# PID Controller Design Module

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Session Objective

1. The session aims to provide a comprehensive understanding of control systems.
2. differentiate between open-loop and closed-loop systems.
3. emphasize the importance of control theory, cover fundamental components.
4. explore real-world examples, and explain the role of feedback.
5. It also focuses on time response metrics control theory's practical applications. and its impact on diverse industries.
6. Participants will gain foundational knowledge for real-world use.
7. First Order System Analysis and practical examples
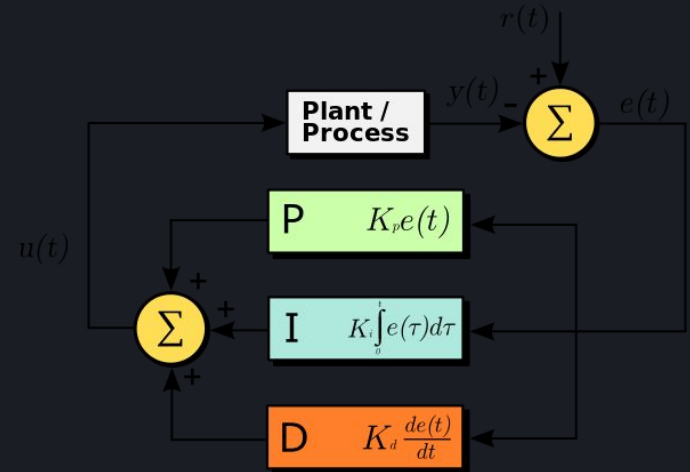
Introduction About Control Theory

Control Theory is a branch of engineering and mathematics that deals with controlling the behavior of dynamic systems. It plays a crucial role in various applications, from industrial processes to robotics, and it forms the foundation for designing controllers like PID controllers.

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Why We Need Control Theory

Control theory is indispensable for optimizing system performance, enhancing safety, efficient resource utilization, ensuring precision and adaptability, and offering economic benefits. It manages complex systems, ensures predictability, advances scientific understanding, fuels innovation, and impacts various industries, from manufacturing to healthcare.

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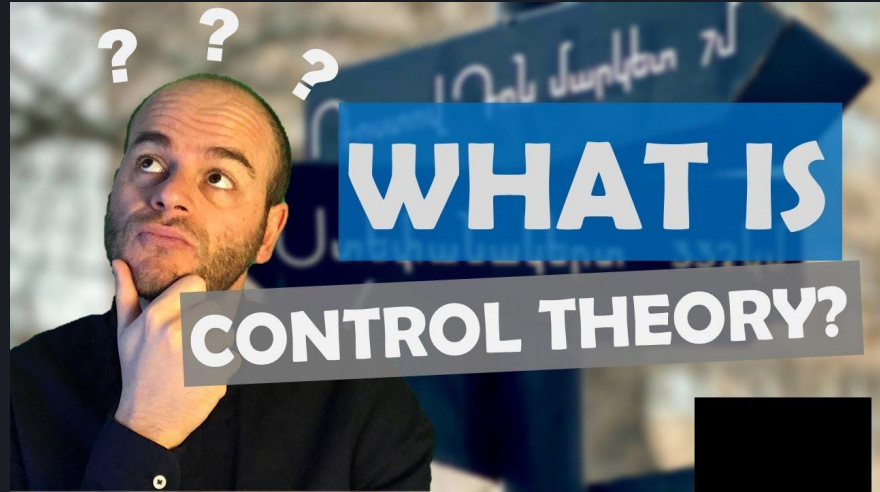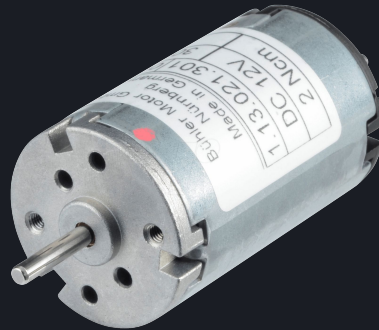
Key Concepts in Control Theory

System

A system is a collection of components or elements that work together to achieve a specific objective or perform a particular function. Systems can be physical or abstract, and they are characterized by inputs, processes, and outputs. In the context of control theory and engineering, a system typically refers to a dynamic or mechanical entity that can be controlled, analyzed, or modified to achieve desired behaviors or outcomes.

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Key Concepts in Control Theory

Disturbance

In the context of control systems and engineering, a disturbance refers to an external or internal influence, force, or change that affects a system's behavior, operation, or performance. Disturbances can introduce variability or unexpected fluctuations in a system's output, making it challenging to maintain the desired control or setpoint. Engineers and control system designers often strive to minimize the impact of disturbances to ensure the stability and reliability of systems. Disturbances can take various forms, such as sudden environmental changes, unexpected events, noise, or variations in input conditions, and they are an essential consideration in control theory and system design.

