# Fundamentals of Automatic Control

Robert C. Weyrick
Community and Technical College
The University of Akron

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*To my mother*

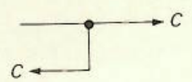



Figure 1-8 Takeoff-point representation

ɔs being combined at a summing point must be in the same ample, two voltages may be combined but a voltage and nnot be brought together. Any number of variables may ning point.

ɔoint is used when the output of a block is applied to two ks. A takeoff point is simply represented by a dot as shown

ıte the block-diagram representation of a system, let us ıe the oven-temperature control described in the preceding system is shown in block-diagram form in Fig. 1-9. In this agram the various blocks may be identified with elements ı. In addition the units associated with the transfer function :k are shown in parentheses.

diagram tends to clarify the physical understanding of the provides a convenient basis for system analysis. We shall t block diagrams are useful in pointing out the similarity ɔarently unrelated systems. It should be emphasized that ınnecting one block with another represent the flow of rmation within the system. The main sources of energy for ıeed not be included in the block diagram.

## 1-6 SIMPLIFICATION OF BLOCK DIAGRAMS

: diagram that is initially drawn for a system may contain ıber of blocks and signal paths and be more complicated rable. In such cases a simplification may be performed to block diagram to a form with fewer blocks. Rearranging

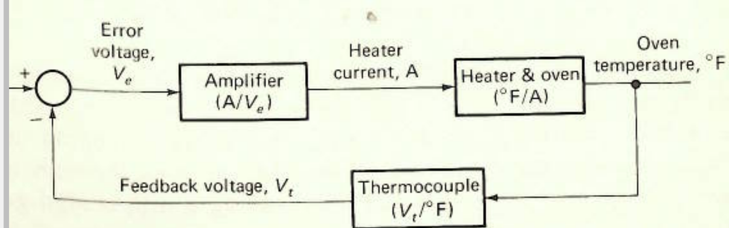



Figure 1-9 Block diagram of oven-temperature control



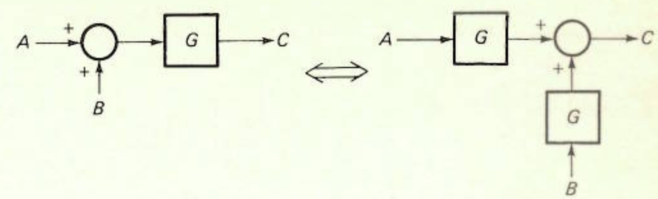



Figure 1-10 Moving summing point around a block

a system diagram to effect simplification is termed *block-diagram algebra* since it is analogous to simplifying algebraic equations. However, reducing a block diagram has the advantage of providing a better understanding of the interrelationships of the various elements in the system as compared to simplifying the system equations.

The combining of cascaded blocks into a single block, as described in Sec. 1-5, is obviously one step toward simplification. As another possibility, it is sometimes useful to move a summing point around a block as indicated in Fig. 1-10. Note that the inputs $A$ and $B$ are introduced through blocks incorporating the function $G$ around which the summing point was moved. Applying the distributive property of algebra, we see that $C = (A + B)G = AG + BG$. Thus the two diagrams are equivalent.

Table 1-1 gives a number of transformations useful in simplifying block diagrams. These transformations can be verified by showing that the outputs from the two equivalent diagrams are the same. Note that the original and equivalent identities can be used interchangeably.

