ACTIVE PENDULUM

ELEC 391 L1C - MINI-PROJECT 2021

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RGC – PROBLEM DEFINITION

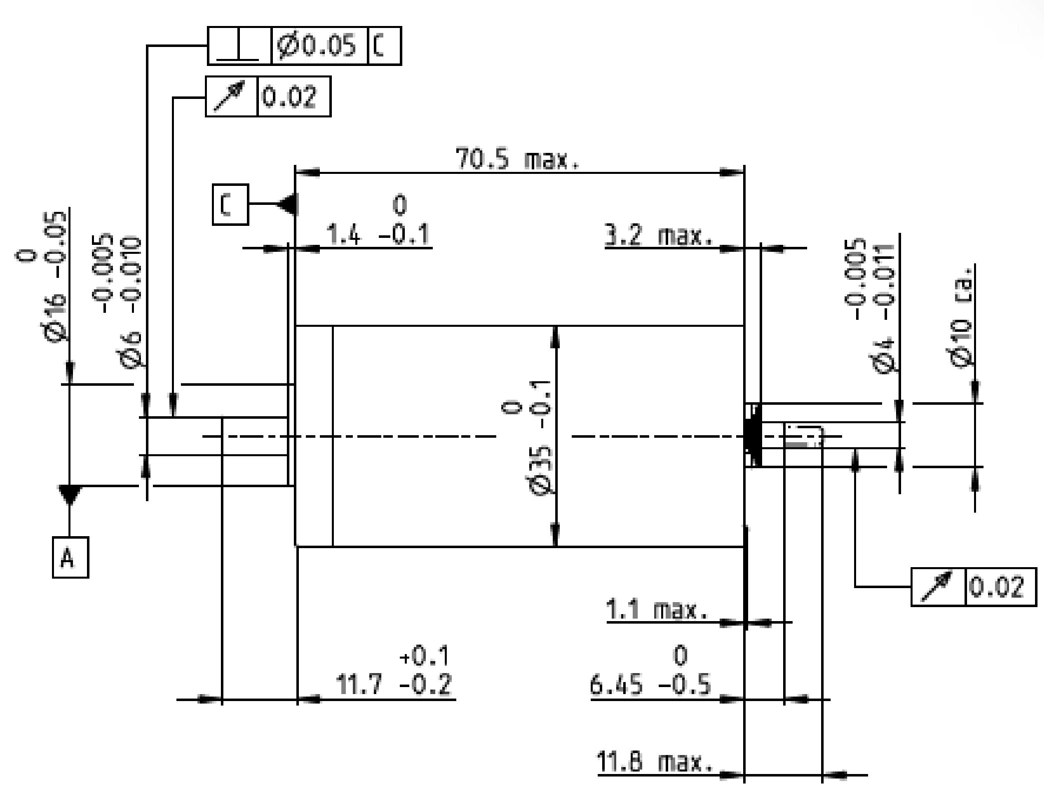
Requirements	Constraints	Goal
Circuit handles peak current	Pendulum uses < 50% of motor torque	Small Voltage overshoot
Circuit works with pos/neg Voltage	Use 50% gain (Ku) from root-locus	Simple and concise circuit design
Regulate logo weight through size and material density (Alloy Steel)	Circuit delivers nominal torque (77.7 nNm) at nominal current (6 A)	Accurate co-simulation step response (reflects Simulink model response)
Simulate 2 motors and 2 models in Simulink and SimulationX	Logo Dimensions = motor diameter, Arm length = motor height	Both pendulums can rotate to a 90 deg position

STEP 1: THE MOTOR

Student Number: 12521589

Maxon Product Catalog: Page 96, Voltage 12V

Motor: DCX 35L Graphite Brushes, DC motor 35 mm



KEY SPECS	
Nominal Voltage	12 V
No load Speed	8130 rpm
No load Current	320 mA
Nominal speed	7610 rpm
Nominal Torque	77.7 mNm
Nominal Current	6 A
Terminal Resistance	0.079 Ω
Terminal Inductance	0.026 H
Torque Constant	13.7 nNm/A
Speed Constant	699 rpm/V
Rotor Inertia	99.5 gcm^2