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Key Concepts in Control Theory

Plant

In the context of control systems and engineering, a "plant" refers to the physical or mathematical representation of a system or process that is being controlled, regulated, or analyzed. The plant is the object or entity that the control system interacts with or regulates. It can be a real, physical system, such as a chemical reactor, an electrical motor, a robotic arm, or a heating system. Alternatively, it can be an abstract mathematical model used to simulate and analyze the behavior of a system.

In a control system, the plant receives control inputs and produces outputs, and the objective of control is often to manipulate the inputs in such a way that the plant's outputs meet certain criteria or follow a desired setpoint. Understanding the behavior of the plant and designing an appropriate controller are essential tasks in control theory and engineering to achieve desired system performance and stability.

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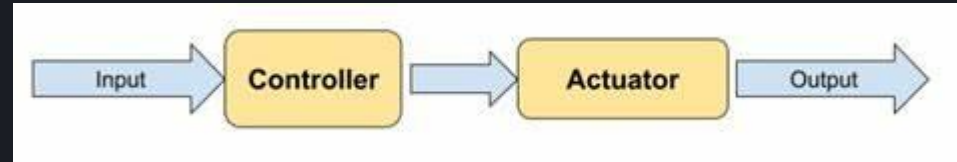# Types Of Control Systems

Open-Loop Control System

An open-loop control system, also known as a non-feedback control system, is a type of control system in which the control action is predetermined and not based on feedback from the output. In other words, the system does not continuously monitor its performance or the output to make adjustments. Instead, it operates based on a predefined input and does not take into account the actual system response.

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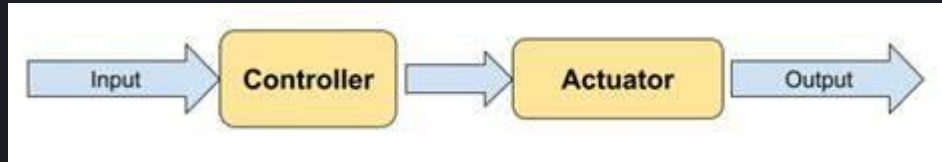
Types Of Control Systems

Key Characteristics of Open-Loop Control system

1. No Feedback: These systems do not use feedback from the output to adjust the control input.
2. Simple Design: Open-loop systems are often simpler and less complex compared to closed-loop systems.
3. Limited Accuracy: They may lack the ability to correct errors or disturbances, which can result in reduced accuracy and reliability.

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Types Of Control Systems

Examples of Open-Loop Control system

Toaster: A common household toaster is a classic example of an open-loop control system. You set the toasting time and temperature manually, and the toaster operates for the specified duration without monitoring the actual state of the toast. The result depends on the preset settings rather than the actual state of the toast.

Washing Machine: Many older washing machines operate as open-loop systems. You select the wash cycle and duration, and the machine carries out these settings without adjusting for variables like the load size, water temperature, or the cleanliness of the clothes.

Irrigation System: In agriculture, some basic irrigation systems are open-loop. They turn on and off at specified times or durations but do not consider factors like soil moisture levels.

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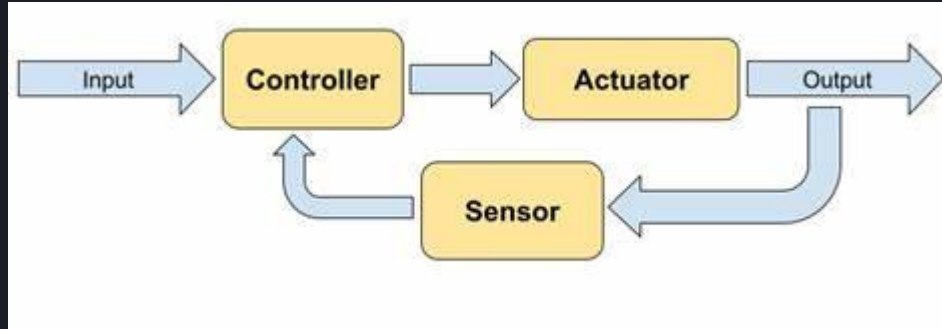# Types Of Control Systems

Open-Loop Control system

It's important to note that open-loop control systems are generally less precise and adaptable compared to closed-loop (feedback) control systems, which continuously monitor the system's behavior and adjust the control input accordingly. While open-loop systems have their applications, they are more suited for processes where the exact outcome is not critical, and precise control is not required.

