# EC 5030
# CONTROL SYSTEMS
# DESIGN PROJECT

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GROUP EG19

SEMESTER 5

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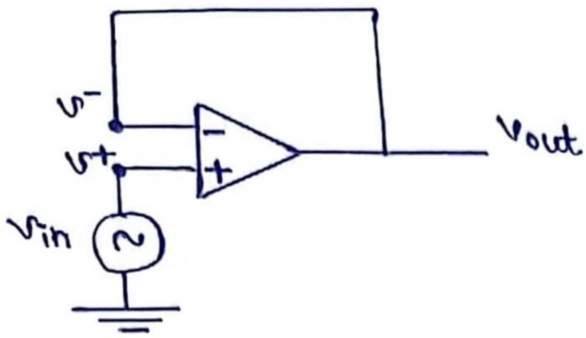
TITLE: IMPLEMENTATION OF PID CONTROLLER

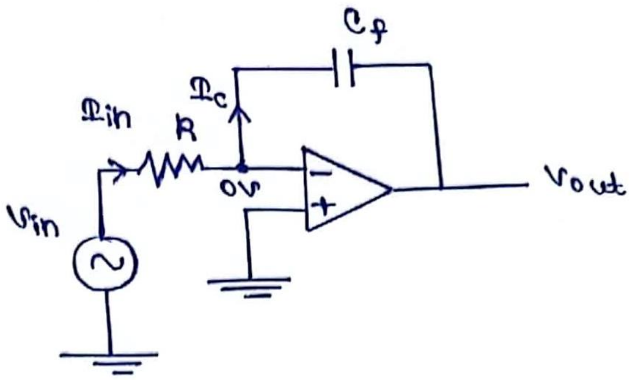
**Design 1 – Design of a second-order system**