STEP 2: ARDUINO

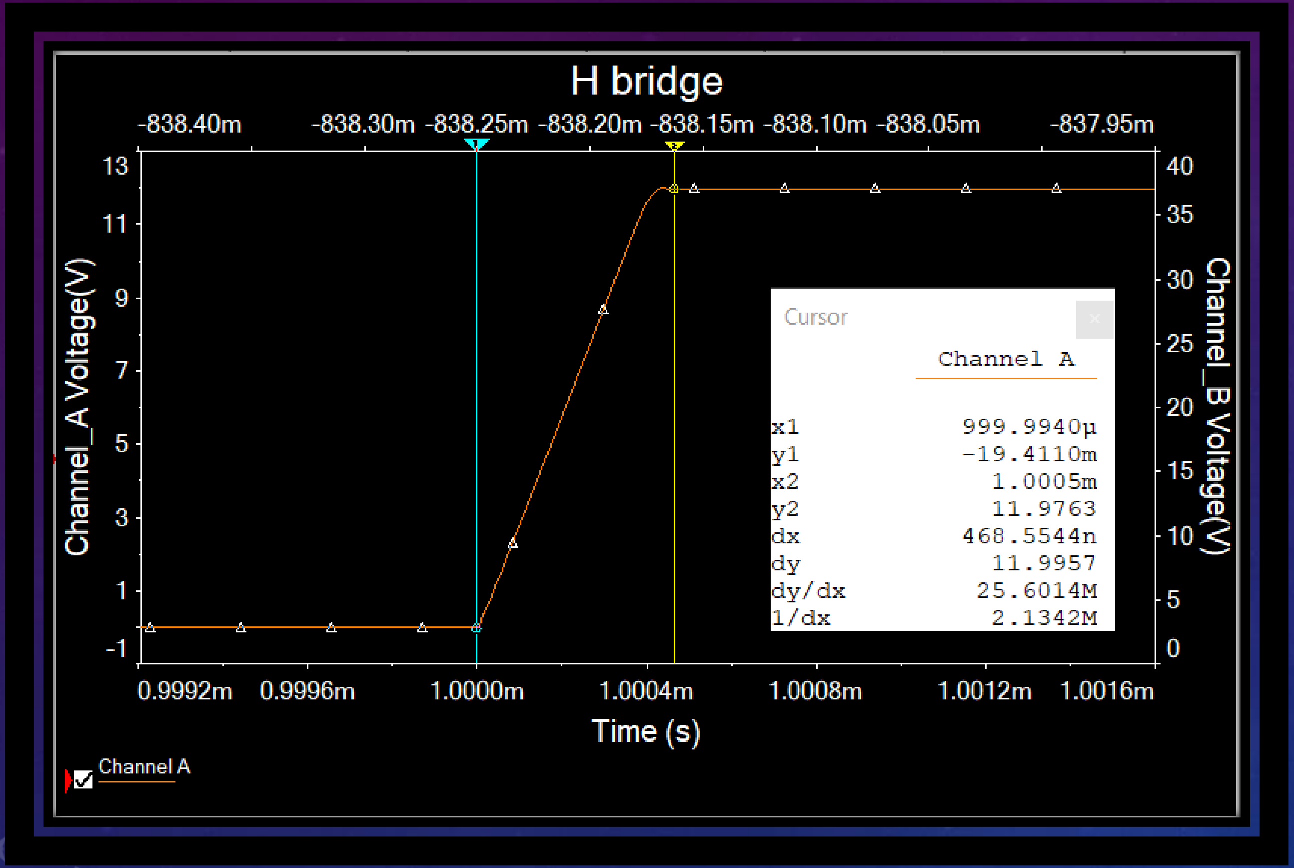
- Programmed a simple C controller taking sensor information from pin, compares to desired position, then sends the output to the motor
- Execution time was approximated by counting the clock cycles for the Atmega processor using the datasheet
- The ISR rate was calculated

```
voltage = analogRead(inputSensorPin);

error = voltagePoint - voltage;
motorOutput = error * Kp;

digitalWrite(outputMotorPin, motorOutput);
```

Clock Speed = 16 MHz (16 clock cycles/sec)
Clock Cycles = 107
Execution time = # clock cycles/clock freq
= 107/16MHz = 6.6875E-9 sec

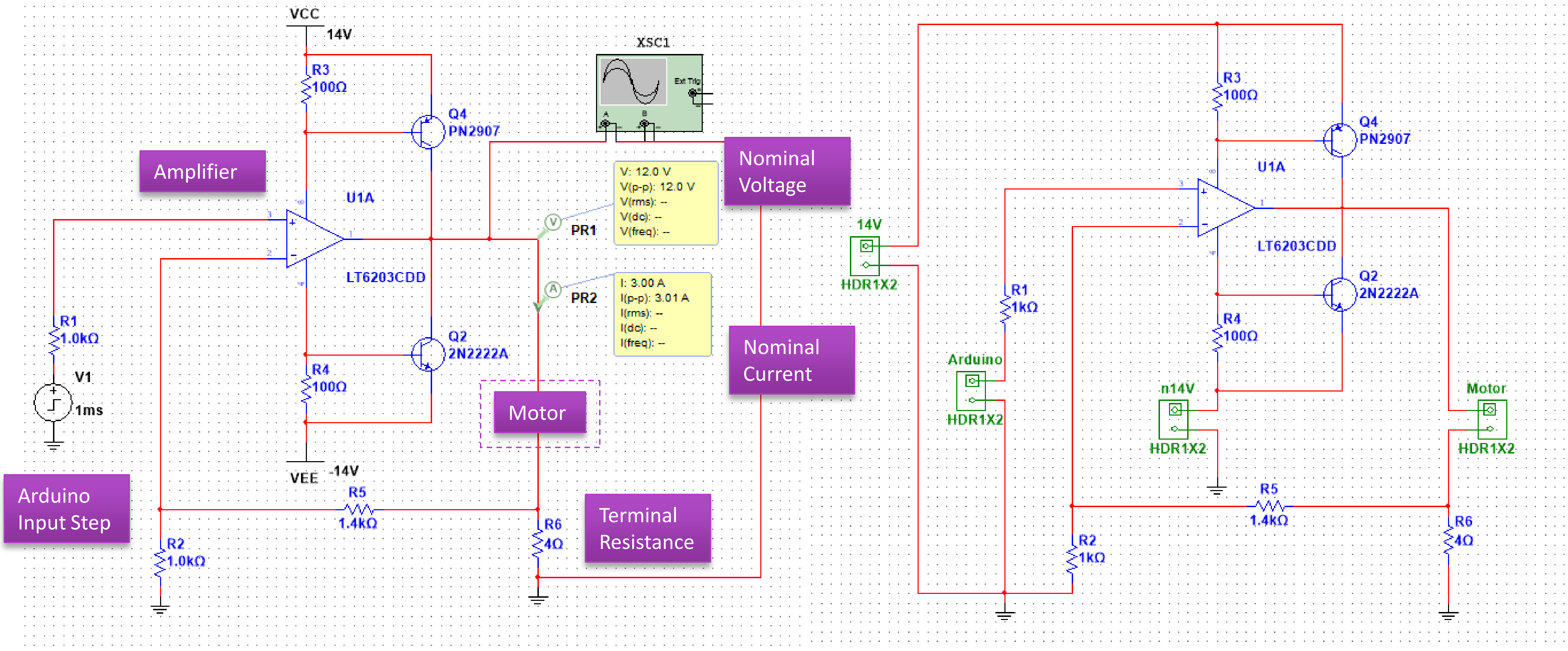
ISR Frequency = 1/Exec Time
= 1/6.6875E-9 = 1.496E8

