Lesson 1: Introduction to Control Systems Technology

ET 438a

Automatic Control Systems Technology

Learning Objectives

After this presentation you will be able to:

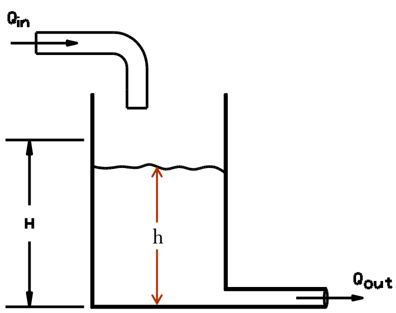
- Explain the function of an automatic control system.
- Identify a block diagram representation of a physical system
- Explain the difference between an open loop and closed loop control system
- Define a transfer function and compute the gain for sinusoidal input/output cases.
- Reduce block diagram systems using algebra.

The Control Problem

Fundamental Control Concepts

Maintain a variable of process at a desired value while rejecting the effects of outside disturbances by manipulating another system variable.

Examples:
Heating and Cooling homes and offices
Automobile cruise control
Hold the position of a mechanical linkage
Maintain level in a tank



Q_{out} depends on h
If $Q_{out} = Q_{in}$, h constant
$Q_{out} > Q_{in}$, tank empties
$Q_{out} < Q_{in}$, tank overflows

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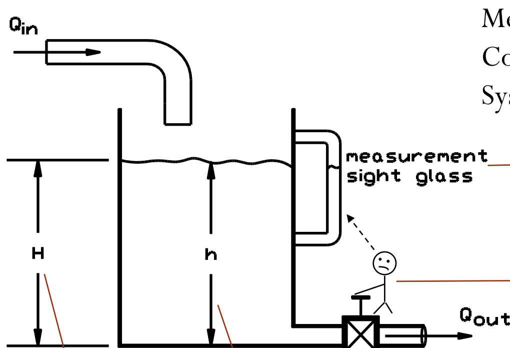
Basic Subsystems of Control

Feedback Control Subsystems
Measurement
Control decision
System modification



Measurement- sight glass

Control Decision
Human adjusts Q_{out} to maintain h =H

Reference (setpoint)
h = control variable

Process- Maintain tank level

Final Control Element
Valve

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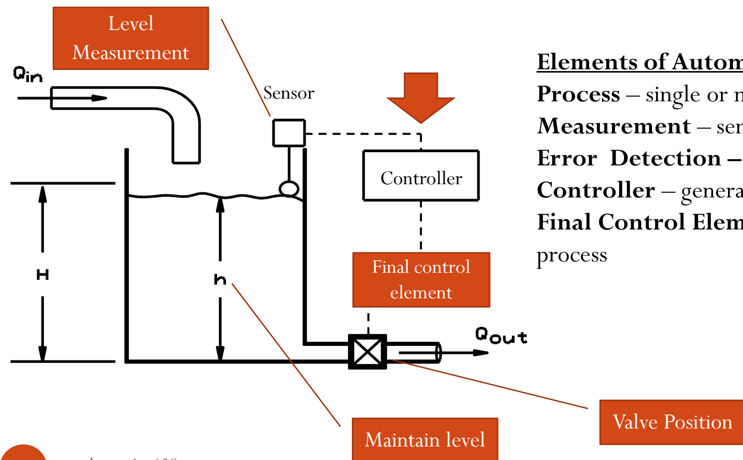
Automatic Control Systems

Use sensors and analog or digital electronics to monitor and adjust system



<u>Elements of Automatic Control</u>

Process – single or multiple variables
Measurement – sensors
Error Detection – compare H to h
Controller – generate corrections
Final Control Element – modify process

