3.5. Block Diagram Representation and Simplification of Systems:

Systems are denoted as transfer elements or blocks. Transfer elements possess a unique direction of action indicated by arrows; their action is not reversible. Every controllable and observable transfer element has at least one input and at least one output. The output of a transfer element depends only on its own input but not on the loading effect of the following connections. Transfer processes are described by block diagrams with appropriate connections among the blocks. Within each block, the mathematical description of the transfer element is written; when it is too large and complex to be accommodated, a symbol denoting the transfer relation is shown. In the case of static nonlinear elements, the description in the block symbol is either in the form of the functional description of the nonlinear characteristic or the graph of the nonlinear function.

Linear time invariant system models transformed into the *s*- and *z*-domains attain simple algebraic properties as has been already observed above enabling system models to be manipulated algebraically. For example in the s-domain, if a system $G(s)$ is excited by an input signal U(s), the response is given by $G(s).U(s)$. If two systems $G_1(s)$ and $G_2(s)$ are in cascade, the transfer function of the overall system is given by their product $G_1(s).G_2(s)$ as shown in Figure 11.

Fig. 11: Simplification of systems in cascade

A system with feedback can be simplified as shown in Figure 12.

Fig. 12: Simplification of systems in a feedback loop

Signal flow diagrams are close in spirit to the block diagrams. In a signal flow graph the signals are denoted by nodes and the transfer relations by branches between nodes. A block diagram and its signal flow graph are shown in Figure 13. In manipulating and simplifying a signal flow graph, Mason's rule offers a general procedure:

The overall transfer function G of a system represented as a signal flow graph is given by

$$G = \frac{\sum_k T_k \Delta_k}{\Delta}$$

where

k = the number of forward (from the input end of the graph towards the output end) paths

T_k = the transfer function of the forward path given by the product of the transfer functions of the cascaded elements.

Δ = 1 – sum of loop transfer functions + sum of non-touching loop transfer functions taken two at a time – sum of loop transfer functions taken three at a time + ……..

$\Delta_k = \Delta$ - sum of the loop transfer functions touching the k-th forward path.

Figure 13: The block diagram and signal flow diagram for a system

Referring to the signal flow graph shown in Figure 13(b) we identify the following:

Transfer function of the forward path = $G_1G_2G_3G_4G_5$

Loop transfer functions: $G_2H_1, G_4H_2, G_7H_4, G_2G_3G_4G_5G_6G_7G_8$

Non-touching loops taken two at a time: $G_2H_1G_4H_2, G_2H_1G_7H_4, G_4H_2G_7H_4$

Non-touching loops taken three at a time: $G_2H_1G_4H_2G_7H_4$

$\Delta = 1 - [G_2H_1 + G_4H_2 + G_7H_4 + G_2G_3G_4G_5G_6G_7G_8] + [G_2H_1G_4H_2 + G_2H_1 G_7H_4 + G_4H_2 G_7H_4] - [G_2H_1G_4H_2 G_7H_4]$

$\Delta_1 = 1 - G_7H_4$

$G = T_{k\Delta 1} / \Delta$