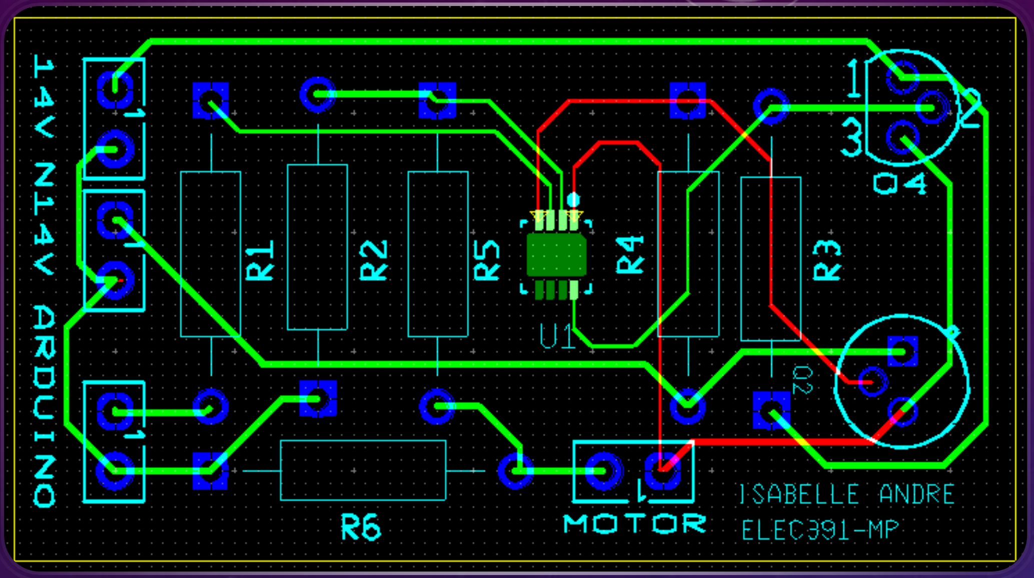
STEP 3: MULTISIM



- Amplifier circuit built in Multisim with a simulated Arduino pin
- Supports positive and negative nominal Voltage
- A 4 Ω resistor was used to simulate the motor terminal resistance
- Transient settles at 12V, showing very little overshoot