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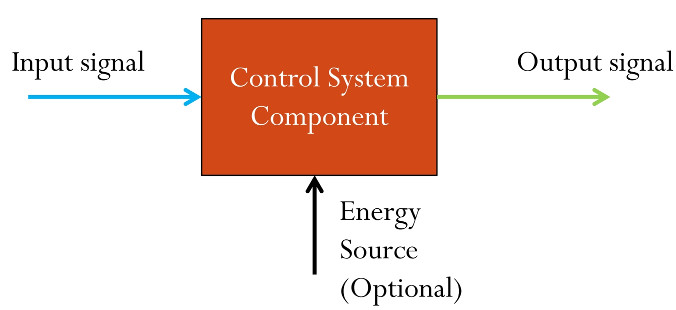
Block Diagrams

Automatic control systems use mathematical descriptions of subsystems to reduce complex components to inputs and outputs



Signals flow between components in system based on arrow direction

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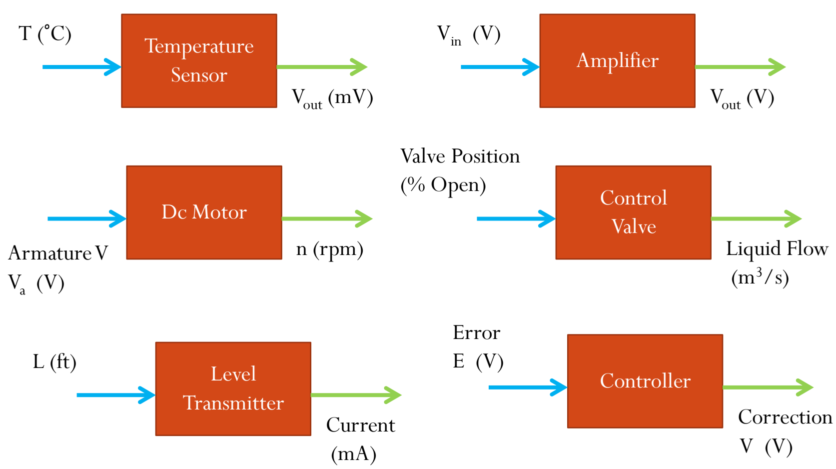
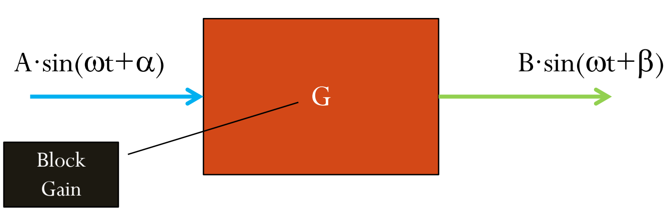
Typical Component Block Diagrams



Transfer Functions

Transfer function - ratio of the output to the input of a control system component. Generally a function of frequency and time.



Convert to phasors and divide

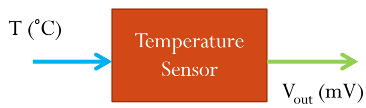
$$G=\frac{\overline{B}}{\overline{A}}=\frac{\text{OutputSignal}}{\text{InputSignal}}=\frac{B\angle\beta}{A\angle\alpha}=\frac{B}{A}\angle\beta-\alpha$$

Phase shift related to time delay

Transfer Functions

Examples

Example 1-1: Find transfer function of temperature sensor in block diagram



$$G = \frac{\text{Output Signal}}{\text{Input Signal}} = \frac{V_{out}}{T}\ \text{mV/C}^{\circ}$$

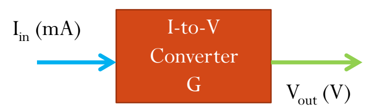
Example 1-2: a current-to-voltage converter takes an input of $17.5\angle 30^{\circ}$ mA and produces an output of $8.35\angle 37^{\circ}$ V Determine the transfer function gain and sketch the block diagram.

