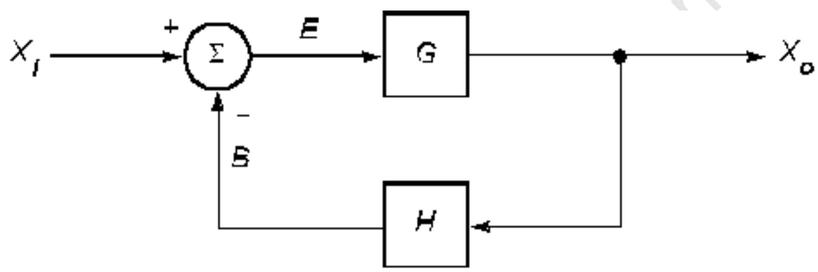
Feedback Circuit Misconceptions

by Dennis L Feucht

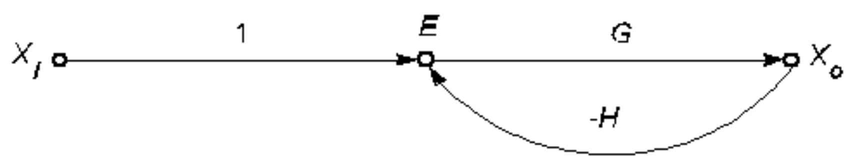
Typical circuit textbooks tell us that there are four basic feedback topologies. The impression is given (if not stated) that any feedback circuit will conform to one of these four topologies. One of the tasks of feedback analysis, it would seem then, is to identify to which of the four basic topologies a given feedback circuit conforms. But this is misleading. This article attempts to clarify the resulting confusion.

Feedback-Circuit Topologies

The basic goal of feedback-circuit analysis is to take the circuit diagram, which is sometimes a spaghetti-like connection of components, and adduce from it the transmittances (or *gains* or *transfer functions*) of the blocks *G* and *H* of the classical feedback topology, shown below in block diagram (a) and signal flow-path (b) representations. (Generalized electrical quantities - voltages or currents - are designated here as "*x*" quantities, where *x* is either *v* or *i*.)

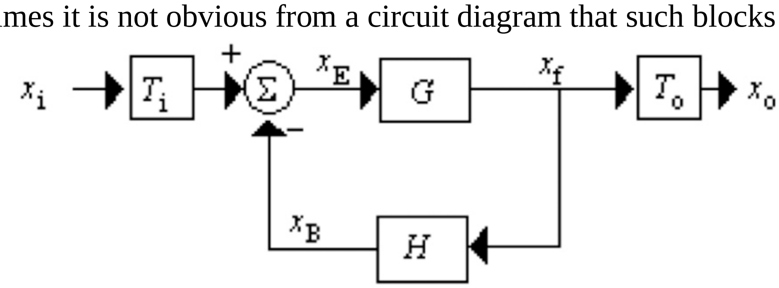


(a)



(b)

Actual circuits can also have additional associated transmittances. The more general feedback topology is shown below. T_i and T_o are outside the feedback loop but are included because they commonly occur with feedback circuits. Sometimes it is not obvious from a circuit diagram that such blocks should be included.



Block diagrams do *not* represent circuit interconnections (*topology*) but instead describe the flow of electrical cause and effect. Each block has an input (cause) and an output (effect) which is an electrical quantity. The arrows represent causal constraints, pointing from output to input. The input multiplied by the *transmittance* or *transfer function* written in the block is the output. For example, $x_f = G \times x_E$. The summing block, S, adds its inputs according to the sign by the arrowhead.