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Types Of Control Systems
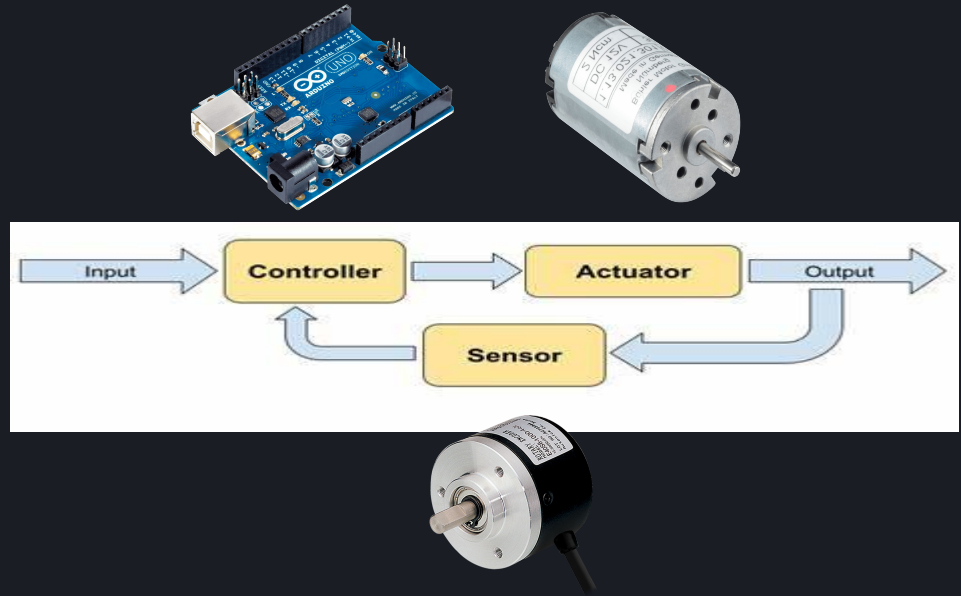
Closed-Loop Control system

A closed-loop control system, also known as a feedback control system, is a type of control system that uses feedback from the system's output to continuously monitor and adjust the control input. It is designed to maintain and regulate the system's behavior, ensuring that the output closely follows the desired setpoint or reference signal. Closed-loop control systems are widely used in engineering and various applications where precision and accuracy are crucial.

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Types Of Control Systems

Key Characteristics of Closed-Loop Control system

1. Feedback Loop: These systems have a feedback loop that continuously measures the system's output and compares it to the desired reference or setpoint.
2. Continuous Adjustment: Based on the feedback, the control system makes continuous adjustments to the control input, aiming to reduce any error between the actual output and the desired output.
3. Improved Accuracy and Stability: Closed-loop systems are known for their ability to maintain system stability and achieve precise control, even in the presence of disturbances.

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Types Of Control Systems

Examples of Closed-Loop Control system

Thermostat Control: A thermostat in a heating or cooling system is a classic example of a closed-loop control system. It measures the room temperature (feedback) and adjusts the heating or cooling to maintain the desired temperature setpoint. The thermostat continuously compares the actual temperature to the setpoint and makes adjustments as needed.

Robotics Control: Robots use closed-loop control to execute precise movements and tasks. Sensors on the robot's joints and end-effectors provide feedback to ensure accurate positioning and control.

Cruise Control in Vehicles: Cruise control systems in cars are closed-loop control systems. They maintain a constant vehicle speed by adjusting the throttle and monitoring the actual speed with feedback from speed sensors. If the car's speed deviates from the setpoint, the system adjusts the throttle to correct it.

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Types Of Control Systems

Closed-Loop Control system

Closed-loop control systems are favored when accuracy, stability, and the ability to adapt to changing conditions are essential. They are capable of mitigating disturbances and providing a high degree of control precision, making them suitable for a wide range of applications.

