Block Diagram & Signal Flow

*Rectangular block diagram* represents the cause-and-effect relationship between the input and output of a physical system.

*Control element* represents any of the system component such as controller, process, sensor, transmitter, transducer, control valve, metering pump, solenoid valve, etc.

*Arrow* represents the direction of signal flow.

![Concept](a) ![Example](b)

Fig. 1: Concept (a) and example (b) of block diagram.

**Signal Operations**

*Circle block diagram* represents the signals operation. A negative or positive sign is placed inside the circle to represent deduction or addition of the respective signals.

![Concept](a) ![Example](b)

Fig. 2: Concept (a) and example (b) of addition and deduction of signals using circle.

*Takeoff point* is a point where the signal is diverted into multiple flows which has similar values to various operators or control elements.

![Concept](a) ![Example](b)

Fig. 3: Concept (a) and example (b) of signal splitting.
Examples

Example No. 1

Draw a block diagram for the following equation:

\[ x_3 = a_1 x_1 + a_2 x_2 - 5 \]

**Step 1**

a. Identify control elements: \(a_1\) and \(a_2\)
b. Identify signals: \(x_1, x_2\) and \(5\)

**Step 2**

Identify summing junction and arrows

\[ a_1 x_1 \]

\[ a_2 x_2 \]

\[ 5 \]

\[ x_3 \]

**Step 3**

Draw and label complete block diagram.

\[ x_1 \]

\[ a_1 \]

\[ x_2 \]

\[ a_2 \]

\[ 5 \]

\[ x_3 \]
Example No. 2

Draw a block diagram for the following equation:

\[ x_4 = \int x_1 \, dt + \frac{d^2 x_1}{dt^2} + \sqrt{x_1} \]

**Answer**

Transformation Theorem

**Canonical Form:** The reduced (simplest) form of a complicated block diagram. Figure 4 below shows a canonical form of a control system.

\[ \frac{E}{R} = \frac{1}{1 \pm GH} \quad \frac{B}{R} = \frac{GH}{1 \pm GH} \quad \frac{C}{R} = \frac{G}{1 \pm GH} \]

Fig. 4: Canonical form of a control system.

The relationship between the signals (B, C, E & R) and the control elements (G & H) are shown below.
Definition:

\( G \) = direct transfer function = forward transfer function
\( H \) = feedback transfer function
\( GH \) = loop transfer function = openloop transfer function
\( C/R \) = closed-loop transfer function = control ratio
\( E/R \) = actuating signal ratio = error ratio
\( B/R \) = primary feedback ratio

Example No. 3

Reduce the following block diagram to canonical form, isolating block \( K \) in the forward loop. Then, calculate \( C/R \).

\[ R \rightarrow - \times - + \times + \rightarrow K \rightarrow \frac{1}{s+1} \rightarrow C \]

Step 1

\[ R \rightarrow - \times - + \times + \rightarrow K \rightarrow \frac{1}{s+1} \rightarrow C \]
Example No. 4

Reduce the block diagram below to canonical form.

\[
\begin{align*}
R & \rightarrow K \rightarrow \frac{1}{s+1} \\
& \quad \downarrow \quad \uparrow \\
& \quad s + 0.1 \rightarrow s + 1 \\
& \quad 0.1 \rightarrow s + 1 \\
C & \rightarrow \\
\end{align*}
\]
Answer

Step 1

Apply transformation 1

Step 2

Apply transformation 4
Step 3 - Finally

Apply transformation 4

\[ \frac{C}{R} = \frac{K}{(1 + K)s + 1} + 0.1K \]

Exercise

Calculate C/R of the following control system.

(a) System 1

\[ \frac{K_1}{s(s + p)} \]

(a) System 2