This block diagram is a graphic way of expressing the algebraic equations:

$$x_f = G \cdot x_E$$

$$x_E = T_i \cdot x_i - H \cdot x_f$$

$$x_o = T_o \cdot x_f$$

The first two equations describe the feedback loop itself. The loop is closed and consists of *G*, *H*, and S. Solving for the overall *closed-loop* gain of the feedback amplifier:

$$T = \frac{x_o}{x_i} = T_i \cdot \left(\frac{G}{1 + G \cdot H} \right) \cdot T_o$$

The middle factor in parentheses is the gain of the closed feedback loop itself. Given a circuit diagram, if the corresponding block transmittances can be found, the closed-loop feedback gain can be calculated from the above general expression. Circuits are often not obviously decomposable into the block transmittances. What is needed is a procedure that derives the blocks from feedback circuits in equivalent circuit form so that circuit analysis can then be used to determine their transmittances.

From Circuits To Block Diagrams

What is usually hardest in going from circuit to block diagram is to identify the summing block, Σ, (and *E*, the error quantity) and the pickoff circuit (and x_f) from the circuit diagram. To simplify this task brings us to the *four topologies* of textbooks. (A circuit *topology* is essentially its schematic diagram, showing its circuit structure through interconnection of its components.) The four topologies are all combinations of current or voltage pickoff and error summing. Thus, there are four possible topological characteristics of the feedback circuit. The usual names given to the four are given as:

Electrical Quantity	**Summing Circuit**	**Pickoff Circuit**
voltage	series comparison	node pickoff ("sampling")
current	shunt comparison	loop pickoff ("sampling")

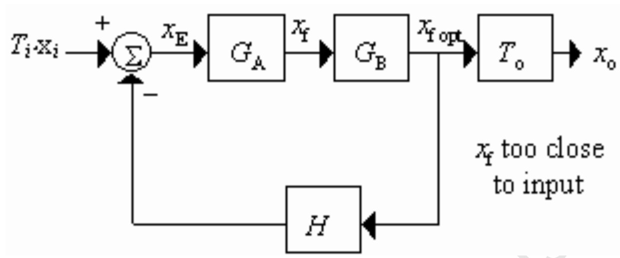
What is misleading in too many circuit textbooks is the notion that any given circuit must have one of these four topologies. In other words, it is conveyed that any given feedback circuit is constrained, for example, to have either a series or shunt comparison for its summing circuit, and either node or loop for its pickoff circuit. The key insight here is <u>that it is not the circuit but the analyzer of it that determines whether voltages or currents are compared and sampled</u>!

If you have been thinking that the circuit itself (and not you) determines the electrical quantity summed or picked off, then you would be looking for some characteristic of the circuit topology to determine which quantity this is. But *you* choose the quantities for summing and pickoff and then analyze the circuit accordingly. The choices are arbitrary, though some choices lead to a simpler analysis than others, as we will see. Only simple circuits with ideal sources constrain the choice to only one quantity because the other choice leads to a circuit degeneracy. However, in general, these reducing constraints might not exist.

Choosing Pickoff Quantities

Starting with the pickoff circuit, what is essential is that an electrical quantity (current or voltage), x_f, be identified as the pickoff quantity, x_f, to be fed back. The choice of x_f is constrained to be the output quantity of G and the input quantity of H. The first step in the analysis is to choose x_f. There is often more than one choice that will result in a correct analysis, but also, one choice many times leads to the simplest analysis.

Because the circuit is not the block diagram, it may not be obvious from the circuit which quantity to choose. To see what might happen, consider the block diagram below. Suppose you choose a quantity that is inside G. G has been decomposed into cascaded blocks G_A and G_B. The additional output block, T_o, is included between the pickoff point and the circuit output quantity, x_o, when the chosen pickoff quantity is not the output quantity.



If x_f is chosen too much toward the input within the forward path, G, then common factors appear in the algebraic expressions for H and T_o. As shown, $G = G_A \cdot G_B$, where x_f is chosen as the output of G_A instead of G_B. This results in the feedback equations:

$$x_f = G_A \cdot x_E$$

$$x_E = T_i \cdot x_i - G_B \cdot H \cdot x_f$$

$$x_o = G_B \cdot T_o \cdot x_f$$

G_B is a common factor in both the H term of x_E and T_o in x_o. By letting x_f be the output of G_B instead, G_B appears as a factor in the first equation and disappears from the others.