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Control Objective

Control objectives are specific, measurable goals or targets that a control system aims to achieve. They define the desired behavior or performance of a system, process, or operation and serve as a basis for the design and operation of control systems. These objectives are crucial in ensuring that a system operates efficiently, safely, and in accordance with the desired standards. Control objectives are particularly relevant in the context of control theory, where they guide the development of control strategies and the tuning of controllers.
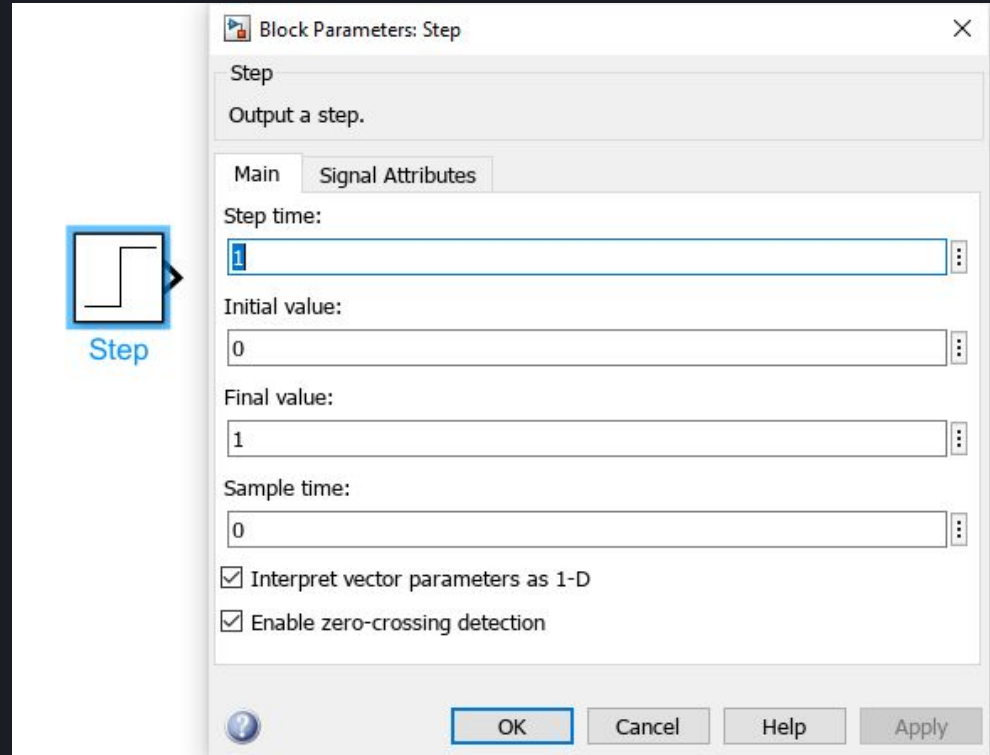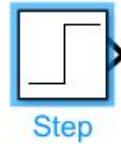
1. Defining Desired Outcomes
2. Performance Standards
3. Stability and Robustness
4. Safety and Reliability
5. Efficiency
6. Quality Control
7. Regulatory Compliance
8. Adaptation to Setpoints
9. Minimization of Oscillations

Control objectives are a foundational concept in control theory and engineering. They guide the design and implementation of control systems, helping to ensure that the controlled processes or systems operate in a controlled and desired manner, meeting various performance and safety criteria.

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Standard Test Signal

Step Function

In Simulink, a "Step Function" block is a fundamental building block used for generating a step signal as part of a Simulink model. A step signal is a common input in control system simulations and can represent a sudden change or transition in a system's input. The Step Function block allows you to specify the amplitude, time at which the step occurs, and other parameters of the step signal.



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Standard Test Signal

Step Function

Step Function Block Parameters:

The Step Function block has several parameters that you can configure:

1. Amplitude: This parameter sets the magnitude of the step change in the signal.
2. Step Time: You specify the time at which the step occurs. The simulation starts at time zero.
3. Initial Value: You can set an initial value before the step. This is particularly useful if your system has an initial condition.
4. Final Value: The value the signal reaches after the step change.