1.
   1. Voltage follower



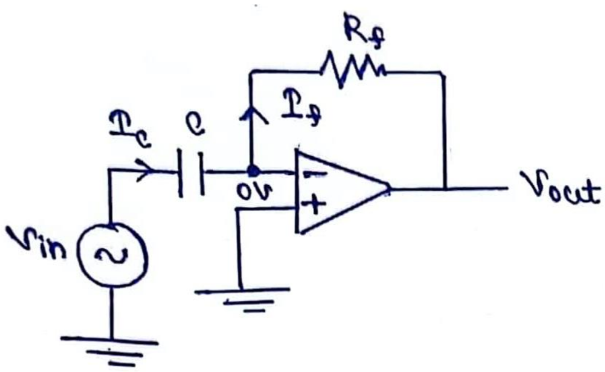

$V^+ = V^-$
$\therefore V_{out} = V_{in}$

   2. Integrator



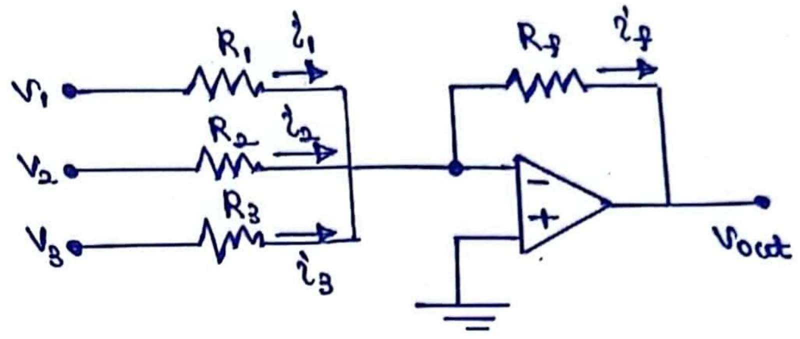

$V_{out\,(t)} = -\frac{1}{RC_f}\int V_{in\,(t)}\,dt$

   3. Differentiator



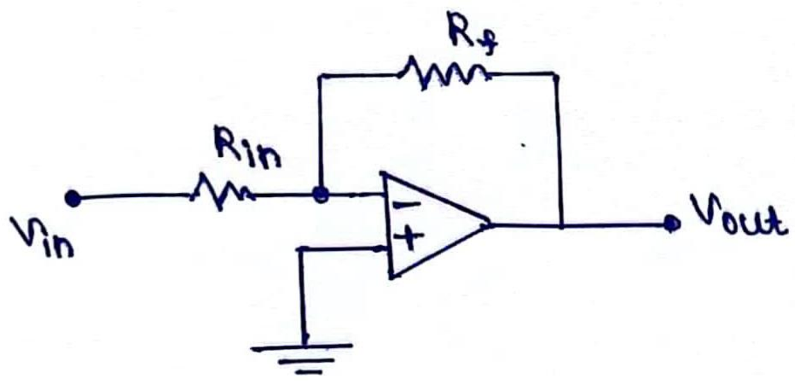

$V_{out\,(t)} = -RC\,\frac{dV_{in\,(t)}}{dt}$

4. Summing amplifier



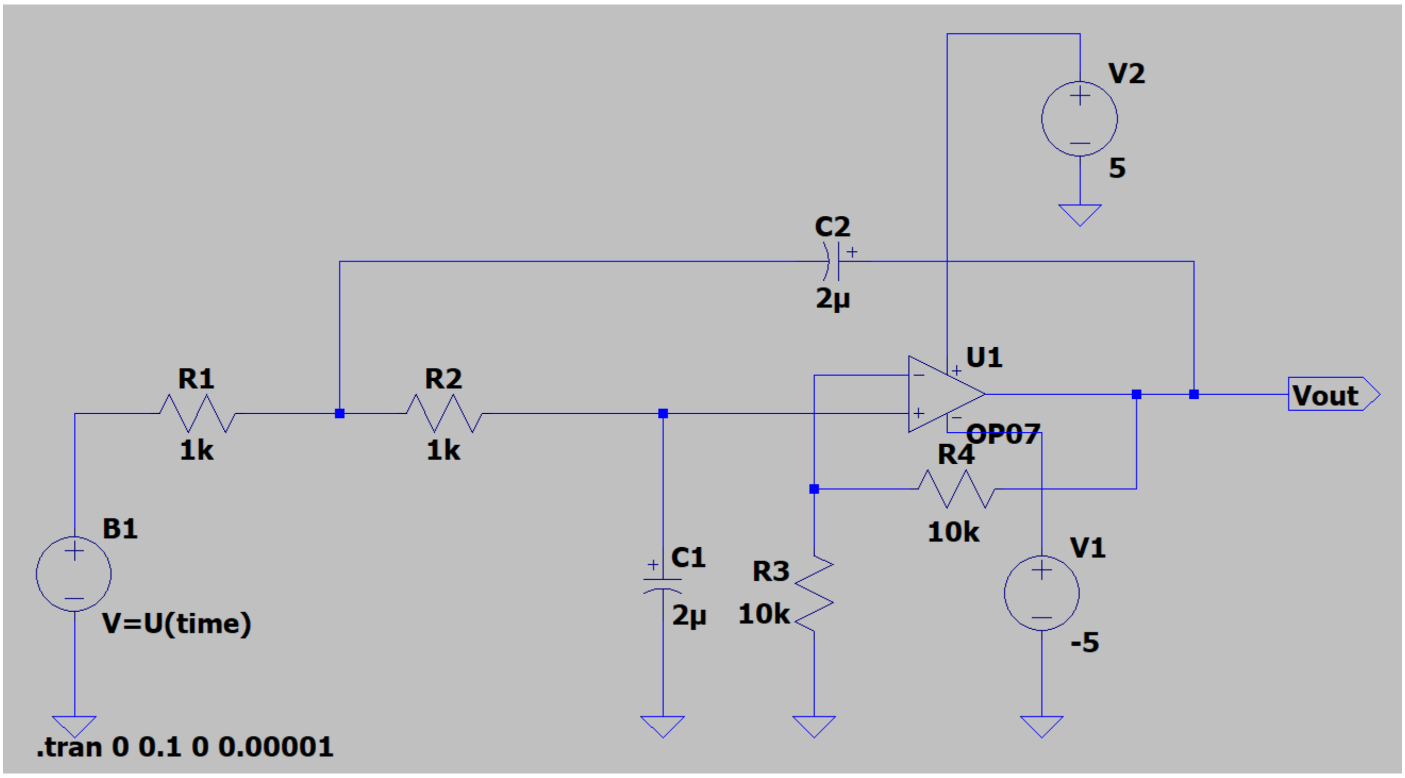

$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}\right)$

5. Inverter




$V_{out} = -\left(\frac{R_f}{R_{in}}\right) V_{in}$

2.

