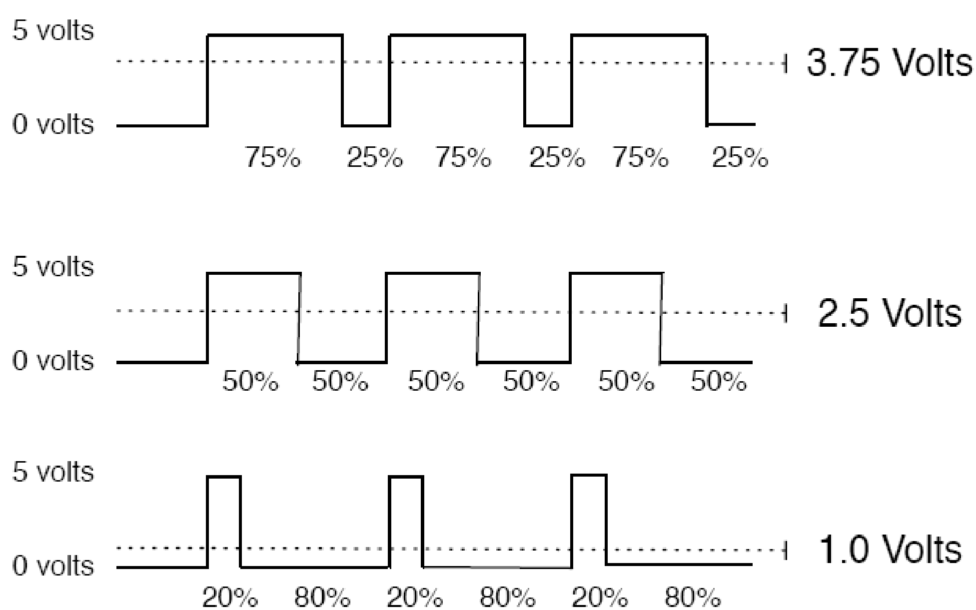


Pulse Width Modulation (PWM)

- Can be used as a substitute for analog output (high frequency switching is filtered out by the physical systems and what is left is the mean voltage).
- Applications include: lamp dimmers, motor speed control, power supplies,…

Output voltage is averaged from on *vs.* off time

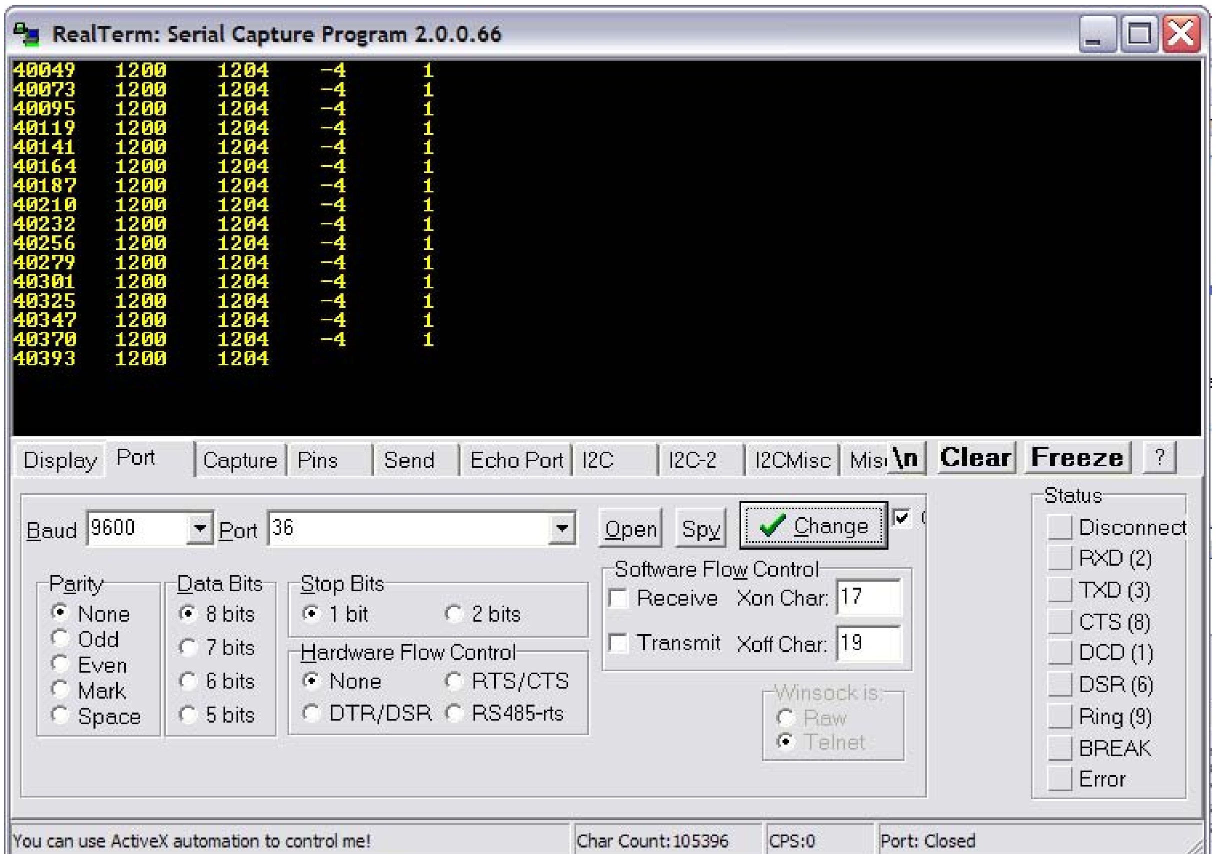
output_voltage = (on_time / off_time) * max_voltage