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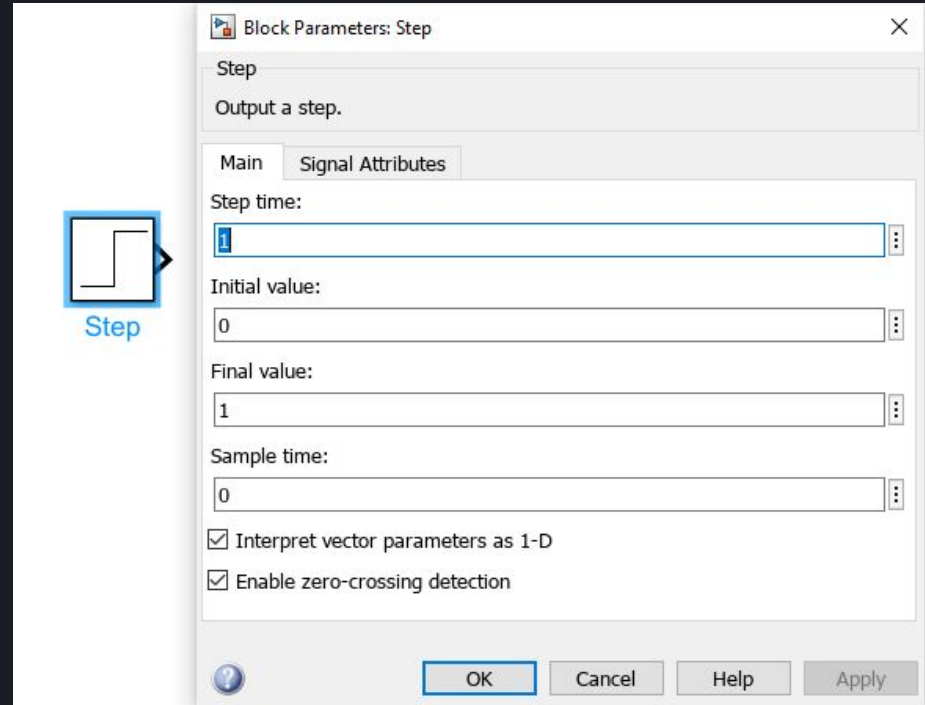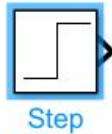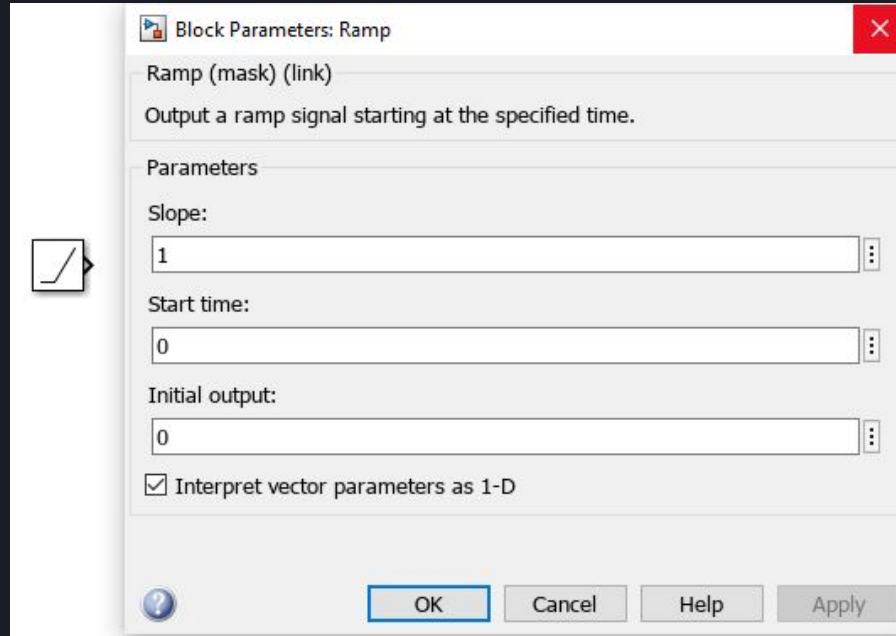
Standard Test Signal

Step Function

Let's say you are simulating a simple control system in Simulink where you want to test the response of a system to a step input. Here's how you can set up a Simulink model using the Step Function block

1. Open Simulink and create a new model.
2. From the Simulink library browser, drag and drop a "Step Function" block onto your model.
3. Double-click the Step Function block to configure its parameters:
   a. Set the "Amplitude" to the desired step size (e.g., 5 for a step change of 5 units).
   b. Specify the "Time of Step" (when the step should occur, e.g., at time t = 1 second).
   c. Optionally, set "Initial Value" (if you have a non-zero initial condition) and "Final Value" (the value after the step).
4. Connect the output of the Step Function block to the input of the system or component you want to test.
5. Add blocks to your model to represent the system, controllers, sensors, etc., as needed.
6. Configure the simulation parameters, such as the solver and simulation time.
7. Run the simulation, and you will observe the response of your system to the step input generated by the Step Function block.

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Standard Test Signal

Ramp Function

A ramp function, also known as a linear ramp or simply a ramp, is a mathematical function that increases or decreases linearly over time. It is a simple and linear signal that can be used in various engineering and mathematical applications to represent gradual changes or continuous processes. In mathematics and engineering, the ramp function is often denoted as "r(t)" or "u(t)" and is a fundamental building block for modeling and analyzing linear systems and signals.

Block Parameters: Ramp

Ramp (mask) (link)

Output a ramp signal starting at the specified time.

Parameters

Slope:
`1`

Start time:
`0`

Initial output:
`0`

☑ Interpret vector parameters as 1-D
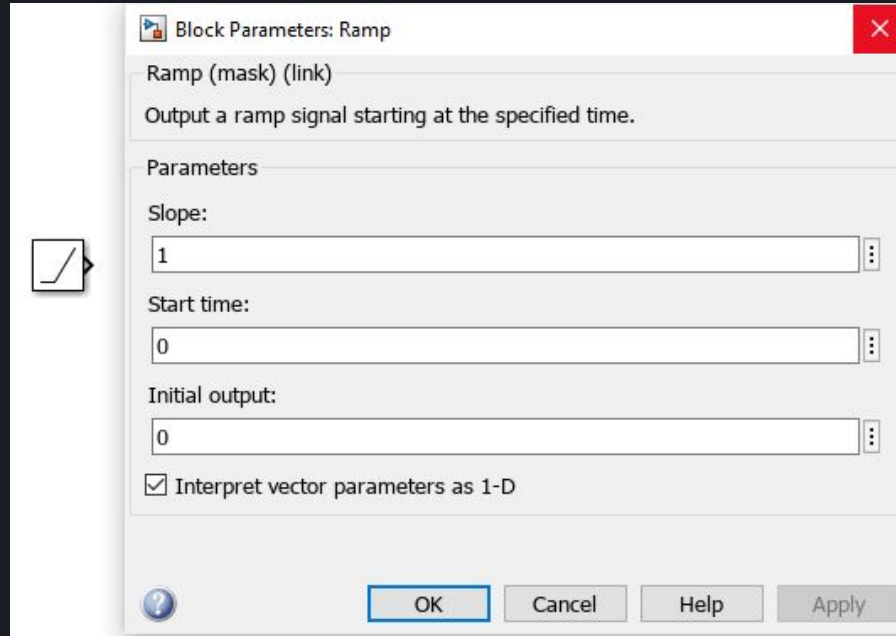
OK   Cancel   Help   Apply