$$I_{in} = 17.5\angle 30^{\circ}\ \text{mA}$$

$$V_o = 8.35\angle 37^{\circ}\ \text{V}$$

$$\overline{G} = \frac{\text{Output Signal}}{\text{Input Signal}} = \frac{\overline{V}_o}{\overline{I}_{in}} = \frac{8.35\angle 37^{\circ}\ \text{V}}{17.5\angle 30^{\circ}\ \text{mA}} = \text{V/mA}$$

$$\overline{G} = 0.477\angle 7^{\circ}\ \text{V/mA}$$



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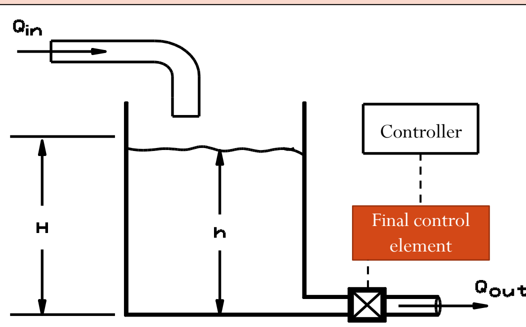
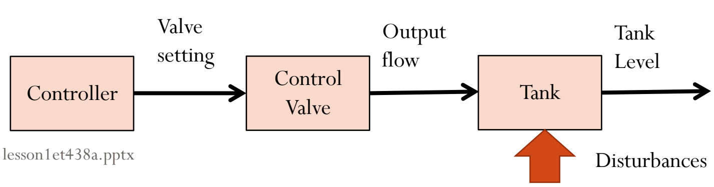
Open-Loop Control

Open loop control modifies output based on predetermined control values. There is no actual measurement of controlled quantity.



Tank level may vary with outside disturbances and system changes



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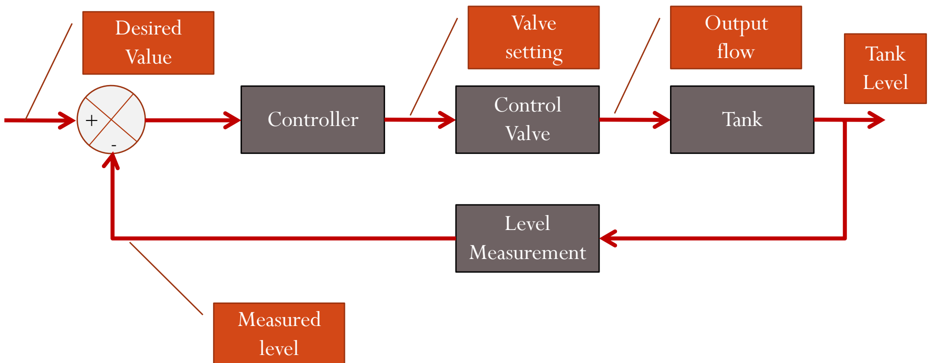
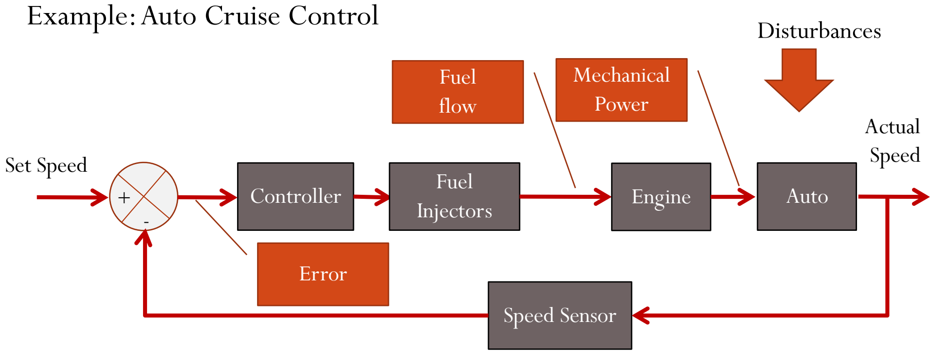
Closed Loop Control

Closed loop control modifies output based on measured values of the control variable. Measured value compared to desired value and used to maintain desired value when disturbances occur. Closed loop control uses feedback of output to input.