Courtesy of Tod E. Kurt. Used with permission.

Serial Data Capture

- **Use "RealTerm" Serial Capture Program (http://realterm.sourceforge.net/) to monitor and capture serial data**
- Import data to MATLAB **for plotting**

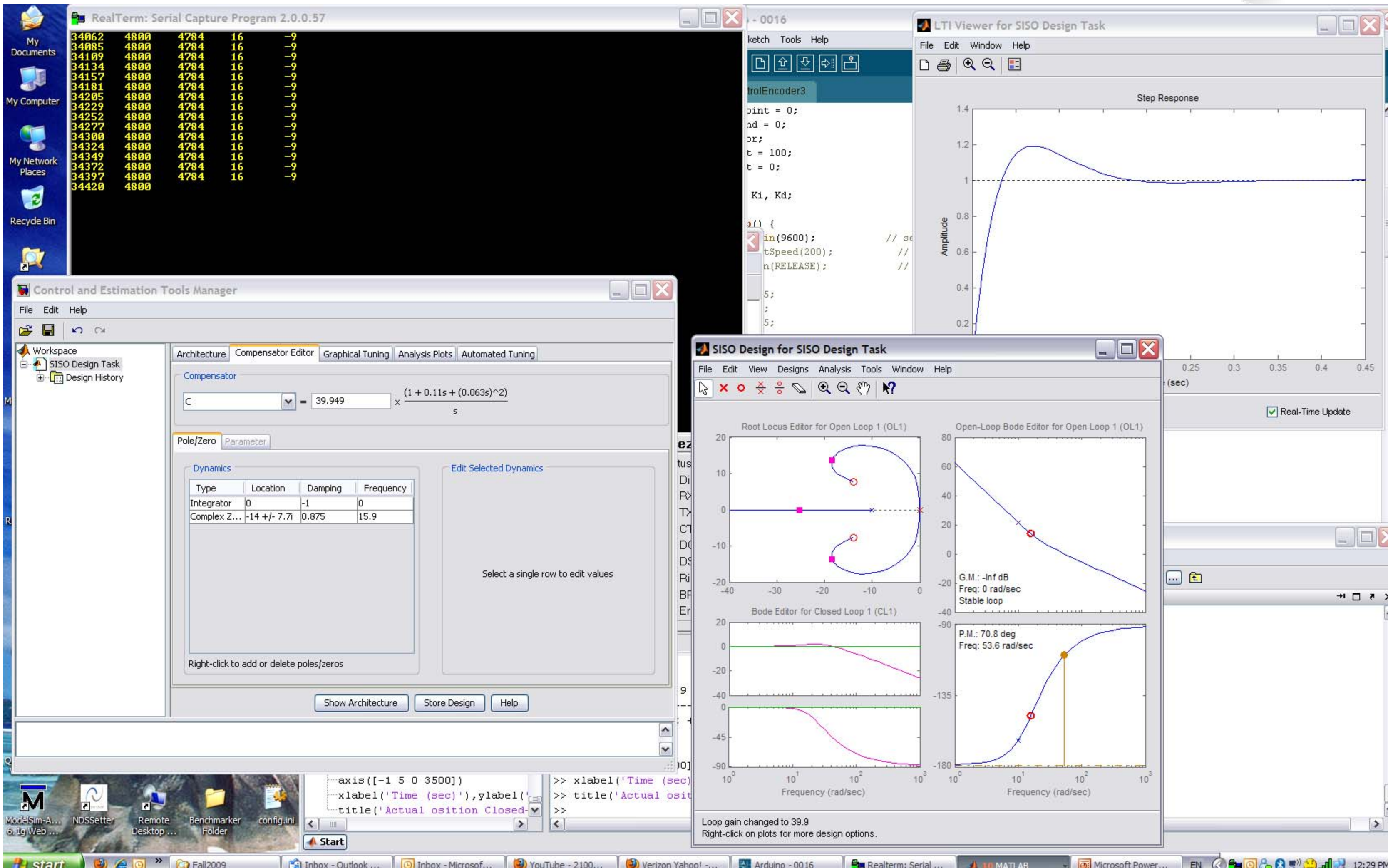


Courtesy of Simon Bridger. Used with permission.

Controller Design

- **Control action Types:**
  - *Proportional* – improve speed but with steady-state error