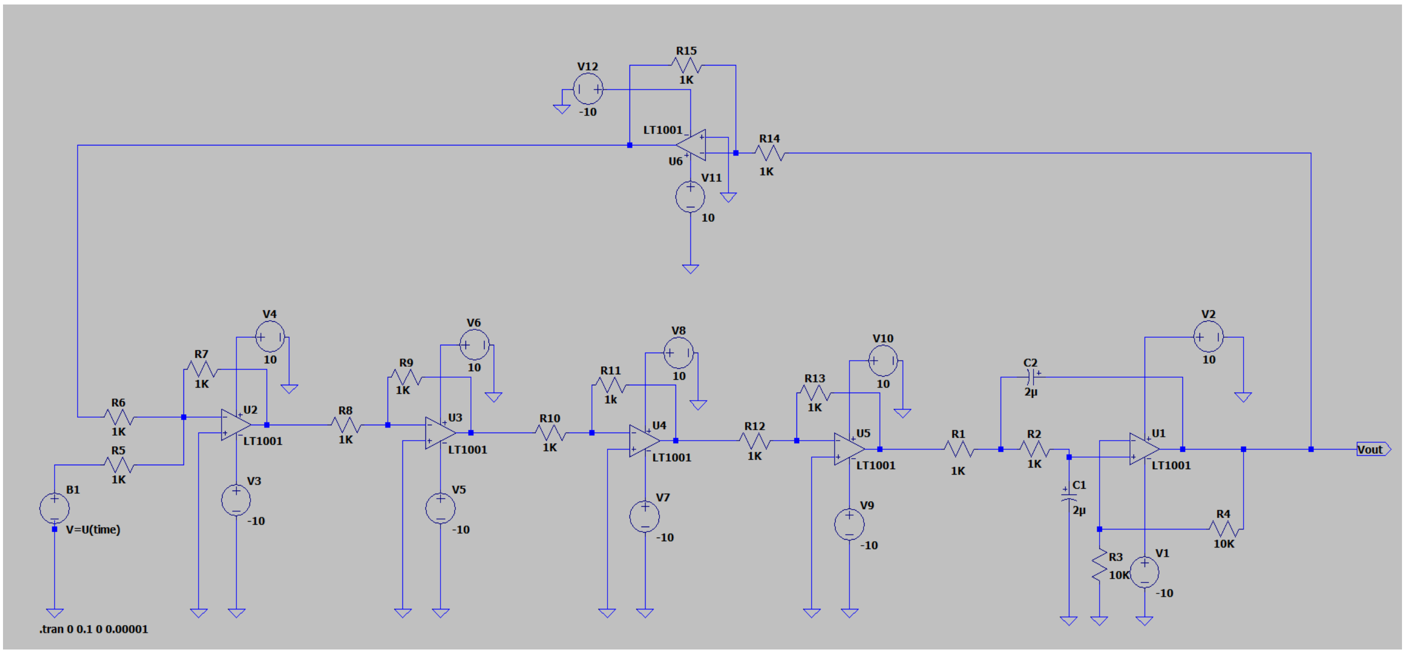


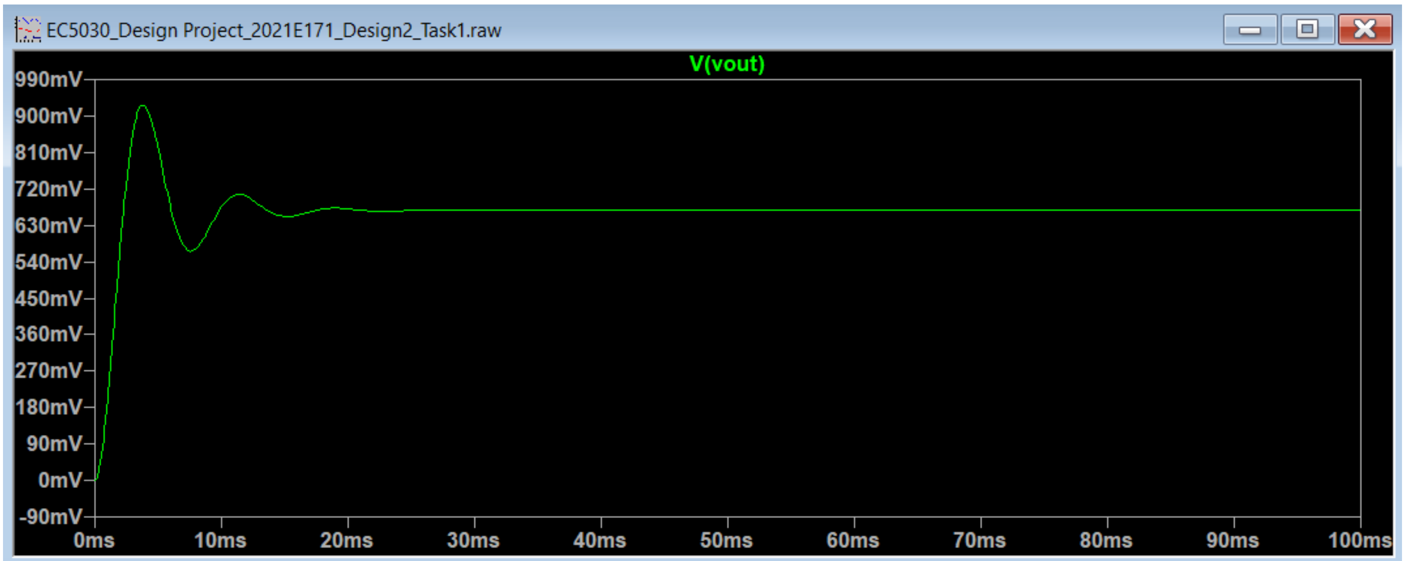


- Maximum peak overshoot = 325.79Mv
- Rise time = 3.2967ms
- Setting time = 14.0659ms

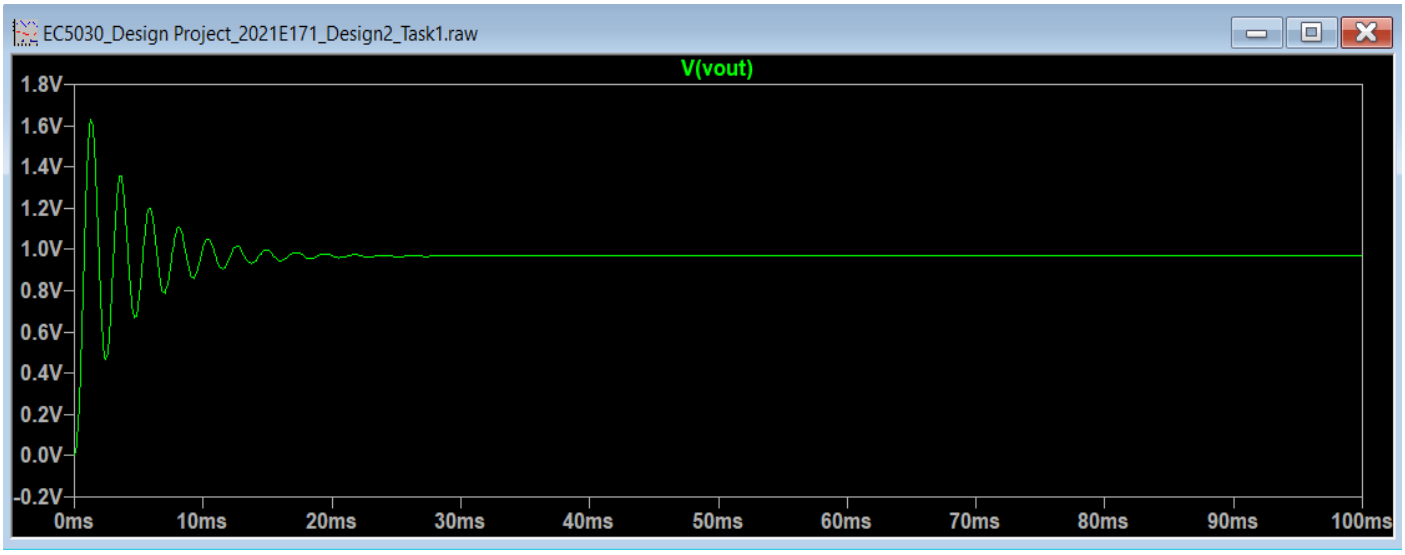
**Design 2 – Design of a second-order system with a PID controller.**