Closed Loop Control

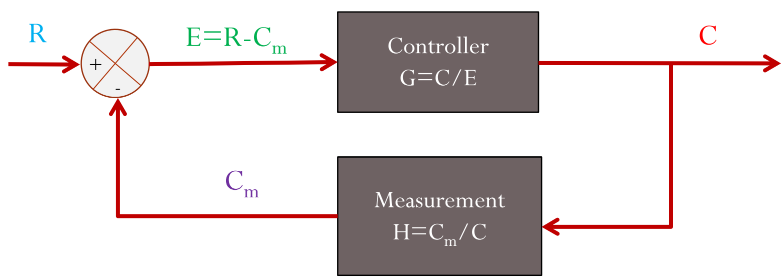
Example: Auto Cruise Control



Disturbances: Up hill/ down hill
Head wind/ tail wind

Generalized Closed Loop Control

Block Diagram of Servo Control-Example Positioning Systems



Reference = R

Measured Variable = C_m

Error = E

Controlled Variable = C

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Generalized Closed Loop Control

Find overall transfer function using signal flow algebra

(Input)(Gain)=(Output)

For servo control Find $\frac{C}{R}$

(1) $E = R - C_m$

(3) $H = \frac{C_m}{C} \Rightarrow C \cdot H = C_m$

(2) $G = \frac{C}{E} \Rightarrow E \cdot G = C$

(1)(3) $E = R - C \cdot H$ (E)

$(R - C \cdot H) \cdot G = C$

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Overall Transfer Function-Servo Control

Find $\frac{C}{R}$

$$(R - C \cdot H) \cdot G = C$$

1 2 3

$$R \cdot G - C \cdot H \cdot G = C$$ Multiply through by G

$$R \cdot G = C + C \cdot H \cdot G$$ Add CHG to both sides

$$R \cdot G = C \cdot (1 + G \cdot H)$$ Factor C out of right hand side

$$\frac{R \cdot G}{(1 + G \cdot H)} = C$$ Divide both sides by (1+GH)

$$\frac{G}{(1 + G \cdot H)} = \frac{C}{R}$$ Divide both sides by R

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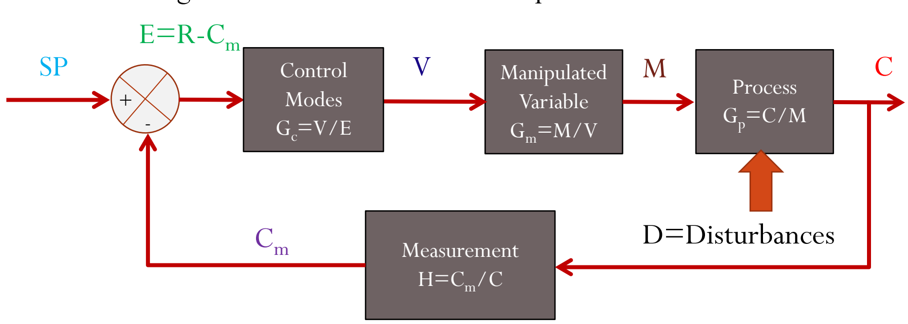
Generalized Closed Loop Control

Block Diagram of Process Control-Example Chemical Reactors



Setpoint = SP

Error = E

Controlled Variable = C

Measured Variable = C_m

Manipulated Variable = M

Controller Output = V

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Overall Transfer Function- Process Control

Find overall transfer function of process control using signal flow algebra

Series blocks multiple $G_c = \frac{V}{E} \quad G_m = \frac{M}{V} \quad G_p = \frac{C}{M}$

$$G = G_c \cdot G_m \cdot G_p = \left(\frac{\cancel{V}}{E}\right)\cdot\left(\frac{\cancel{M}}{\cancel{V}}\right)\cdot\left(\frac{C}{\cancel{M}}\right)$$

$$G = \left(\frac{C}{E}\right)$$

Find overall transfer function C_m/SP C not directly measurable in process control

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Overall Transfer Function- Process Control

As before $E = SP - C_m \quad C_m = H \cdot C \quad \Rightarrow \quad \frac{C_m}{H} = C$

