

## 1.5 SIGNAL FLOW GRAPHS

Signal flow graph is a graphical representation of algebraic equations. In this chapter, let us discuss the basic concepts related signal flow graph and also learn how to draw signal flow graphs.

### Basic Elements of Signal Flow Graph

Nodes and branches are the basic elements of signal flow graph.

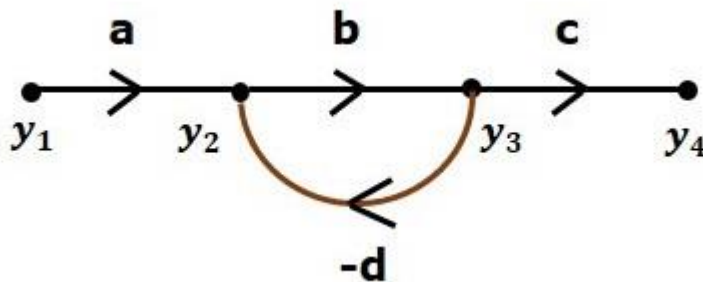
#### Node

**Node** is a point which represents either a variable or a signal. There are three types of nodes — input node, output node and mixed node.

- **Input Node** – It is a node, which has only outgoing branches.
- **Output Node** – It is a node, which has only incoming branches.
- **Mixed Node** – It is a node, which has both incoming and outgoing branches.

#### Example

Let us consider the following signal flow graph to identify these nodes.



- The **nodes** present in this signal flow graph are  $y_1$ ,  $y_2$ ,  $y_3$  and  $y_4$ .
- $y_1$  and  $y_4$  are the **input node** and **output node** respectively.
- $y_2$  and  $y_3$  are **mixed nodes**.

#### Branch

**Branch** is a line segment which joins two nodes. It has both **gain** and **direction**. For example, there are four branches in the above signal flow graph. These branches have **gains** of **a**, **b**, **c** and **-d**.

## Construction of Signal Flow Graph

Let us construct a signal flow graph by considering the following algebraic equations –

$$y_2 = a_{12}y_1 + a_{42}y_4$$

$$y_3 = a_{23}y_2 + a_{53}y_5$$

$$y_4 = a_{34}y_3$$

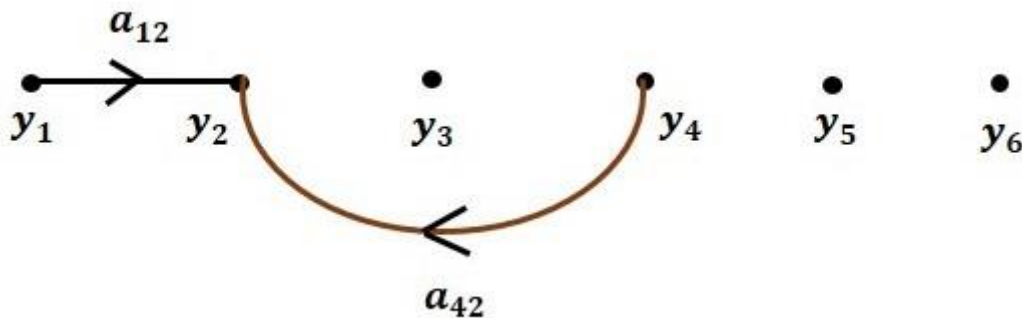
$$y_5 = a_{45}y_4 + a_{35}y_3$$

$$y_6 = a_{56}y_5$$

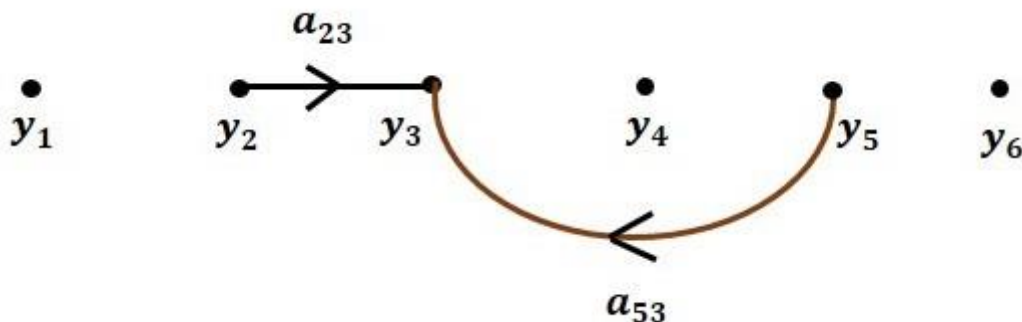
There will be six **nodes** ( $y_1, y_2, y_3, y_4, y_5$  and  $y_6$ ) and eight **branches** in this signal flow graph. The gains of the branches are  $a_{12}, a_{23}, a_{34}, a_{45}, a_{56}, a_{42}, a_{53}$  and  $a_{35}$ .