**Task 1 – Design a second-order system with a proportional controller**

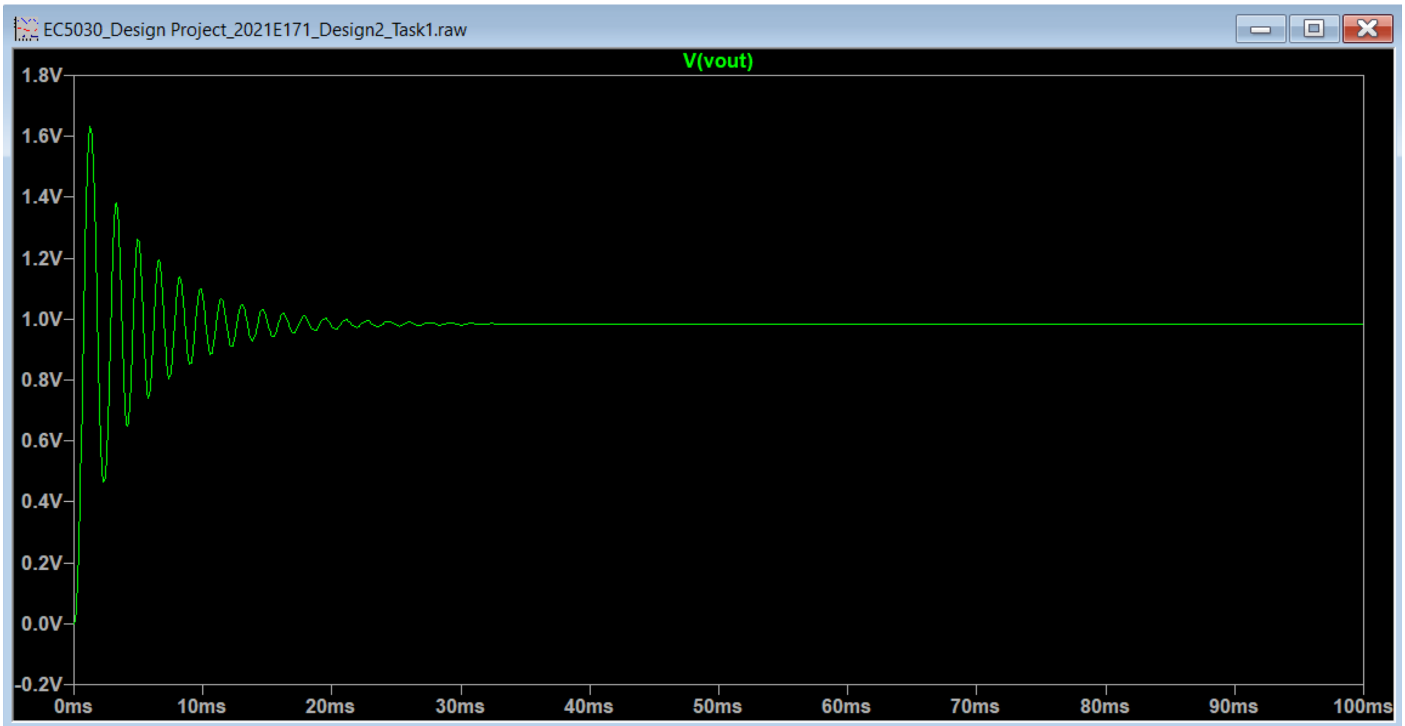



- Changed Resistor Value (R9) = 1kΩ
- Proportional Constant Kp = 1
- Maximum peak overshoot = 259.245mV
- Rise time = 1.5301ms
- Setting time = 15.1913ms

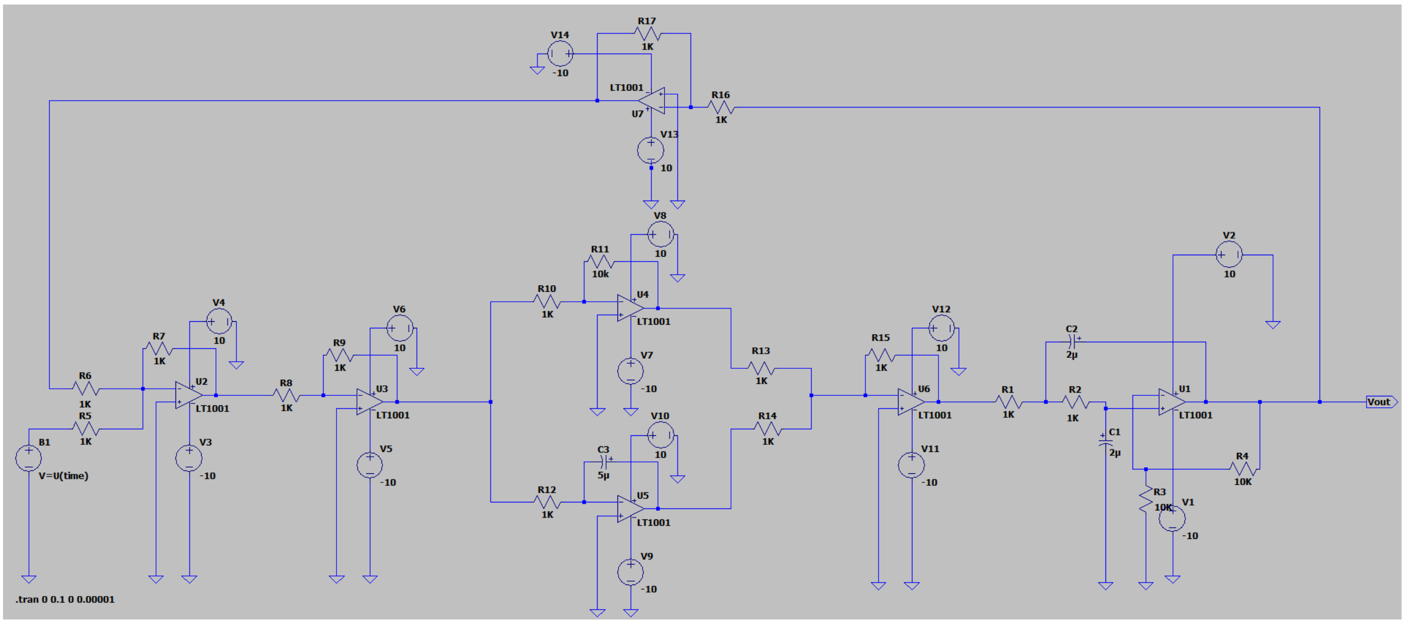



- Changed Resistor Value (R9) = 15kΩ
- Proportional Constant Kp = 15
- Maximum peak overshoot = 663.6823mV
- Rise time = 0.4886ms
- Setting time = 18.2359ms




- Changed Resistor Value (R9) = 30kΩ
- Proportional Constant Kp = 30
- Maximum peak overshoot = 645.6917mV
- Rise time = 0.4886ms
- Setting time = 21.7155ms