$G \cdot E = C$

$G \cdot (SP - C_m) = C$ — Substitute in for E

$G \cdot (SP - C_m) = \frac{C_m}{H}$ — Substitute in for C eliminate it

$G \cdot H \cdot (SP - C_m) = C_m$ — Multiple both sides by H

$G \cdot H \cdot SP - G \cdot H \cdot C_m = C_m$ — Multiple L.H. side by GH

$G \cdot H \cdot SP = C_m + G \cdot H \cdot C_m$ — Add GHC_m to both sides

$G \cdot H \cdot SP = C_m \cdot (1 + G \cdot H)$ — Factor C_m from right side

$\frac{G \cdot H \cdot SP}{1 + G \cdot H} = C_m$ — Divide both sides by (1+GH)

$\frac{G \cdot H}{1 + G \cdot H} = \frac{C_m}{SP}$ — Divide both sides by SP

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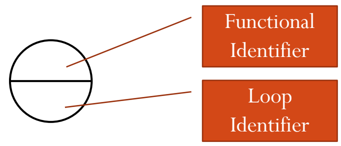
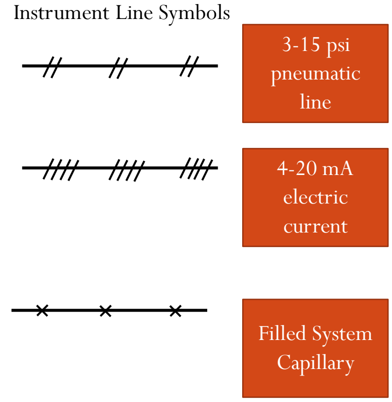
Control System Drawings

Industrial system standard ANSI/ISA-S5.1-1984 Uniform designation for Instruments, instrument systems and control.



General Instrument Symbol

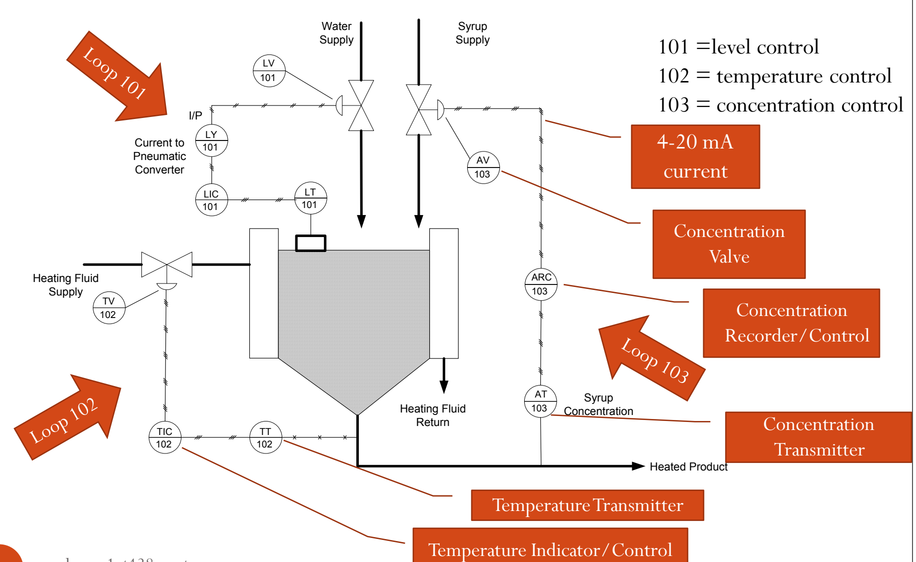
Instrument Line Symbols



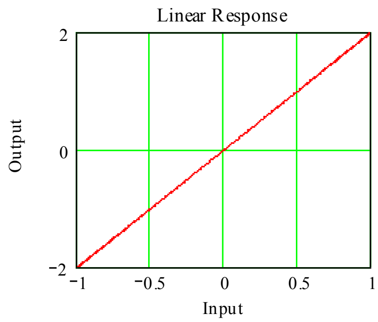
First ID Letter	Following ID Letter
A = Analysis	C= Controller
L = Level	I=Indicator
T = Temperature	R=Recorder
	T=Transmitter
	V = Valve
	Y = Relay/Converter