To get the overall signal flow graph, draw the signal flow graph for each equation, then combine all these signal flow graphs and then follow the steps given below –

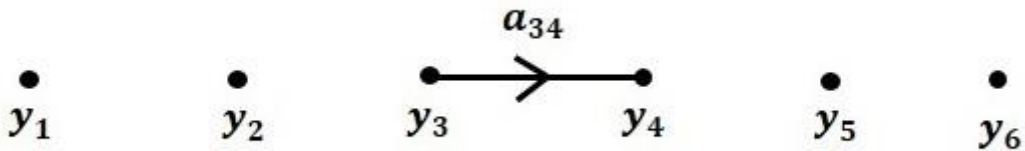
**Step 1** – Signal flow graph for  $y_2 = a_{12}y_1 + a_{42}y_4$  is shown in the following figure.



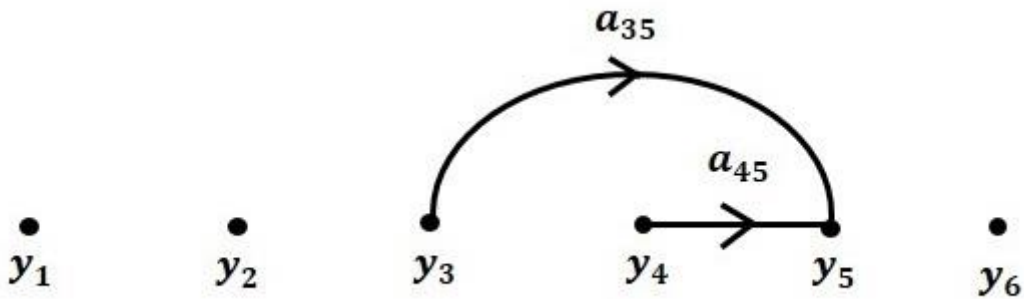
**Step 2** – Signal flow graph for  $y_3 = a_{23}y_2 + a_{53}y_5$  is shown in the following figure.



**Step 3** – Signal flow graph for  $y_4 = a_{34}y_3$  is shown in the following figure.



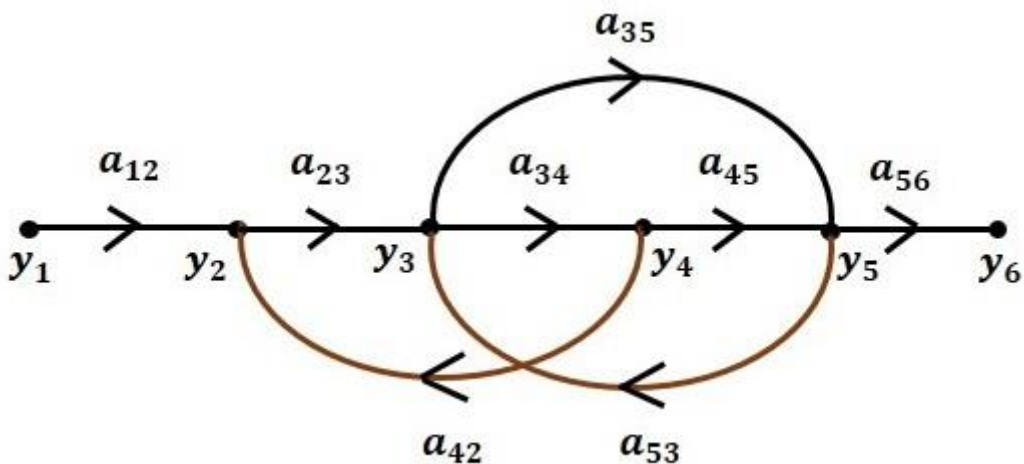
**Step 4** – Signal flow graph for  $y_5 = a_{45}y_4 + a_{35}y_3$  is shown in the following figure.