**Task 2 – Design a second-order system with a PI controller**



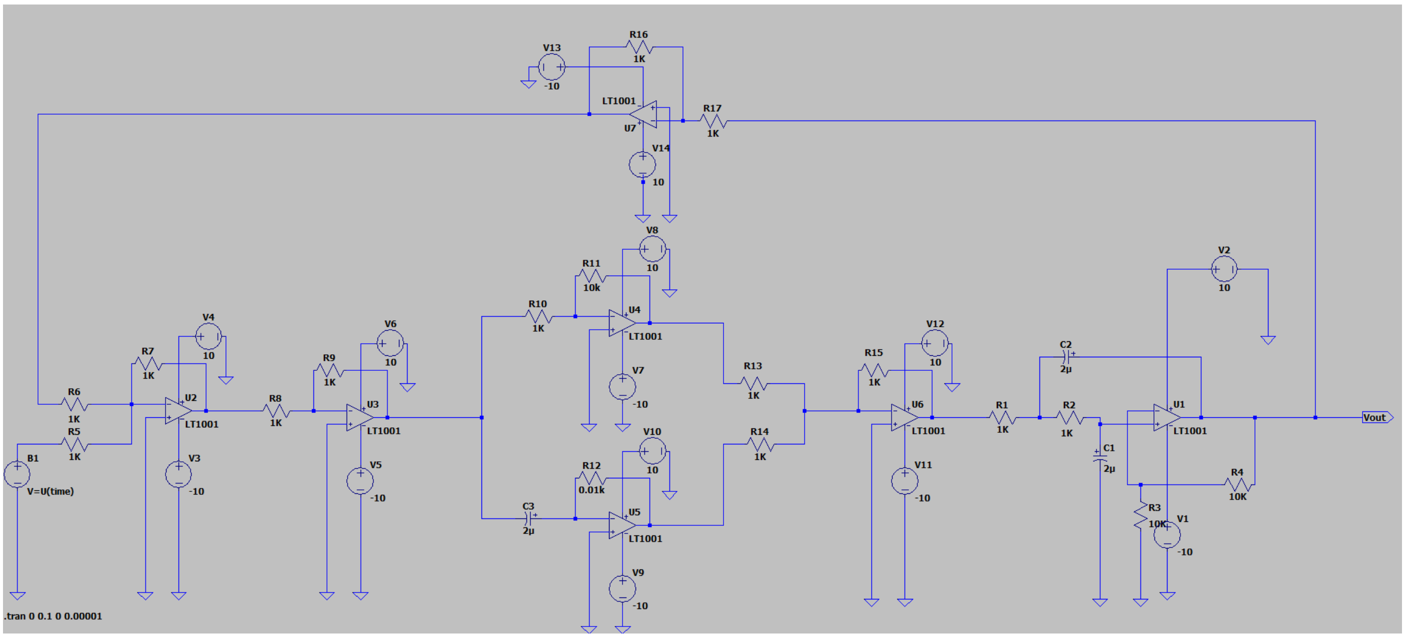
- Proportional Constant Kp = 10


- Changed Capacitor Value (C3) = 5µF
- Integral Constant Ki = 200
- Maximum Peak Overshoot = 657.6805mV
- Rise time = 0.5429ms
- Settling time = 19.4896ms

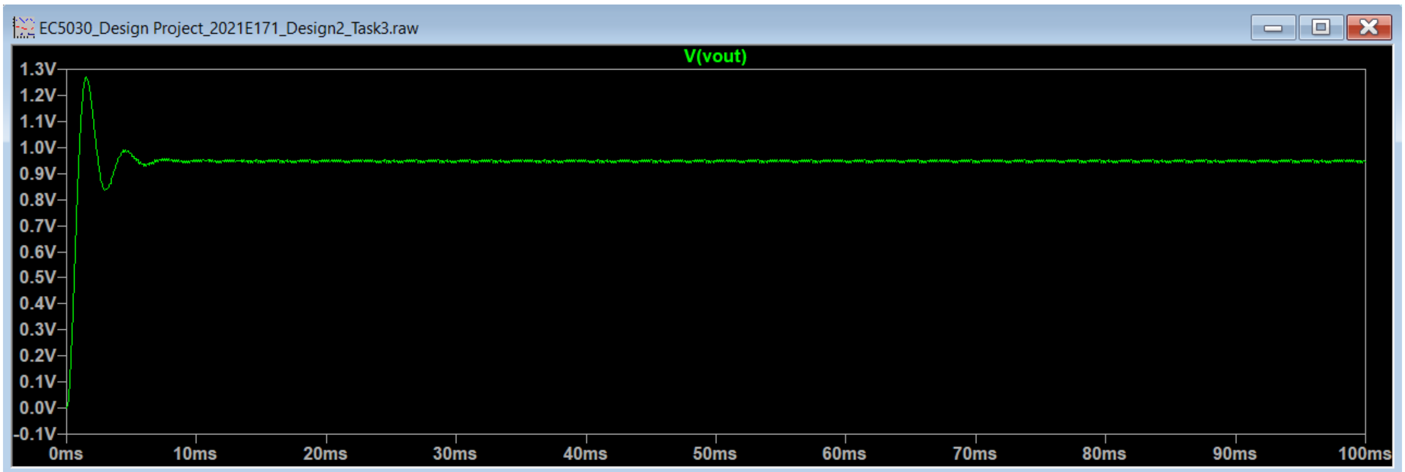

- Changed Capacitor Value (C3) = 100µF
- Integral Constant Ki = 10
- Maximum Peak Overshoot = 672.2758mV
- Rise time = 0.5429ms
- Settling time = 19.4896ms


- Changed Capacitor Value (C3) = 200µF
- Integral Constant Ki = 5
- Maximum Peak Overshoot = 675.1219mV
- Rise time = 0.5429ms
- Settling time = 19.2725ms