  - *Integral* – improve steady state error but with less stability, overshoot, longer transient, integrator windup
  - *Derivative* – improve stability but sensitive to noise
- **Reduce overall gain can increase stability but with slower response**
- **Avoid saturation**
- **Set integrator limit to prevent windup**

MATLAB **SISOTOOL Controller Design Tool**



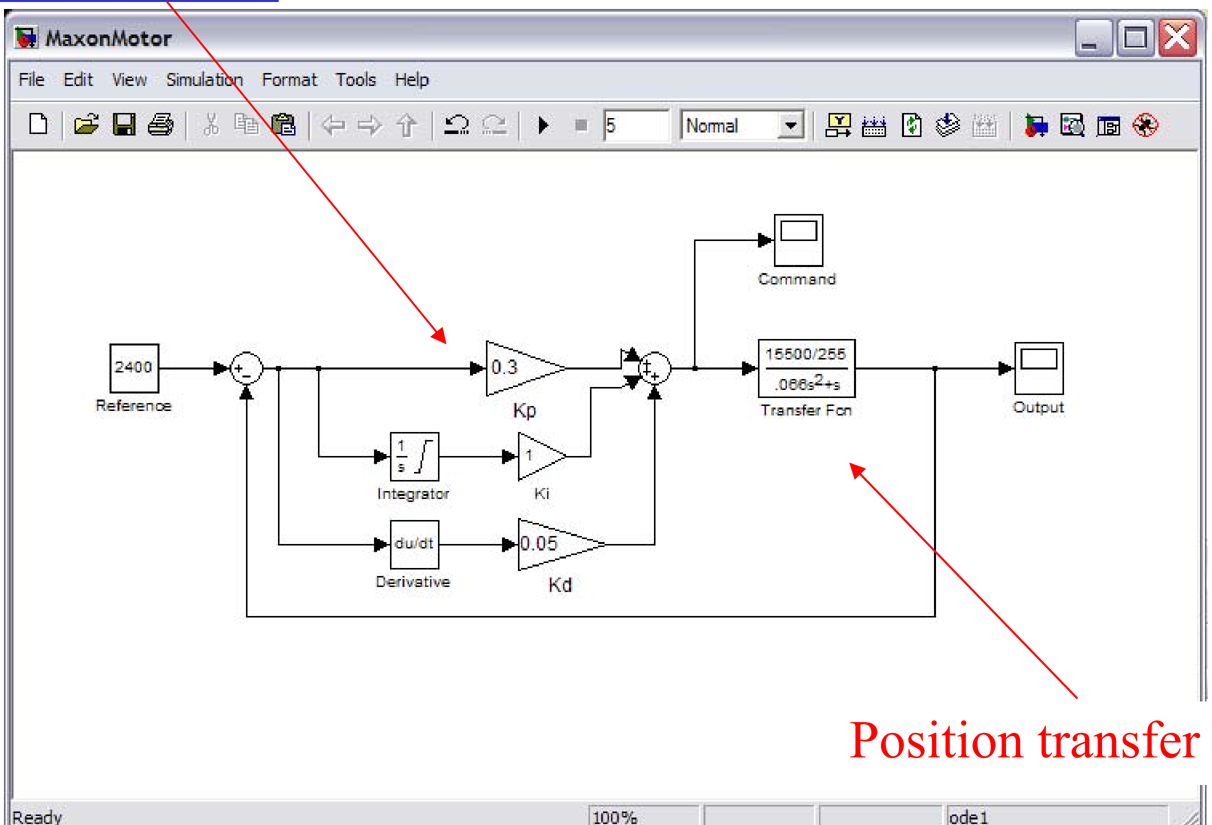
Courtesy of The MathWorks, Inc. Used with permission.