Standard Test Signal

Ramp Function

Ramp Function Equation:
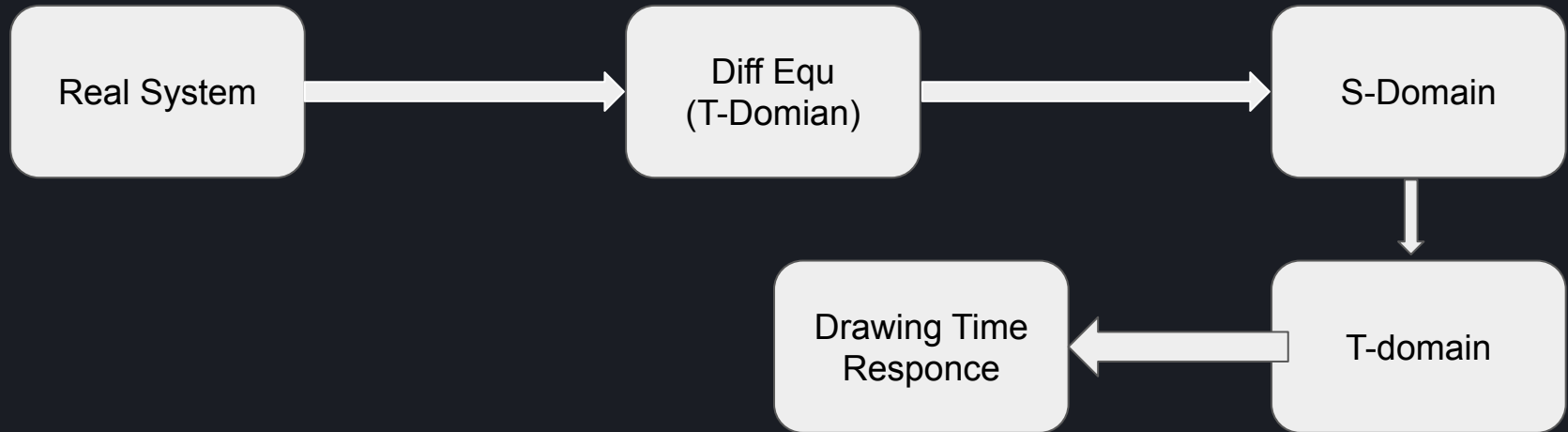
The ramp function can be defined mathematically as follows:

$r(t) = t$ for $t \geq 0$

In this equation, "t" represents time, and the function "r(t)" increases linearly with time for values of "t" greater than or equal to zero. In other words, it starts from zero and increases at a constant rate of one unit per unit of time.

Block Parameters: Ramp

Ramp (mask) (link)

Output a ramp signal starting at the specified time.

Parameters

Slope:
1

Start time:
0

Initial output:
0

☑ Interpret vector parameters as 1-D

OK   Cancel   Help   Apply

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T-Domain and S-Domain

Transforming from the time-domain to the s-domain is crucial because it simplifies mathematical analysis, facilitates steady-state and frequency response analysis, enables transfer function and pole-zero analysis, and allows for a seamless transition between time-domain and frequency-domain analysis. It is essential for understanding and designing linear time-invariant systems in engineering, enhancing analytical capabilities, and simplifying complex systems' study and design.

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[ Real System ]  →  [ Diff Equ (T-Domian) ]  →  [ S-Domain ]
                                                      ↓
[ Drawing Time Responce ]  ←  [ T-domain ]
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Time Response Analysis

Time response refers to the behavior of a dynamic system or process over time, particularly in response to a sudden change or disturbance in its input or initial conditions. It is the analysis of how a system reacts, adjusts, and settles down after a change in its input or initial state. Time response analysis is crucial in control systems, signal processing, and various engineering disciplines for evaluating the performance and stability of systems.