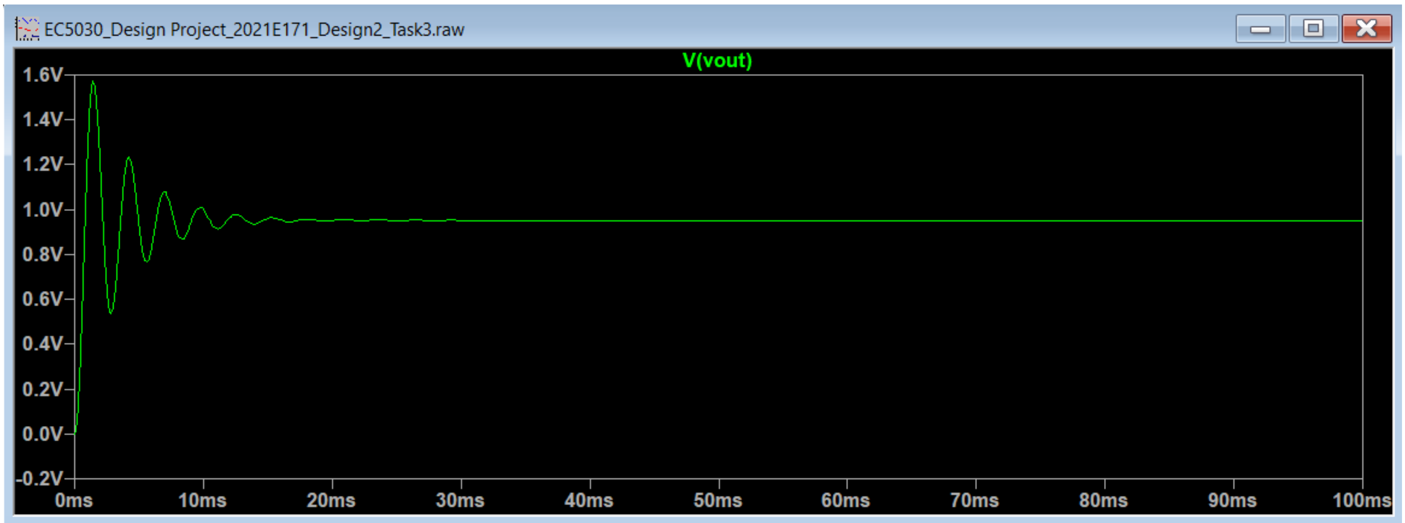
## Task 3 – Design a second order system with a PD controller



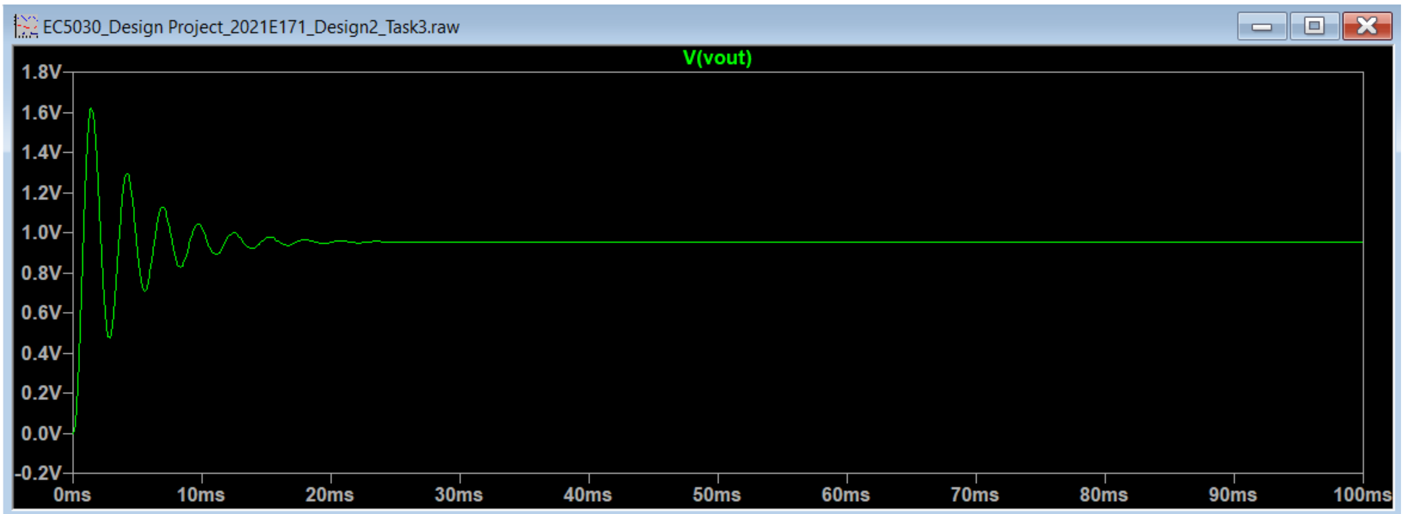
- Proportional Constant Kp = 10




- Changed Resistor Value (R12) = 1kΩ
- Differential Constant Kd = 0.002
- Maximum Peak Overshoot = 323.2895mV
- Rise time = 0.6515ms
- Settling time = 6.2432ms