Simulink Simulation

P I D

$$K_p + \frac{K_i}{s} + K_d s$$

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$



Position transfer function

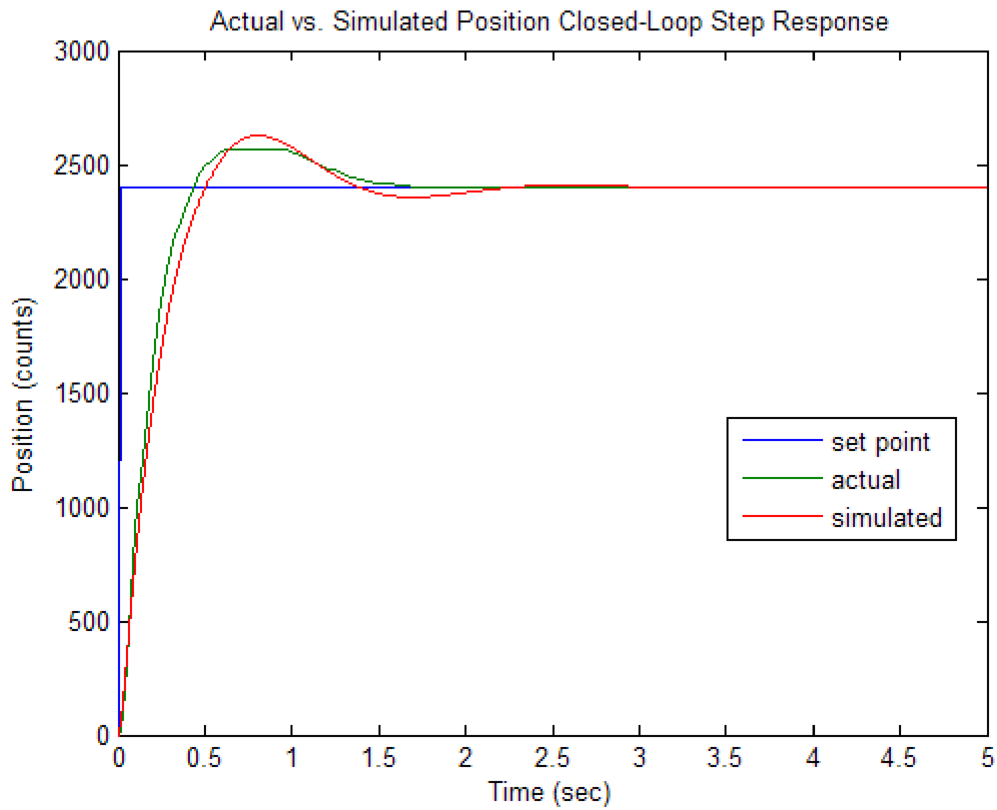
Motor Control Template Code

```
void setup() {
  Serial.begin(9600);            // set up Serial library at 9600 bps
  Kp = 0.0;
  Ki = 0.0;
  Kd = 0.0;

  pinMode(ClockPin, INPUT);
  pinMode(UpDownPin, INPUT);

// encoder pin on interrupt 0 (pin 2)
  attachInterrupt(0, doEncoder, CHANGE);
  time_1 = millis();              // read the initial time stamp
}

void loop() {
  // Serial.println("Motor Control");
  time_2 = millis();              // read the current time stamp
  dt = time_2 - time_1;           // compute delta time
  time_1 = time_2;                // reassign new time_1

  //*** Remeber time is in milliseconds!!!

  // update state variables for use in PID controller
  vel = (float) (encoder0Pos - oldPos) / dt;  // velocity estimate in ms
  error = setPoint - encoder0Pos;             // position error in counts

  // reassign state variables
  oldPos = encoder0Pos;

  //***********************************
  // Insert controller here
  // command = ????
  //
  // remember command should be an integer
  //***********************************
```