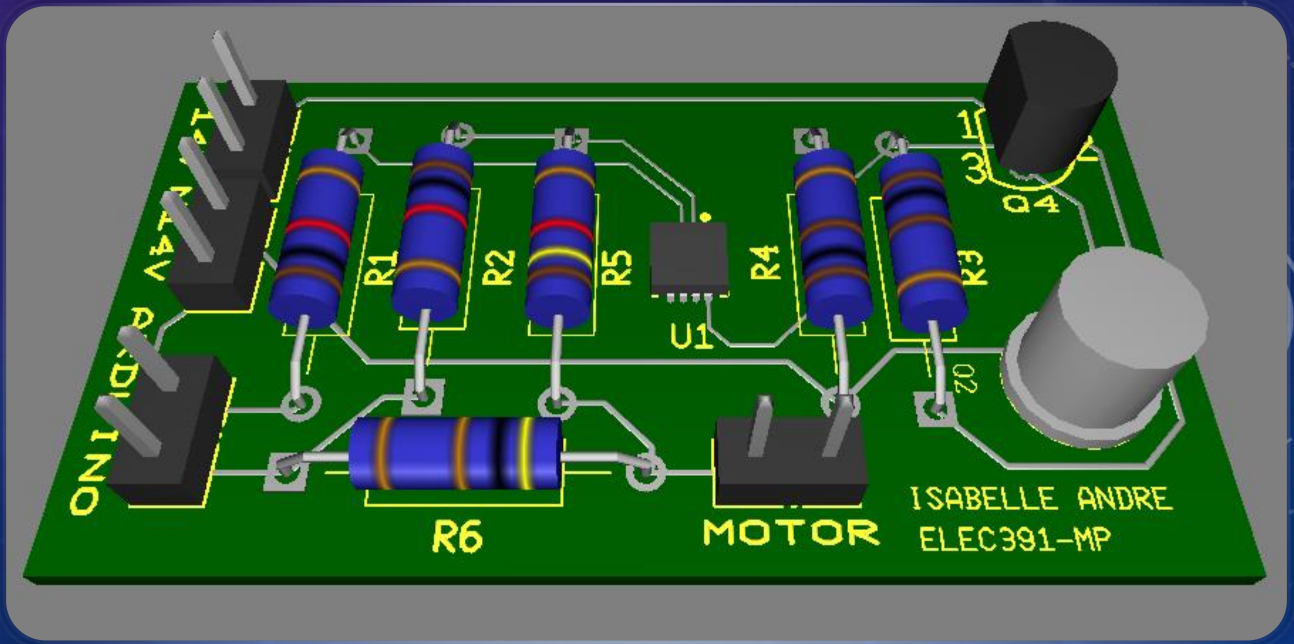
MULTISIM MOTOR AMPLIFIER CIRCUIT



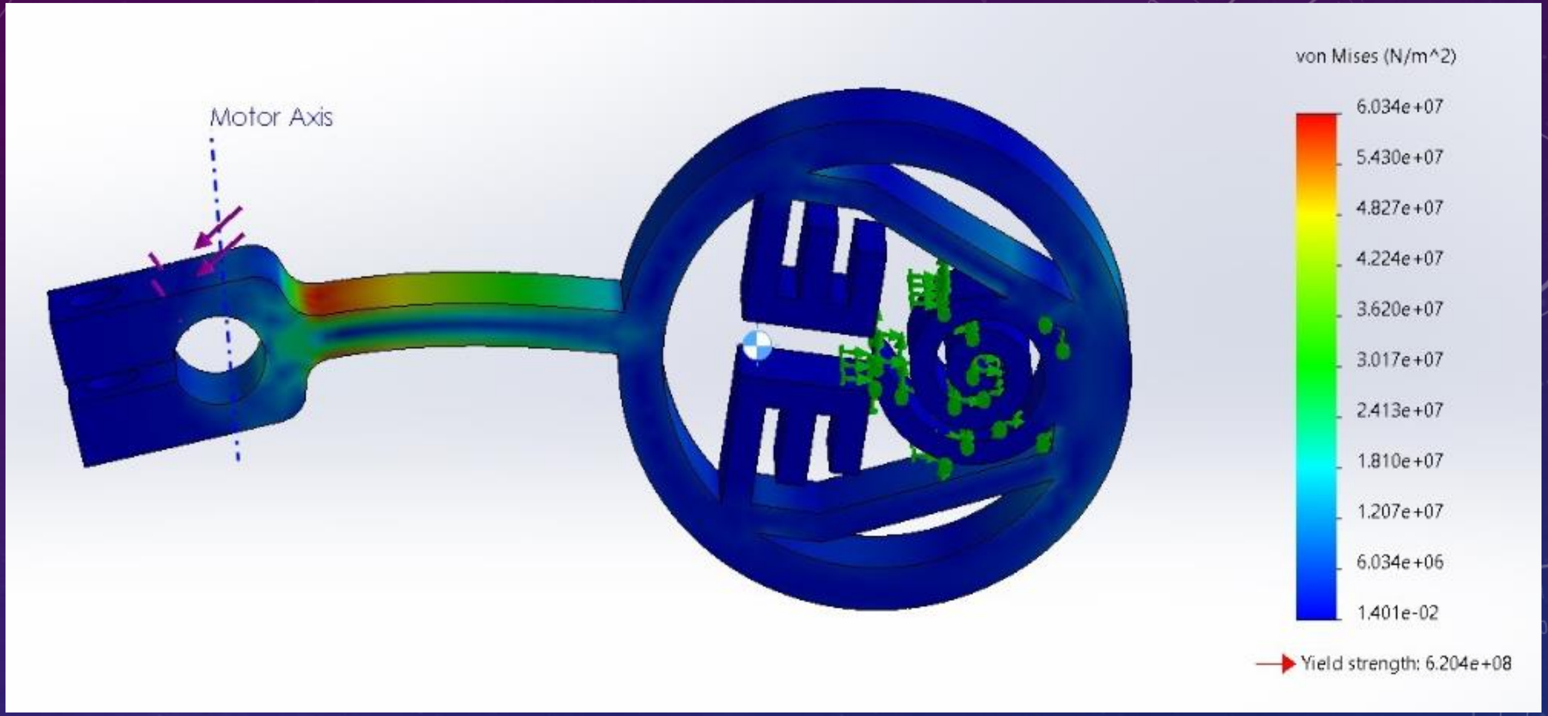


STEP 4: ULTIBOARD

- Multisim circuit exported to Ultiboard
- Optimized and simplified PCB

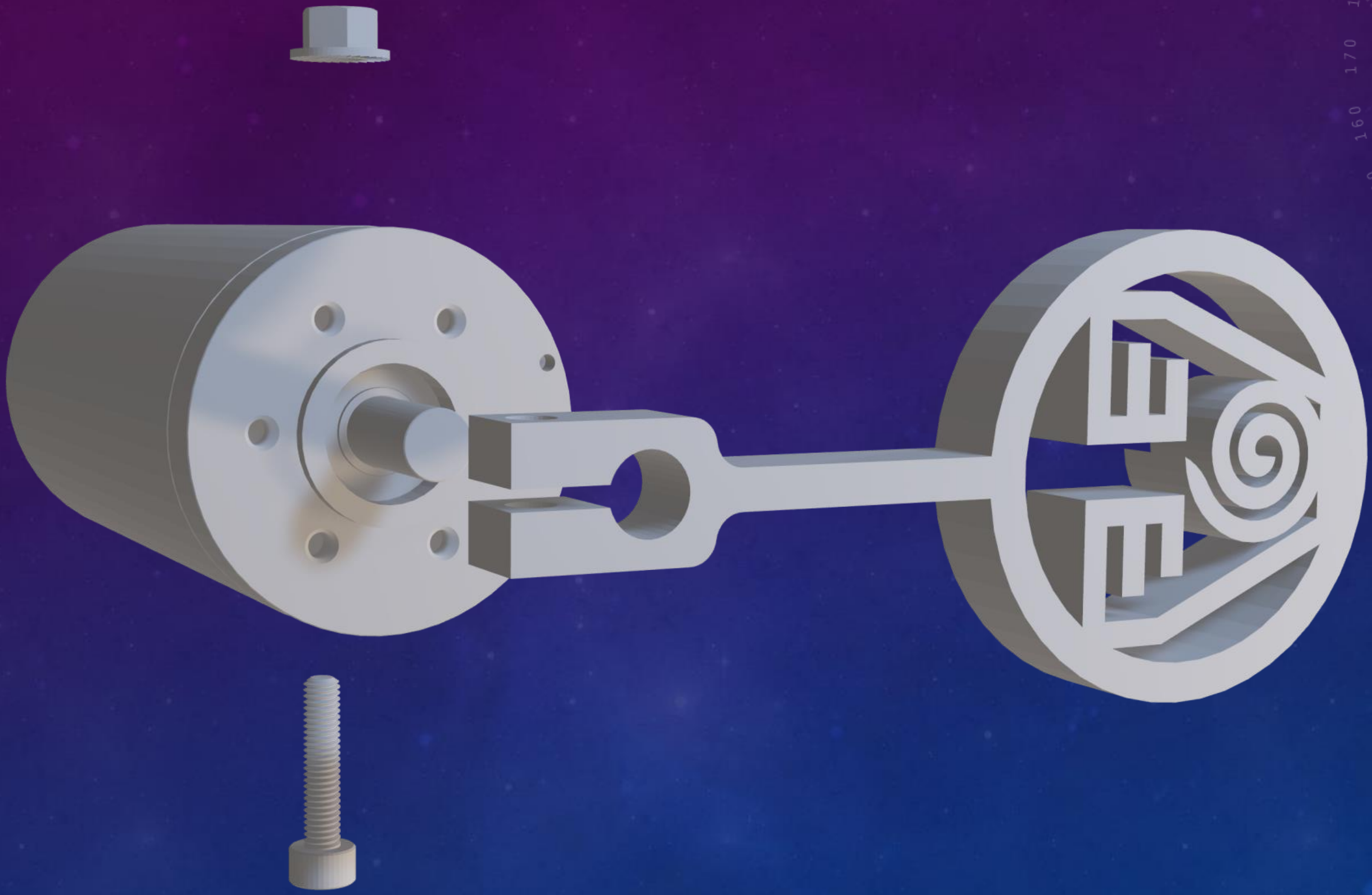


STEP 5: SOLIDWORKS



- Pendulum uses max 50% of motor torque
- Logo approximately size of motor diameter
- Arm approximately length of motor