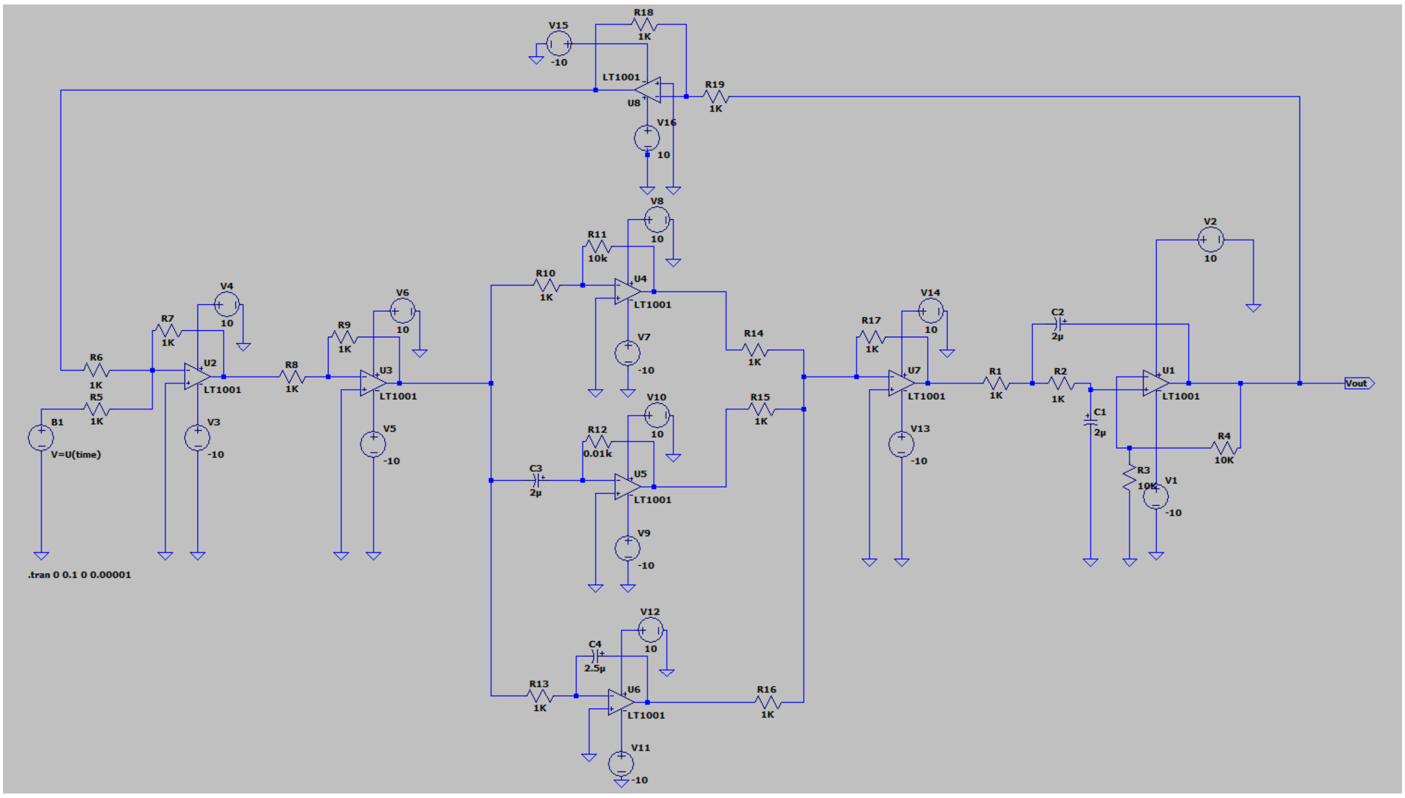


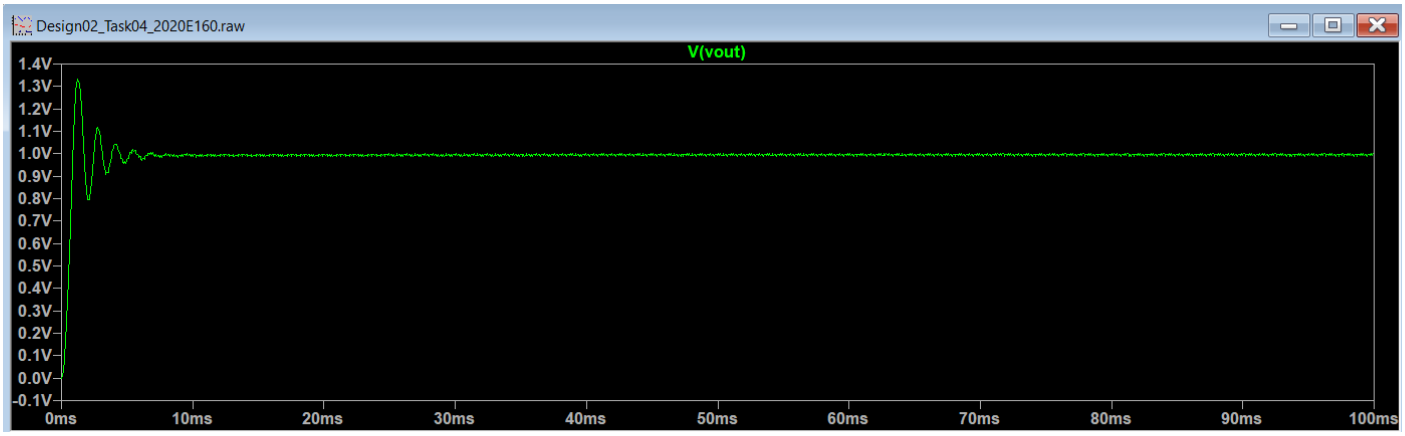

- Changed Resistor Value (R12) = 0.1kΩ
- Differential Constant Kd = 0.0002
- Maximum Peak Overshoot = 618.8288mV
- Rise time = 0.4886ms
- Settling time = 14.0608ms




- Changed Resistor Value (R12) = 0.01kΩ
- Differential Constant Kd = 0.00002
- Maximum Peak Overshoot = 669.8141mV
- Rise time = 0.4886ms
- Settling time = 16.5038ms

## Task 4 – Design of a second order system with PID controller




- Changed Resistor Value (R11) = 50kΩ
- Changed Capacitor Value (C3) = 2.5µF
- Changed Capacitor Value (C4) = 2.5µF
- Proportional Constant Kp = 50
- Integral Constant Ki = 400
- Differential Constant Kd = 0.0025
- Maximum Peak Overshoot = 336.4334mV
- Rise time = 0.5429ms
- Settling time = 5.9175ms

DISCUSSION:

1. Tabulate the changes in proportional, integral, and differential constants of a PID controller affecting the second order system behavior. Analyze the changes in Maximum Peak Overshoot, Rise time, and Settling time of the system.

| Constants | Behavior of constant | Maximum Peak Overshoot | Rise time | Settling time |
|---|---|---|---|---|
| Proportional (Kp) | Increase | Increase | Decrease | No effect |
| Integral (Ki) | Decrease | Increase | Decrease | Increase |
| Differential (Kd) | Decrease | Decrease | No effect | Decrease |

2. State the importance of a PID controller in a control system.

- Proportional Control (P): The proportional term provides an output that is proportional to the current error value. This helps to reduce the overall error by applying an immediate correction based on the magnitude of the error.