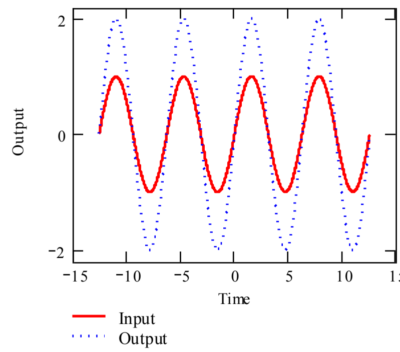
Control System Drawings

101 =level control
102 = temperature control
103 = concentration control



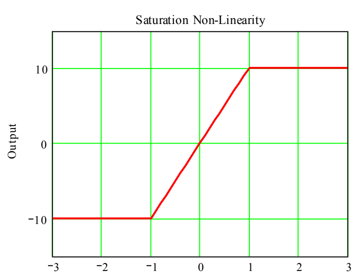
Linear and Non-linear Response

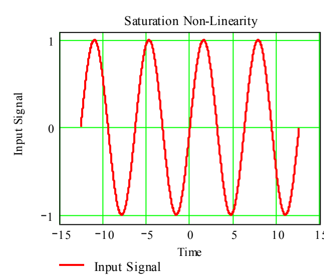


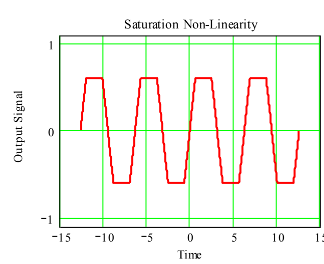


Linear transfer functions give proportional outputs. In this case the factor is 2

Non-linear Response

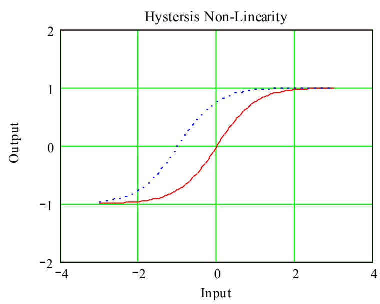


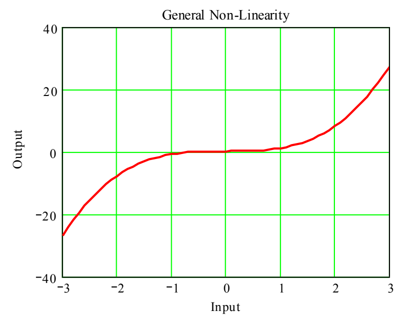




Saturation non-linearity typical of practical systems that have physical limits. Amplifiers, control valves

Other Non-Linearities

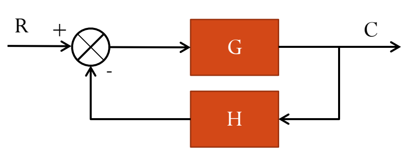


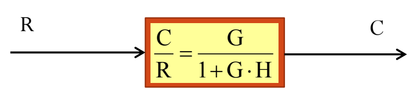


Typical in magnetic circuit and in instrumentation transducers

Non-linearities cause distortion in sine waves response that is not proportional to inputs value for all signal values.

Block Diagram Simplifications





$$\frac{C}{R} = \frac{G}{1 + G \cdot H}$$

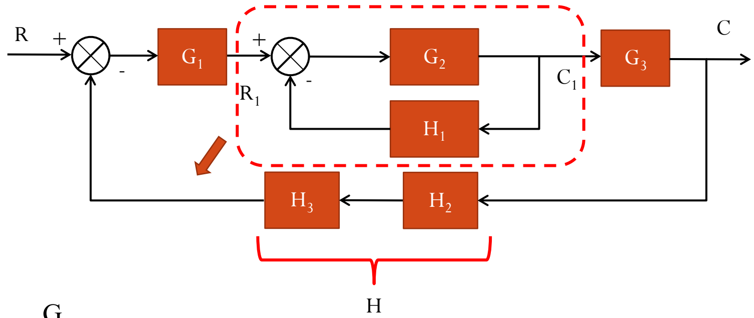
Block diagram at left simplifies to the above. Can use this to reduce multiple loops into one Block.