Density	0.01 g/mm^3
Mass	40.88 g
Center of Mass	X = 0 mm, Y = 7.92 mm, Z = 3.5 mm



STEP 6: SIMULINK

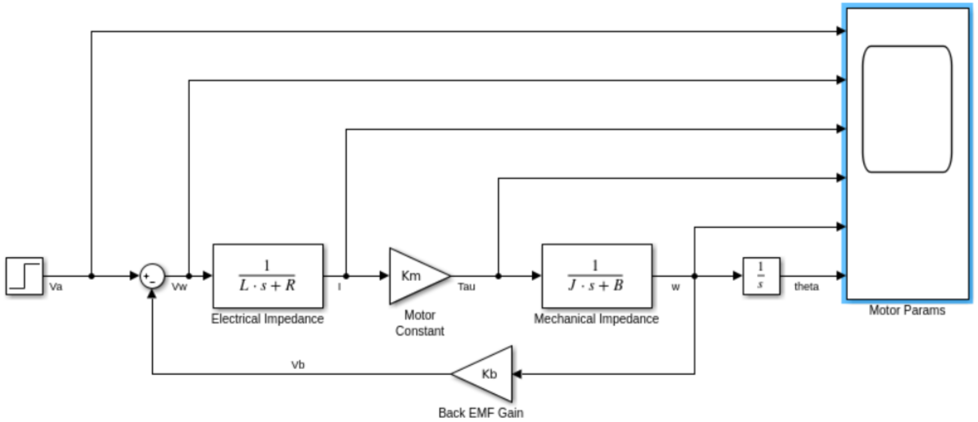
MOTOR MODEL

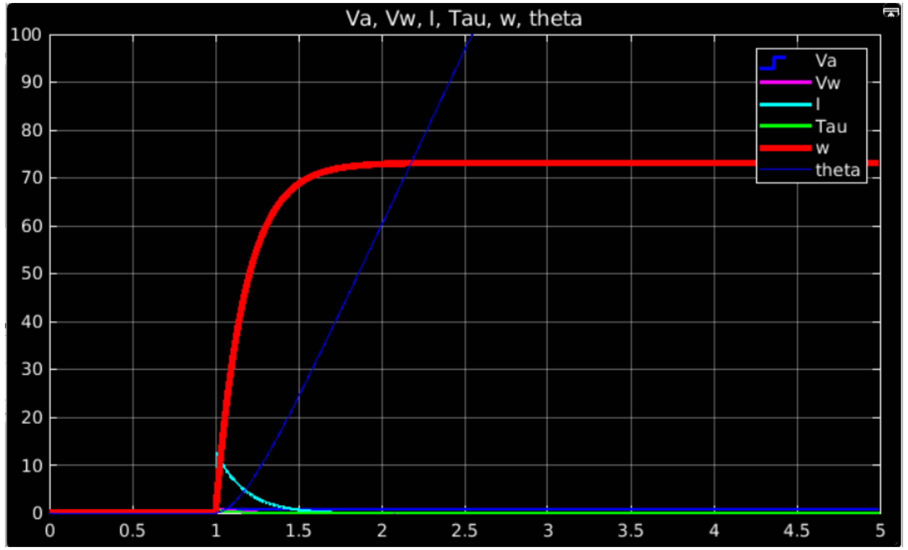
Electrical

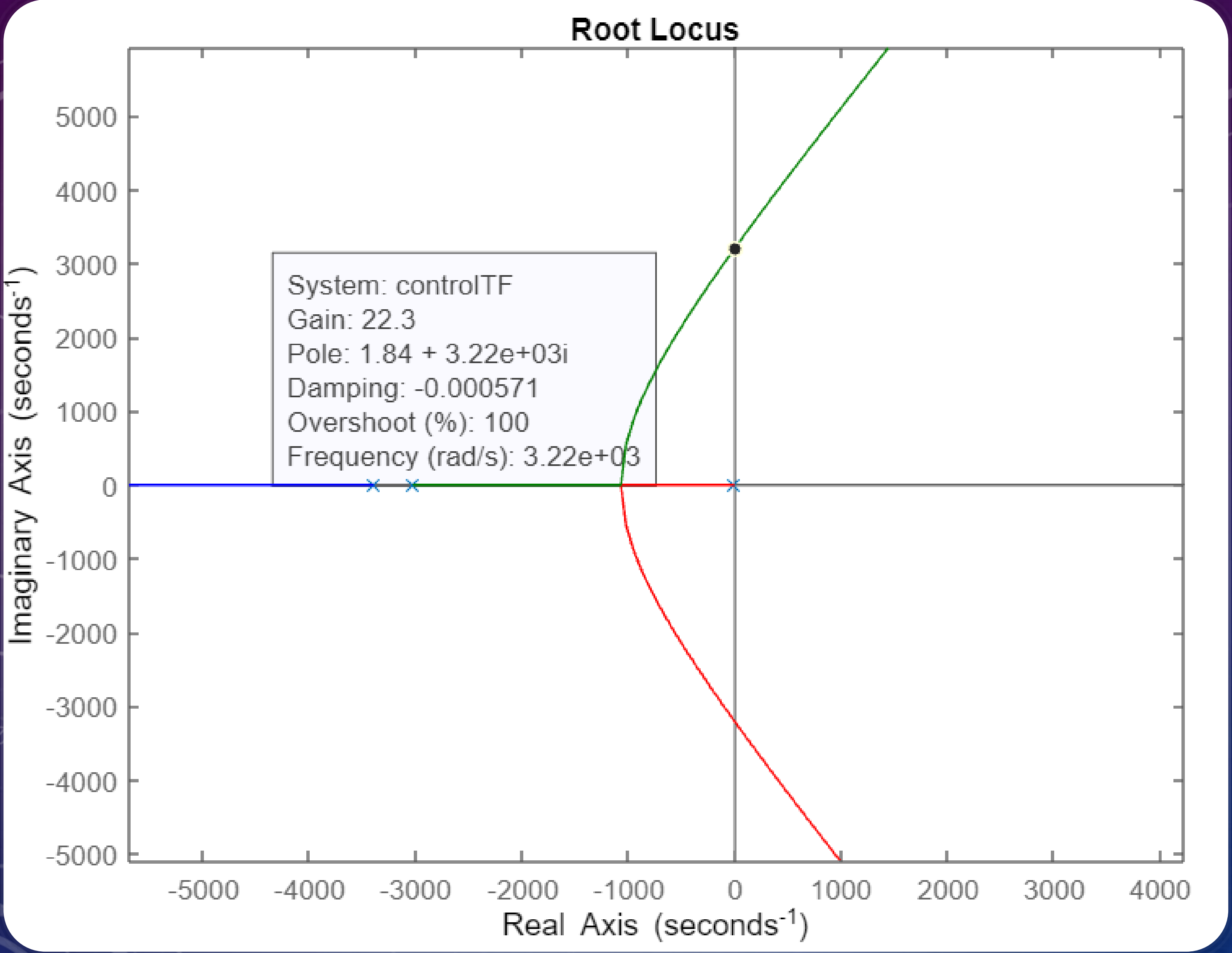
- Kt = Torque Constant
- Kv = Speed Constant
- Kb = Back-EMF Constant = 1/Kv
- Km = Motor Constant = Kt/sqrt(R)