Fill in your PID gains

Fill in your controller equations

Step Response Comparison



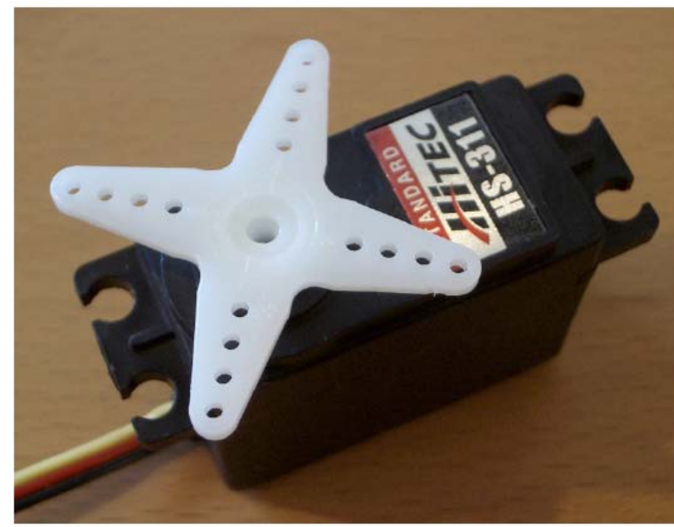
$$K_p = 0.25$$

$$K_i = 1.0$$

$$K_d = 0.05$$

Servomotor Control

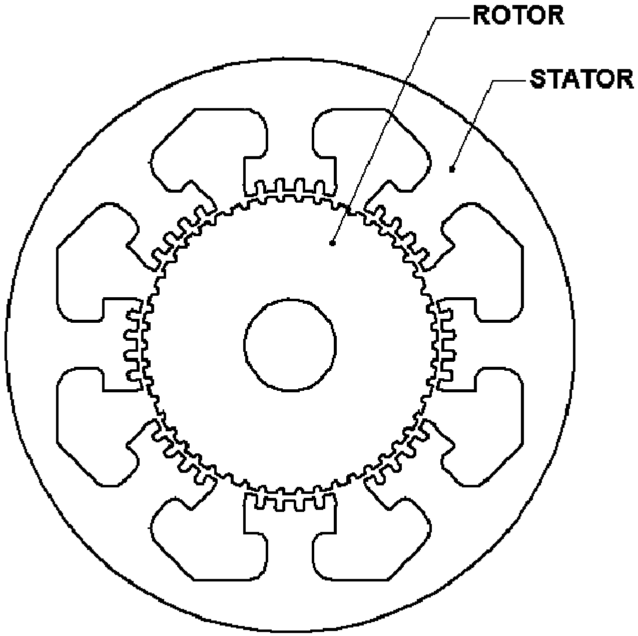
- Can be positioned from 0 to 180 degrees
- An internal DC motor connected to a potentiometer
- High torque gearing
- Internal feedback circuitry to control motor position
- Three wire connector: Ground, +5 V, and PWM (typically at 50 Hz)

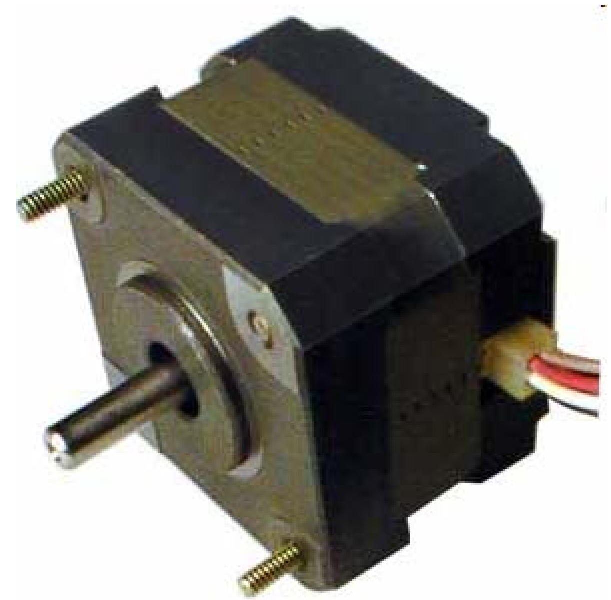


Modify the code to use a potentiometer (or a photo resistor) to control the shaft angle

Stepper Motor

Hybrid Stepper Motor





- Permanent magnet in rotor
- Windings on stator poles
- Excitation of phase windings produces discrete steps
- 2 phase, 1.8°/step most common

Project Discussion

- Project proposal feedback

Deliverables

- Answer all the questions in the Lab 4 handout
- Plots
- Show the teaching staff your lab notebook