If x_f is instead chosen too close to the output, so that $T_o = T_{oA} \times T_{oB}$ and x_f is the output of T_{oA}, then:

$$x_f = G \cdot T_{oA} \cdot x_E$$

$$x_E = T_i \cdot x_i - T_{oA}^{-1} \cdot H \cdot x_f$$

$$x_o = T_{oB} \cdot x_f$$

In this case, introducing factor T_{oA} into the third equation removes it from the first two.

The optimal pickoff quantity is the one which minimizes common transmittances in these equations. However, it is not necessary to choose, or even identify, such a pickoff quantity. Let your intuition pick a quantity which seems most appropriate. It becomes the input quantity to H and T_o, if it is not x_o (in which case $T_o = 1$).

Suppose you choose x_f to be a voltage. Voltages occur at nodes. Consequently, x_f is identified with a circuit node from which a connection to the feedback-path (H) input is made. For a current, a pickoff loop must exist in which this current flows. A loop of G generates this current, and it flows through circuitry comprising the input of H.

Choosing Summing Quantities

Now let's apply the same kind of reasoning to the summing circuit. If x_E is chosen somewhere inside G, too much toward the output, common factors occur in the two terms of x_E. Let x_E be the input to G_B. Then:

$$x_f = G_B \cdot x_E$$

$$x_E = G_A \cdot T_i \cdot x_i - G_A \cdot H \cdot x_f$$

$$x_o = T_o \cdot x_f$$

By letting $G = G_A \times G_B$, G_A becomes a factor in the first equation and is eliminated from the second.

The other case is that of choosing x_E too close to the input, somewhere inside T_i, as the input of T_{iB}. Then T_{iB} appears as a common factor with G and in the error term containing H:

$$x_f = G \cdot T_{iB} \cdot x_E$$

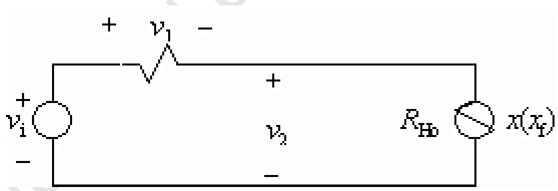
$$x_E = T_{iA} \cdot x_i - T_{iB}^{-1} \cdot H \cdot x_f$$

$$x_o = T_o \cdot x_f$$

By moving x_E to the output of T_{iB}, T_{iB} is eliminated from the first equation and from the H term of x_E, and it becomes a factor in the first x_E term so that $T_i = T_{iA\times}\, T_{iB}$.

You Choose Pickoff And Error Quantities

The form of input-network topology (series or shunt) is *not* generally determined by the circuit. But the choice of error quantity x_E affects the choice of input topology. This can be seen from the following input network.



In this circuit, the output of the H block is represented by a generalized source (either Thévenin or Norton equivalent) consisting of transmittance $x(x_f)$ and source resistance R_{Ho}. The feedback-circuit input is a voltage source in series with an input resistance across which is voltage v_1.

If v_1 is chosen as v_E, the H-path port is made a Thévenin circuit and the input forms a loop -- a series topology. If v_2 is chosen for v_E instead, then converting the input and feedback ports to Norton equivalent circuits results in a common node with voltage v_E -- a shunt topology. The feedback circuit input topology is determined by choice of error quantity, and not by the circuit.

The same kind of argument applies to pickoff circuits. Once x_f is chosen, then either a loop (for i_f) or node (for v_f) as the pickoff circuit results. Often, either choice can lead to a successful analysis, though the amount of algebra might differ appreciably.

Closure

The key steps in analyzing a feedback circuit are to choose pickoff and error quantities. With an awareness that input and output blocks may be required for some choices, consistent analysis will subsequently produce correct transmittance equations for G and H (and T_i and T_o). But do not be confused into thinking that your choices of x_E and x_f are determined by the circuit topology. Which of the four topologies results in your analysis depends on your choice of error and pickoff quantities, and not the circuit itself.