Mechanical

- Armature Damping: B = Kt * NL Current/NL speed
- Armature Inertia: J = Rotor Inertia + (Mass * Center of Mass)





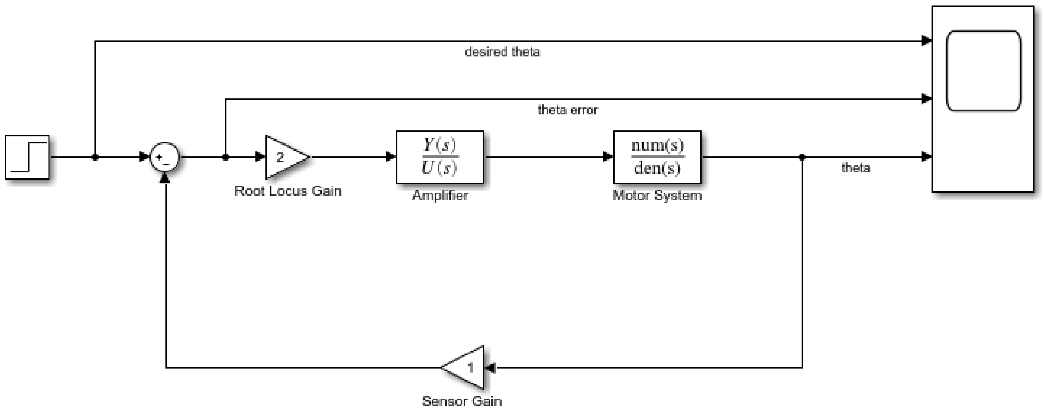


ROOT LOCUS OF TRANSIENT

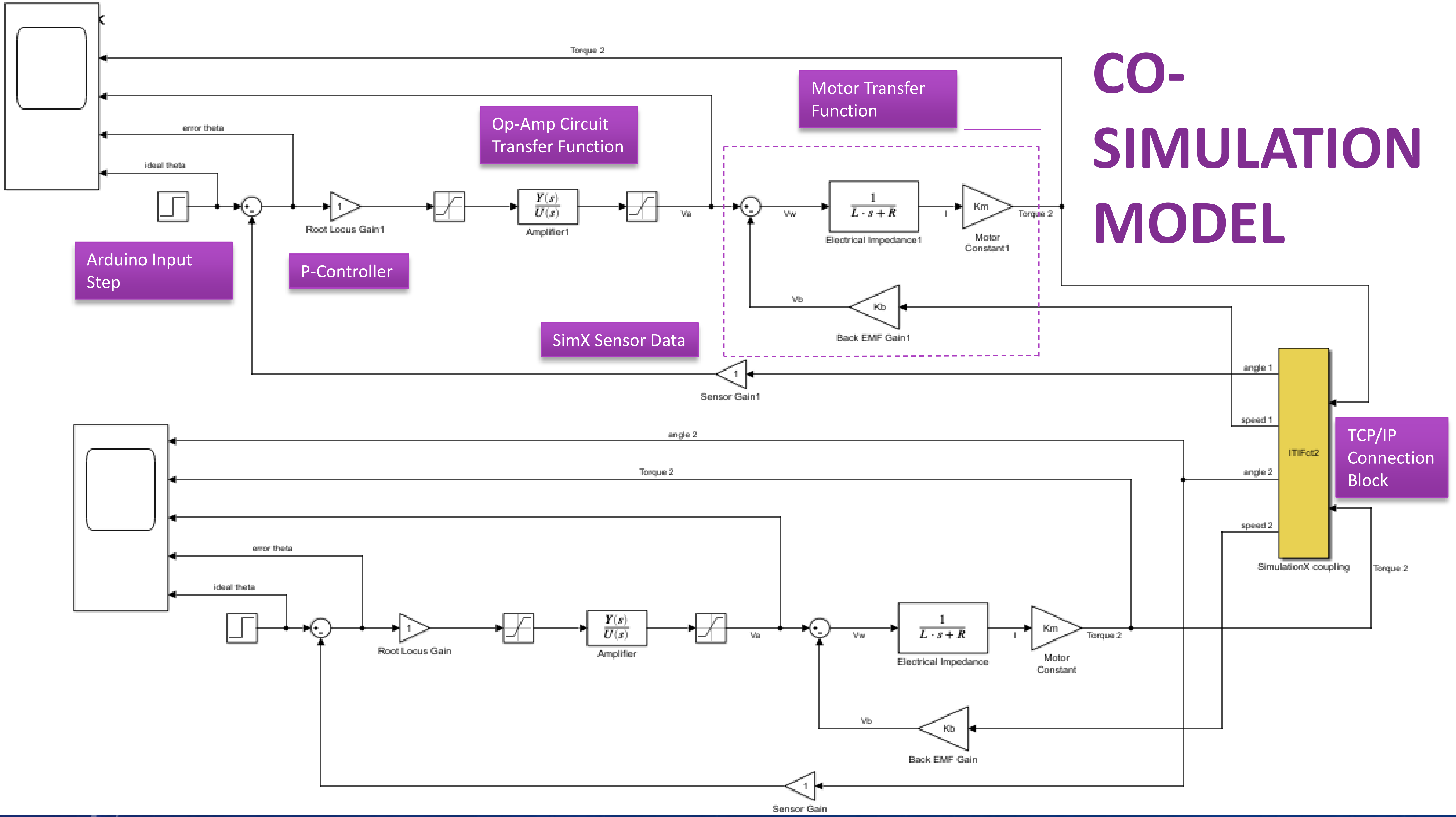
- 50% Gain (Ku) from root-locus
- Gain: Ku/2 = 22.3