- Integral Control (I): The integral term accumulates the error over time, which helps to eliminate any residual steady-state error that may be present. This ensures that the system output eventually matches the setpoint precisely.

- Derivative Control (D): The derivative term predicts future error based on its rate of change. This helps to dampen the system's response, reducing overshoot and settling time, and improving system stability.

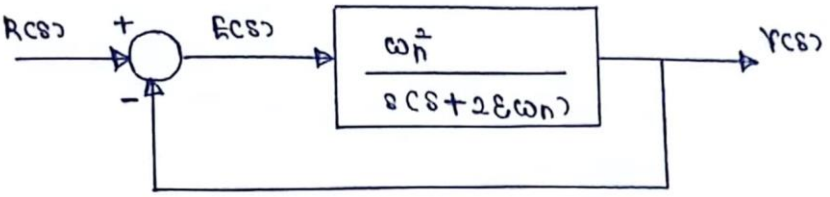
- A PID controller can be tuned to meet various performance criteria by adjusting the proportional, integral, and derivative gains. This makes it versatile and suitable for a wide range of applications.

- The PID controller improves the stability and accuracy of the system by adjusting the control input based on the error between the desired setpoint and the actual process variable.

- Due to its simplicity and effectiveness, the PID controller is widely used in industrial control systems, including temperature control, speed control, flow control, and many other processes.

- By combining the three terms (P, I, and D), the PID controller can provide a balanced response that optimizes the performance of the control system, ensuring quick response, minimal overshoot, and stable behavior.

3. Obtain the mathematical derivatives for the Maximum Peak Overshoot, Rise time, and Settling time of the closed-loop system and analyze how the changes in the PID controller parameter affect the second-order systems for a given unit step response.




closed loop transfer function $= \dfrac{Y(s)}{R(s)}$

$$\frac{Y(s)}{R(s)} = \frac{\dfrac{\omega_n^2}{s(s+2\xi\omega_n)}}{1+\dfrac{\omega_n^2}{s(s+2\xi\omega_n)}}$$

closed loop transfer function $= \dfrac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$

Unit step function ; $R(s) = \dfrac{1}{s}$

$$Y(s) = \frac{\omega_n^2}{s(s^2+2\xi\omega_n s+\omega_n^2)}$$

Inverse Laplace transform;

$$y(t) = 1 - \frac{e^{-\xi\omega_n t}}{\sqrt{1-\xi^2}} \sin\left(\omega_n\sqrt{1-\xi^2}\,t + \cos^{-1}\xi\right) \quad t \geq 0$$

Time at which the maximum overshoot;

$$t_{max} = \frac{\pi}{\omega_n\sqrt{1-\xi^2}}$$

maximum overshoot $= C_{max} - 1 = e^{\frac{-\pi\xi}{\sqrt{1-\xi^2}}}$

rise time $= \dfrac{\pi-\phi}{\omega_n\sqrt{1-\xi^2}}$ ; $\cos^{-1}\xi = \phi$

settling time $= \dfrac{4}{\xi\omega_n}$

To obtain the peak time;

$$\frac{dy(t)}{dt} = 0$$

$$\therefore t_{peak} = \frac{\pi}{\omega_n\sqrt{1-\xi^2}}$$

$y(t)$ max; $t = \dfrac{\pi}{\omega_n\sqrt{1-\xi^2}}$

$$\text{maximum overshoot} = y(t)_{max} - 1$$

$$= 1 + e^{\frac{-\pi\xi^2}{\sqrt{1-\xi^2}}} - 1$$

$$= e^{\frac{-\pi\xi^2}{\sqrt{1-\xi^2}}}$$

Settling time approximately 4 times of the time constant of a signal

The time constant of this case $= \dfrac{1}{\xi\omega_n}$

| Constants | Maximum Peak Overshoot | Rise time | Settling time |
|---|---|---|---|
| Proportional (Kp) | Increase | Decrease | No effect |
| Integral (Ki) | Increase | Decrease | Increase |
| Differential (Kd) | Decrease | No effect | Decrease |

4. State two examples of actual that would be benefitted by the PID controllers. Describe how the PID controllers are used in these applications.

   - Temperature Control in Industrial Furnaces

     Proportional Control (P): The controller measures the difference between the setpoint temperature and the actual furnace temperature. If the temperature is below the setpoint, the controller increases the fuel supply or heating element power proportionally to the error.

     Integral Control (I): To address any persistent deviation from the setpoint (steady-state error), the integral component accumulates the error over time and makes adjustments to bring the temperature exactly to the desired level.

     Derivative Control (D): To prevent overshoot and oscillations, the derivative component reacts to the rate of change of the temperature. If the temperature is rising too quickly, the derivative action will reduce the heating input to avoid overshoot.

     The combined action of the PID controller ensures that the furnace temperature reaches the setpoint quickly and remains stable, improving the quality of the processed materials and reducing energy consumption.

- Speed Control of Electric Motors

  Proportional Control (P): The controller measures the speed of the motor and compares it to the desired setpoint. If the motor is running slower than the setpoint, the proportional action increases the voltage or current supplied to the motor to increase its speed.

  Integral Control (I): Any small discrepancies in speed that persist over time are corrected by the integral component, which sums the errors and adjusts the motor control to eliminate steady-state errors.

  Derivative Control (D): To avoid sudden changes in speed that could cause mechanical stress or instability, the derivative component reacts to the rate of change of speed. If the speed is increasing too rapidly, the derivative action will reduce the control input to smooth out the acceleration.

  The PID controller ensures that the motor reaches and maintains the desired speed quickly and smoothly, enhancing the efficiency and lifespan of the motor and improving the overall performance of the machinery it drives.