Also remember that blocks in series multiply

$$G = G_1 \cdot G_2 \cdot G_3$$

Equivalent Block

Block Diagram Simplification Example

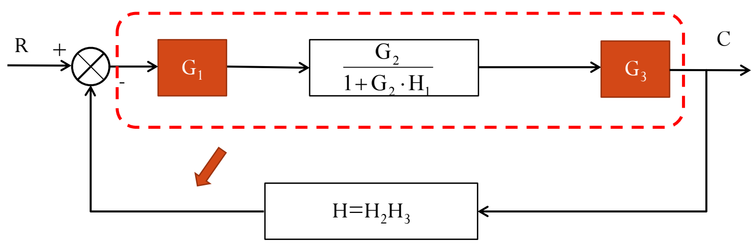


$$\frac{C_1}{R_1} = \frac{G_2}{1 + G_2 \cdot H_1}$$ Reduce the inner loop

$$H = H_2 \cdot H_3$$ Combine outer feedback block

Combine reduced inner loop with remaining forward gain blocks

Block Diagram Simplification Example (1)



$$G = G_1 \cdot \left[\frac{G_2}{1 + G_2 \cdot H_1}\right] \cdot G_3 = \left[\frac{G_1 \cdot G_2 \cdot G_3}{1 + G_2 \cdot H_1}\right]$$ Compute the value of G

$$\frac{C}{R} = \frac{G}{1 + G \cdot H} = \frac{\left[\frac{G_1 \cdot G_2 \cdot G_3}{1 + G_2 \cdot H_1}\right]}{1 + \left[\frac{G_1 \cdot G_2 \cdot G_3}{1 + G_2 \cdot H_1}\right] \cdot H_2 \cdot H_3}$$

Substitute the values of G and H into formula and simplify

Block Diagram Simplification Example (2)

$$\frac{C}{R} = \frac{G}{1+G\cdot H} = \frac{\left[\dfrac{G_1 \cdot G_2 \cdot G_3}{1+G_2 \cdot H_1}\right]}{1+\left[\dfrac{G_1 \cdot G_2 \cdot G_3}{1+G_2 \cdot H_1}\right]\cdot H_2 \cdot H_3}$$

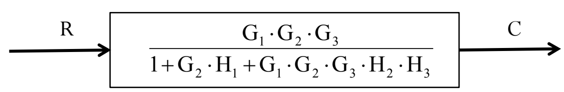
Multiply top and bottom of ratio by $(1+G_2H_1)$ and simplify

$$\frac{C}{R} = \frac{\left[\dfrac{G_1 \cdot G_2 \cdot G_3}{1+G_2 \cdot H_1}\right]\cdot(1+G_2 \cdot H_1)}{\left(1+\left[\dfrac{G_1 \cdot G_2 \cdot G_3}{1+G_2 \cdot H_1}\right]\cdot H_2 \cdot H_3\right)\cdot(1+G_2 \cdot H_1)} = \frac{G_1 \cdot G_2 \cdot G_3}{(1+G_2 \cdot H_1)+(1+G_2 \cdot H_1)\cdot\left[\dfrac{G_1 \cdot G_2 \cdot G_3 \cdot H_2 \cdot H_3}{1+G_2 \cdot H_1}\right]}$$

$$\frac{C}{R} = \frac{G_1 \cdot G_2 \cdot G_3}{1+G_2 \cdot H_1 + G_1 \cdot G_2 \cdot G_3 \cdot H_2 \cdot H_3}$$

Answer

Reduced block



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