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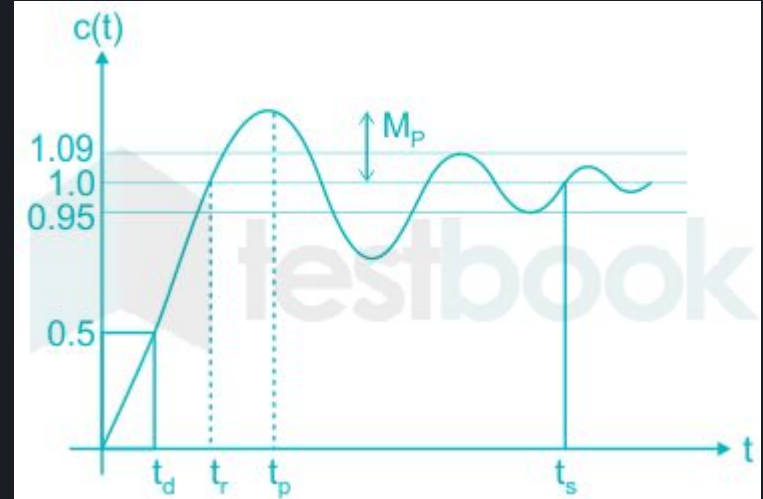
Time Response Analysis

Rise Time (tr): Rise time is the time it takes for the system's response to transition from a specified lower percentage (e.g., 10%) to a specified higher percentage (e.g., 90%) of its final steady-state value after a step input change. It measures the speed at which the system reaches its final value.

Settling Time (ts): Settling time is the duration required for the system's response to settle within a specified percentage (e.g., 5%) of the final steady-state value and remain within that range without significant oscillations. It reflects the system's ability to reach and maintain a stable state.

Peak Time (tp): Peak time is the time it takes for the system's response to reach the maximum overshoot from its final steady-state value. It is particularly relevant for systems with overshoots in their responses.

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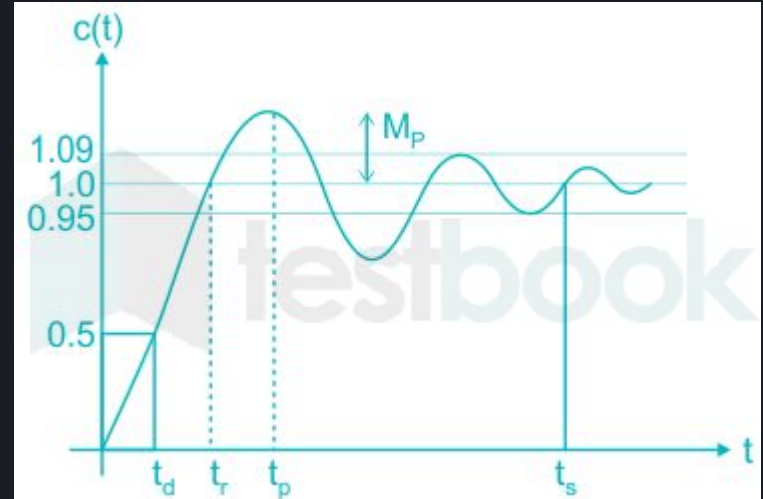
Time Response Analysis

Overshoot (Mp): Overshoot, often denoted as "Mp," represents the maximum deviation of the system's response from the final steady-state value, usually expressed as a percentage. It quantifies the extent of temporary oscillations or over-shooting in the response.

Steady-State Error: Steady-state error is the difference between the desired or reference input and the system's output when the system reaches a stable, unchanging condition in response to a constant input. It is a measure of the system's accuracy in tracking the desired input over time.
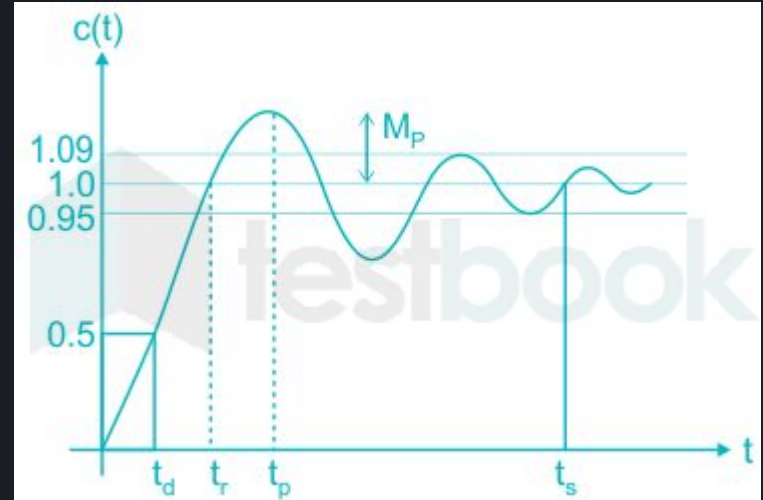
These time response metrics help engineers assess the performance of systems and evaluate their suitability for specific applications. The choice of metrics depends on the nature of the system and the desired behavior. In control systems, for instance, fast rise time and small overshoot might be critical for stability, while in signal processing, steady-state error might be more important for accuracy.