**Step 5** – Signal flow graph for  $y_6 = a_{56}y_5$  is shown in the following figure.



**Step 6** – Signal flow graph of overall system is shown in the following figure.



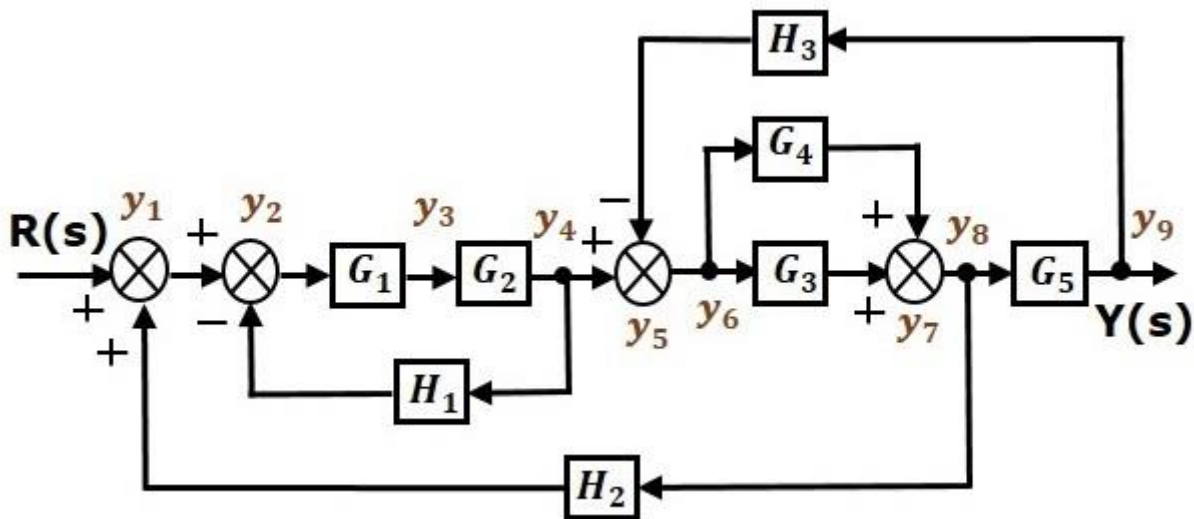
### Conversion of Block Diagrams into Signal Flow Graphs

Follow these steps for converting a block diagram into its equivalent signal flow graph.

- Represent all the signals, variables, summing points and take-off points of block diagram as **nodes** in signal flow graph.
- Represent the blocks of block diagram as **branches** in signal flow graph.
- Represent the transfer functions inside the blocks of block diagram as **gains** of the branches in signal flow graph.
- Connect the nodes as per the block diagram. If there is connection between two nodes (but there is no block in between), then represent the gain of the branch as one. **For example**, between summing points, between summing point and takeoff point, between input and summing point, between take-off point and output.

### Example

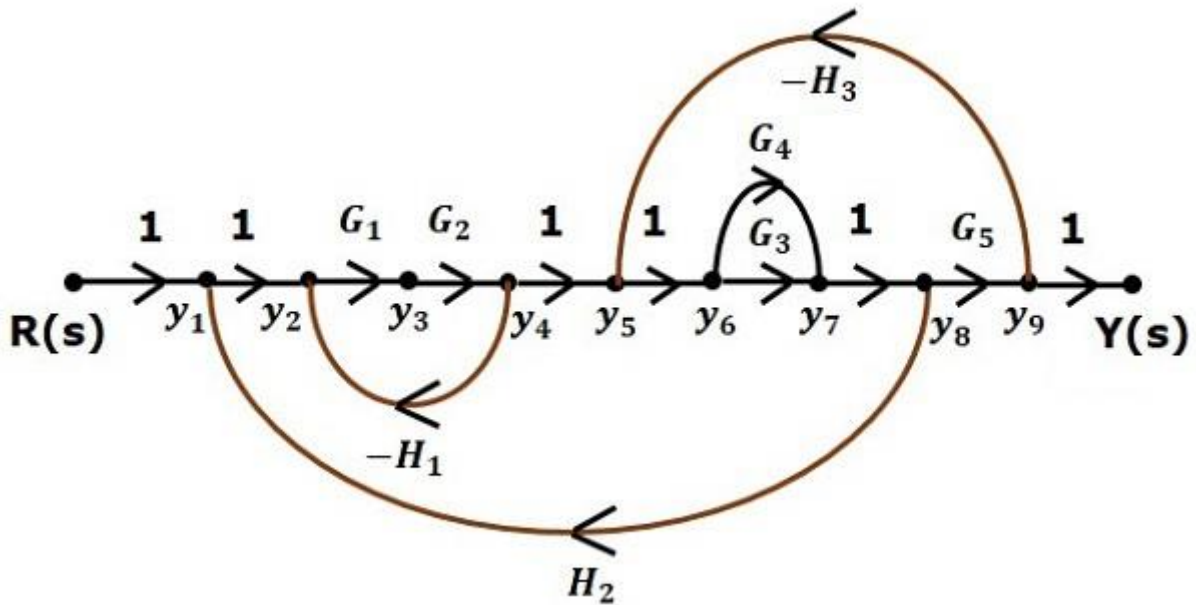
Let us convert the following block diagram into its equivalent signal flow graph.



Represent the input signal  $R(s)$  and output signal  $C(s)$  of block diagram as input node  $R(s)$  and output node  $C(s)$  of signal flow graph.

Just for reference, the remaining nodes ( $y_1$  to  $y_9$ ) are labeled in the block diagram. There are nine nodes other than input and output nodes. That is four nodes for four summing points, four nodes for four take-off points and one node for the variable between blocks  $G_1$  and  $G_2$ .