## 1-7 CLOSED-LOOP TRANSFER FUNCTION

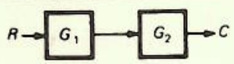
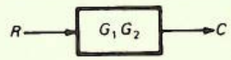
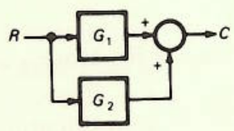
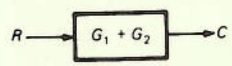
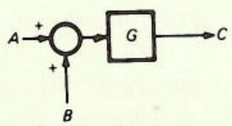
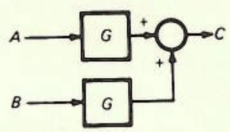
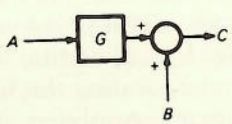
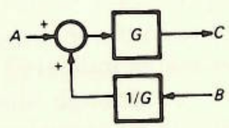
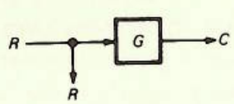
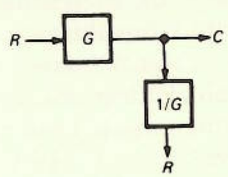
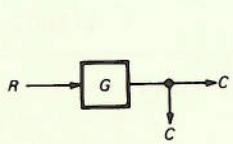
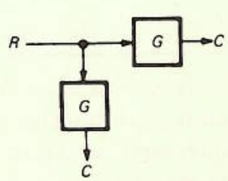
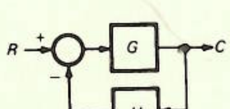
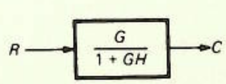
Since certain functions and types of variables are commonly associated with feedback control systems, a generalized block diagram may be formulated and the associated closed-loop transfer function derived. Some standardization of the symbols and terminology relating to feedback control systems has been achieved and is used in this case.

Figure 1-11 is a general block diagram of a closed-loop control system. It is important that the terms used in this diagram be clearly understood.

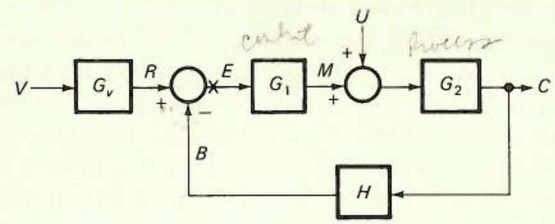
### System Variables

The *desired value* $V$ is an external signal applied to the system to command a specific output from the process. The desired value is sometimes called the system *command* or *set point*.

TABLE 1-1 BLOCK-DIAGRAM IDENTITIES

| tion | Original | Equivalent |
|---|---|---|
| ocks |  |  |
| ocks |  |  |
| ing point lock |  |  |
| ning point block |  |  |
| ff point lock |  |  |
| off point block |  |  |
| closed- m |  |  |






- $G_v$ Reference input elements
- $G_1$ Control elements
- $G_2$ System elements or process
- $H$ Feedback elements
- $V$ Desired value
- $R$ Reference input
- $C$ Controlled output
- $M$ Manipulated variable
- $U$ Disturbance input
- $B$ Feedback signal
- $E$ Error or actuating signal

*Figure 1-11 General block diagram of control system*

The *reference input* $R$ is derived from the desired value and is a signal external to the control loop. It serves as the reference of comparison for the feedback signal.

The *controlled output* $C$ is the process quantity being controlled.

The *manipulated variable* $M$ is the control signal which the control elements apply to the process.

The *feedback signal* $B$ is a signal which is a function of the controlled output and which is summed with the reference input.

The *error* or *actuating* signal $E$ is the algebraic difference between the reference input and feedback signals and provides the signal applied to the control elements.

The *disturbance input* $U$ is an unwanted input signal to the system that tends to cause the controlled output to differ from the value commanded by the reference input. Disturbance inputs are due to changes in the load on the system. For example, a change in the ambient temperature surrounding the oven described in Sec. 1-3 is a disturbance since it changes the heat input required by the oven. Obviously the response of the system to a disturbance input should be minimal.

## System Elements

The *reference input elements* $G_v$ convert the desired value to a reference input signal.

The *control elements* $G_1$, sometimes called the controller, are the components that act on the error signal and generate a control signal to the process.

The *feedback elements* $H$ are the components required to measure or sense the value of the controlled output and convert it to a usable feedback signal.