P-CONTROLLER MODEL

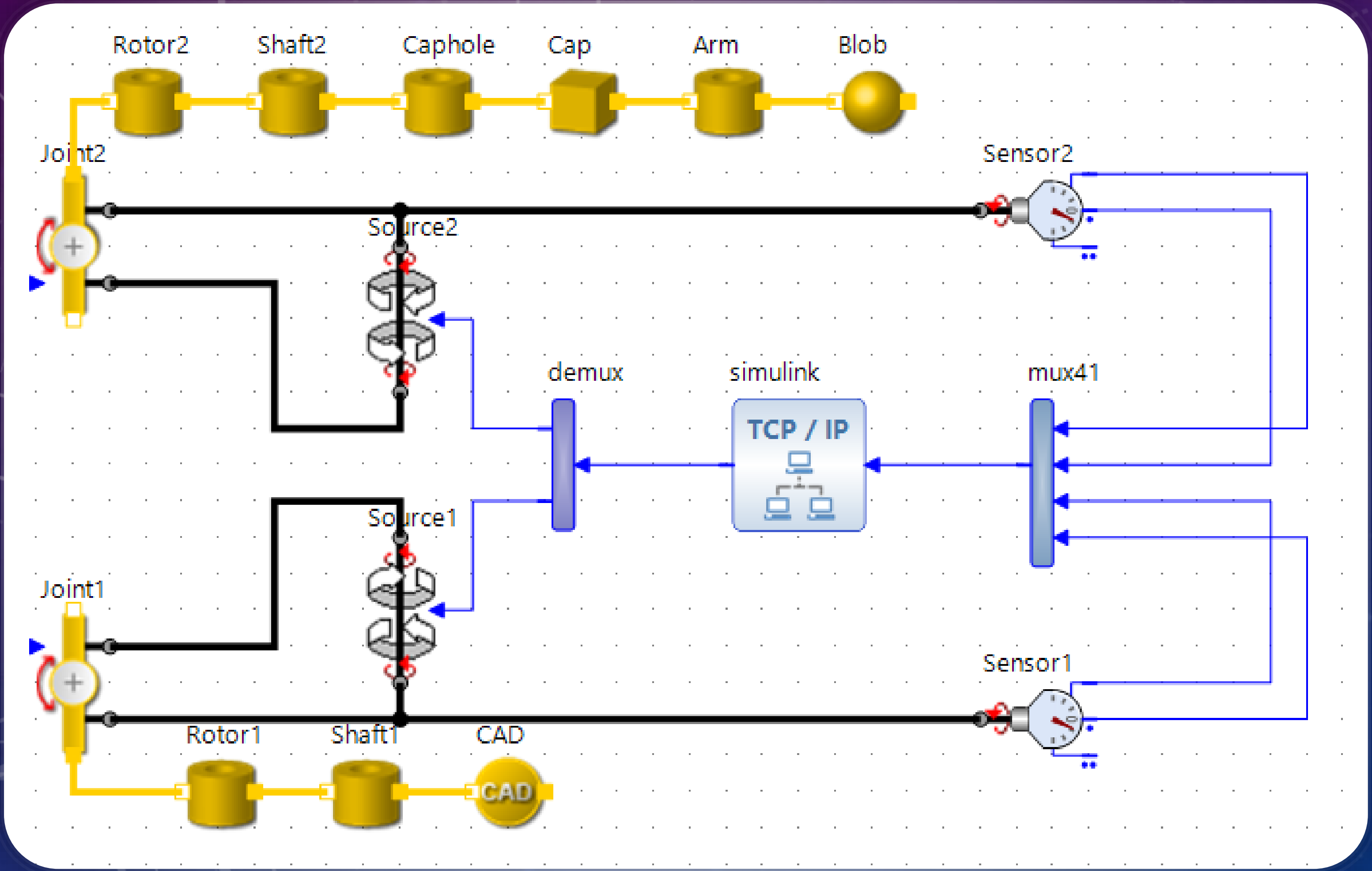
- Due to very little overshoot, error is minimal
- Desired and actual position settle at 90 degrees
- Root locus Gain has been adjusted to 3