The following figure shows the equivalent signal flow graph.



With the help of Mason's gain formula, you can calculate the transfer function of this signal flow graph. This is the advantage of signal flow graphs. Here, we no need to simplify (reduce) the signal flow graphs for calculating the transfer function

There are 'N' forward paths in a signal flow graph. The gain between the input and the output nodes of a signal flow graph is nothing but the **transfer function** of the system. It can be calculated by using Mason's gain formula.

**Mason's gain formula is**

$$T = \frac{C(s)}{R(s)} = \frac{\sum_{i=1}^N P_i \Delta_i}{\Delta}$$

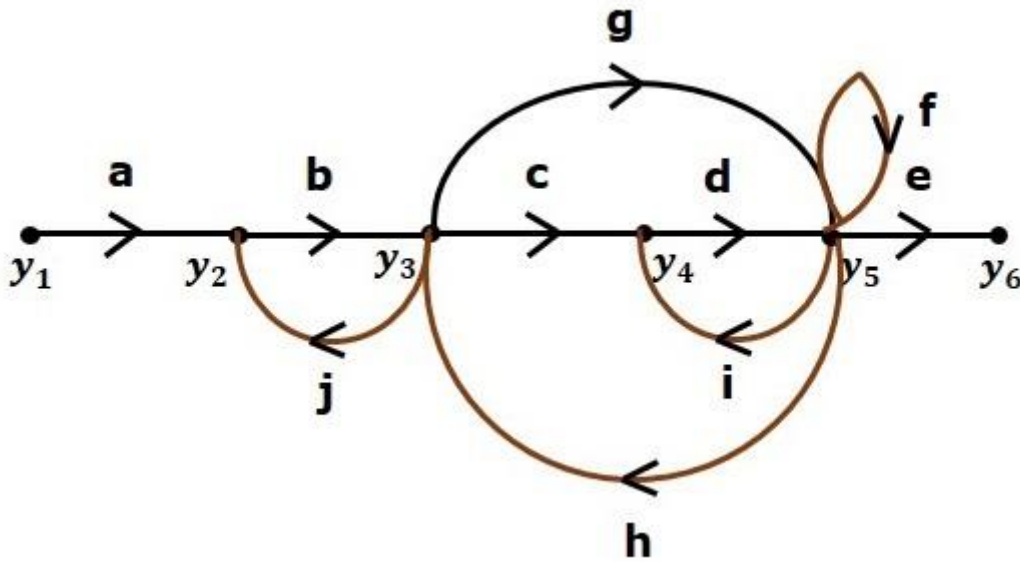
Where,

- $C(s)$  is the output node
- $R(s)$  is the input node
- $T$  is the transfer function or gain between  $R(s)$  and  $C(s)$
- $P_i$  is the  $i^{\text{th}}$  forward path gain

$\Delta = 1 - (\text{sum of all individual loop gains}) + (\text{sum of gain products of all possible two nontouching loops}) - (\text{sum of gain products of all possible three nontouching loops}) + \dots$

$\Delta_i$  is obtained from  $\Delta$  by removing the loops which are touching the  $i^{\text{th}}$  forward path

Consider the following signal flow graph in order to understand the basic terminology involved here.



### Path

It is a traversal of branches from one node to any other node in the direction of branch arrows. It should not traverse any node more than once.

**Examples** –  $y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_5$  and  $y_5 \rightarrow y_3 \rightarrow y_2$

### Forward Path

The path that exists from the input node to the output node is known as **forward path**.

**Examples** –  $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6$  and  $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6$  and  $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_5 \rightarrow y_6$

### Forward Path Gain

It is obtained by calculating the product of all branch gains of the forward path.

**Examples** – abcde is the forward path gain of  $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_4 \rightarrow y_5 \rightarrow y_6$  and abge is the forward path gain of  $y_1 \rightarrow y_2 \rightarrow y_3 \rightarrow y_5 \rightarrow y_6$

### Loop

The path that starts from one node and ends at the same node is known as **loop**. Hence, it is a closed path.

**Examples** –  $y_2 \rightarrow y_3 \rightarrow y_2$  and  $y_3 \rightarrow y_5 \rightarrow y_3$

## Loop Gain

It is obtained by calculating the product of all branch gains of a loop.

**Examples** –  $b_1 b_2$  is the loop gain of  $y_2 \rightarrow y_3 \rightarrow y_2$  and  $g h$  is the loop gain of  $y_3 \rightarrow y_5 \rightarrow y_3$ .

## Non-touching Loops

These are the loops, which should not have any common node.

**Examples** – the loops,  $y_2 \rightarrow y_3 \rightarrow y_2$  and  $y_4 \rightarrow y_5 \rightarrow y_4$  are non-touching.