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Analysis of Steady state error

Steady-State Error Analysis: It's the study of how well a system can track a reference input signal after transient effects have settled. Steady-state error is the difference between the reference input and the system's output when the system is in a stable condition. Engineers analyze this error to tune and design systems for accurate tracking and performance.

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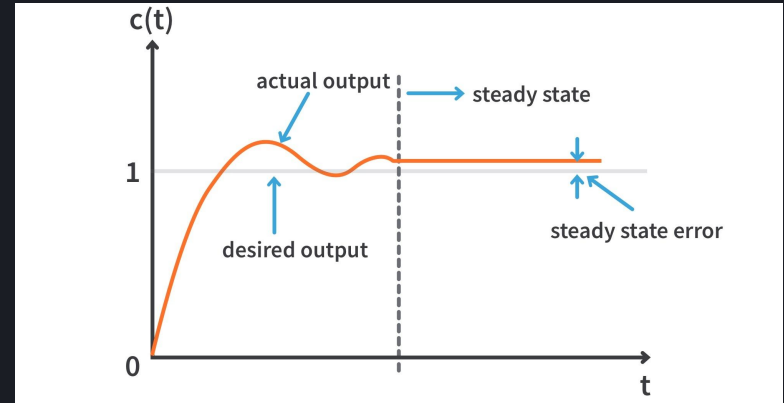
[Quiz 1: Click Here To Start](#)

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Analysis Of First Order System

In control system engineering, a first-order system is a fundamental model used to describe and analyze the dynamics of various physical and engineering systems. It is characterized by a single energy storage element, typically a capacitor or an inductor, and is often employed to represent systems with simple and relatively slow responses. The analysis of a first-order system involves understanding its time response and key parameters.

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Lab 1: Click Here To Start

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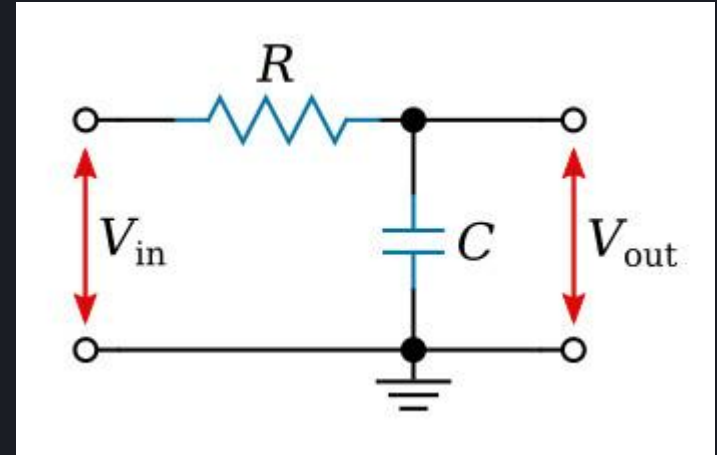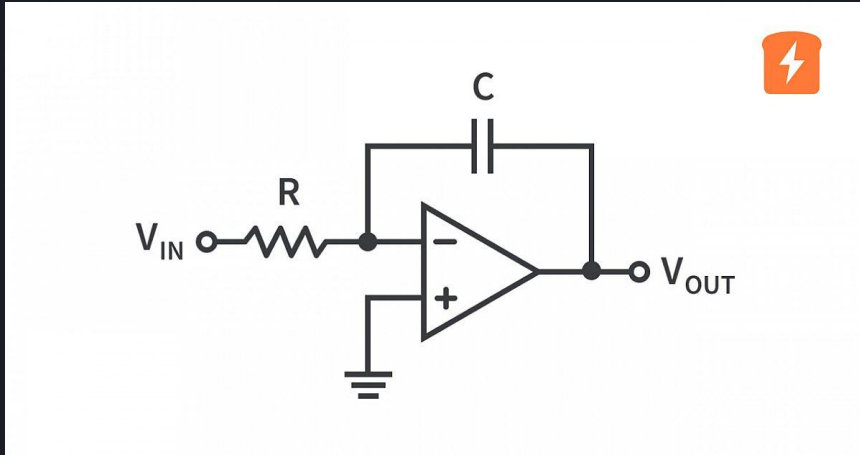
Time Response Specification

Rise Time (*tr*): The time it takes for the system response to go from 10% to 90% of the final steady-state value. A smaller rise time indicates a quicker response.

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