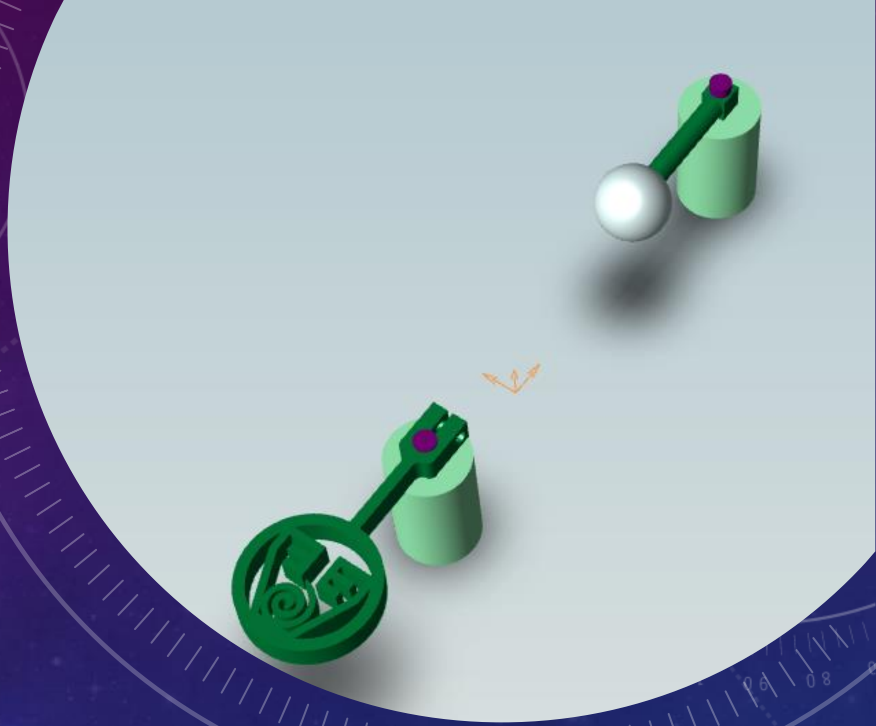


CO-SIMULATION MODEL



STEP 7: SIMULATION X



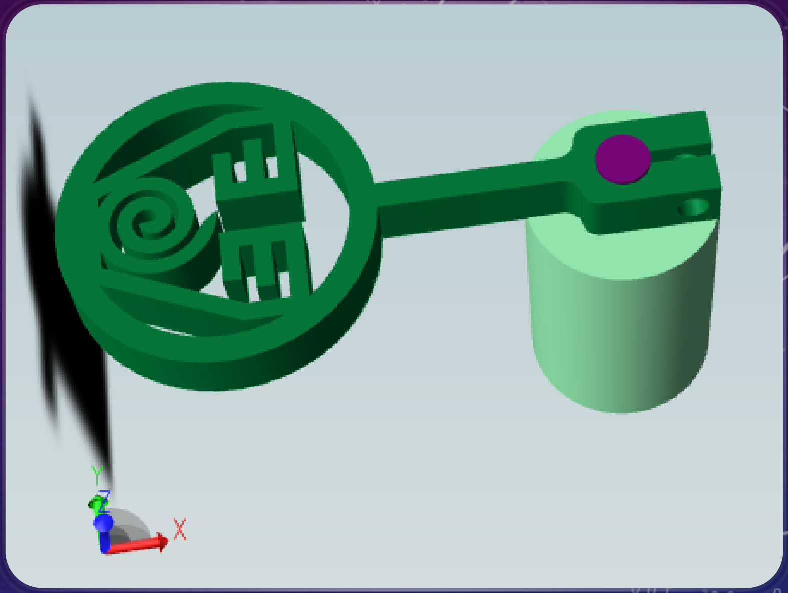


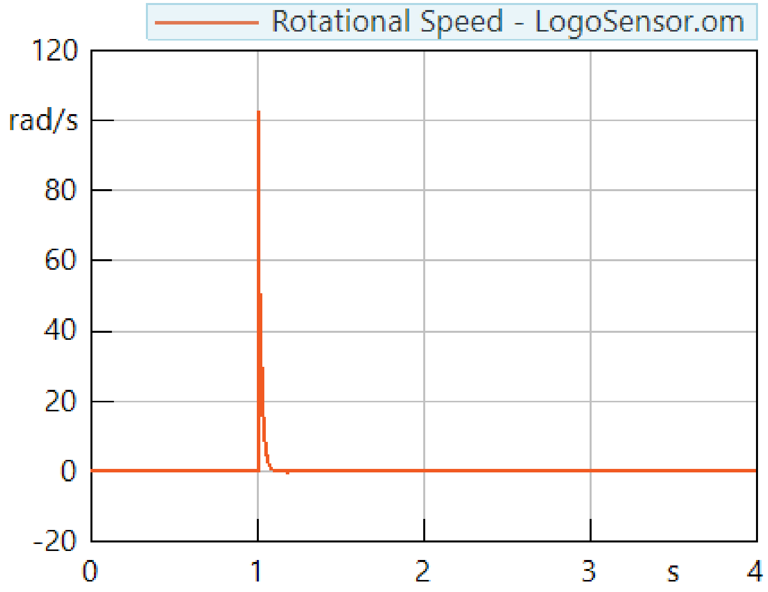
2 MODELS

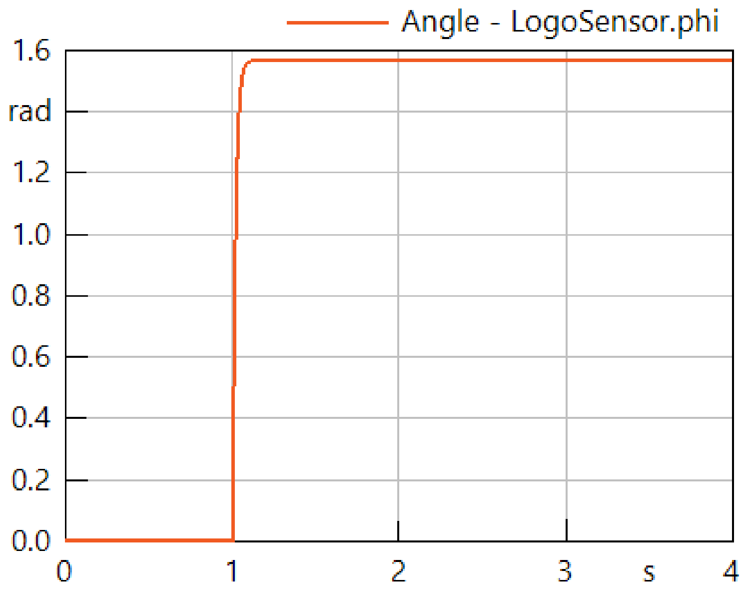
- ARM AND BALL MODEL
- LOGO CAD FILES

STEP 8: CO-SIMULATION

- Coupling blocks used to combine Simulink and Simulation X
- Accurately simulate both pendulum models to rotate 90 degrees







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