**Ideal Power Sources**

The ideal dissipative element defined above should be clearly distinguished from another type of system element which can also model the removal of energy from a system.  The power dissipated in an ideal generalized resistor is a function of the state of the system; it is a passive element which responds to changes within the system.  It is also useful to define active elements which may remove energy from a system but which are independent of its state.  Being independent of the system state, these elements may also supply energy to the system, and thus we are led to define *ideal power sources*.  As we might expect from our discussion of conjugate power variables, there are two types.

An *ideal effort source* is an element which produces an effort independent of the flow from the element.  The bond graph symbol is:

$$S_e \text{———}$$

Figure 3.20:    Bond graph symbol for an ideal effort source.

An *ideal flow source* is an element which produces a flow independent of the effort on the element.  The bond graph symbol is:

$$S_f \text{———}$$

Figure 3.21:    Bond graph symbol for an ideal flow source.

Causal Constraints

By definition, an ideal effort source <u>always</u> imposes effort on the rest of the system.  Consequently, the causal assignment for an effort source must be as shown in figure 3.22.  The dual causal assignment would be logically incompatible with the definition of the element.

$$S_e \text{———|}$$

Figure 3.22:    Causal assignment for an ideal effort source.

Similarly, an ideal flow source <u>always</u> imposes flow on the rest of the system and its causal assignment must be as shown in figure 3.23.  The dual causal assignment would be logically incompatible with the definition of the element.

$$S_f \text{|———}$$

Figure 3.23:    Causal assignment for an ideal flow source.

Note that in both cases the half-arrow depicting the direction of power flow is not determined by the definition of the element. This is because these elements may be used to model sinks (positive power in) as well as sources (positive power out).

<u>Modulated Power Sources</u>

To control something it is necessary to act on it. For a physical system this requires the addition or removal of energy, but that is not sufficient; it is also important to be able to change one's actions to respond to changing events. For a physical system this requires that the energy supplied or removed be modulated, usually as a function of feedback information.

Real devices which perform this function will be examined in depth in a subsequent chapter. For the present we will confine ourselves to defining idealized elements which would serve this purpose: *modulated power sources.* An ideal modulated power source is defined as an ideal power source with an output variable which may be modulated as a function of an input or set of inputs.

*Internal Modulation is Prohibited*

This definition may seem straightforward enough, but an important restriction is that, when used in a physical system model, *the input variable(s) which modulate the power source output must not depend directly on the internal state of the system.*

To understand the reason for this restriction it is important to recognize that an ideal power source, by virtue of its definition, does not come under the jurisdiction the first law of thermodynamics. If we were to include a power source within the boundary of a system, then the total energy within that boundary need not be constant. Ideal power sources are *boundary elements;* they describe the flow of power into and out of a system, due to external influences, and belong on the system boundary, not within it.

If an ideal power source were to be modulated by a variable internal to the system, then it would be possible to describe *all* phenomena as modulated power sources. For example, a generalized resistor could be described as a modulated effort source, with output, $e = R(f)$, modulated by an input flow, f. But that description would not retain the special properties of a dissipator. In particular, a modulated power source is not necessarily passive, whereas a dissipator must be.

Of course, it would be possible to add those special properties as restrictions on the modulating function for that particular source, but that would defeat the purpose of defining idealized elements in the first place. We would, in effect, deny ourselves access to a considerable body of knowledge which has been amassed about the behavior of physical systems. For example, without knowing the details of their constitutive equations, we may conclude that the total energy in a system composed only of passive elements may never increase[1]. If those passive

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[1] The proof of this statement requires a deeper look at the definition of passivity. This is postponed until chapter X.

elements were described instead as modulated sources, we could not draw that conclusion *a priori;* we would have to examine the modulating functions of each of the elements.

This prohibition of internal modulation of power sources does <u>not</u> preclude the modulation of a power source via feedback based on a measurement of the internal state of a system. Indeed, we will frequently encounter that situation in later chapters. However, the feedback modulating functions will not, in general, be subject to the kinds of restrictions which apply to the internal elements of a system. For example, a feedback-modulated power source will usually be an active system, theoretically capable of injecting infinite energy into a system. That is one of the reasons why feedback control systems are intrinsically prone to instability. But we are getting ahead of ourselves; that is the topic of a later chapter.

The main point to be taken from this discussion is that modulated sources should be used only to describe external influences on a system.

Power Bonds vs. Signal Flow Paths

As emphasized above, an ideal power source is a boundary element. An ideal modulated power source also serves as a "boundary" between the description of power flow or energetic interaction (described by bond graph notation) and signal flow or informational interaction (which may be described by block diagram notation). To emphasize the distinction between the two, we reserve the thick line for power flow (and use a half-arrow to denote power sign convention), and use a thin line with a full arrow for signal flow (the usual block diagram convention).

Note that the full arrow on a block diagram connection does not specify any sign convention, but rather the input to a block (and the output from the connected block); it corresponds to the causal stroke on a bond graph. A modulated power source is thus represented graphically as shown in figure 3.24. The labels near the power bond and the signal flow path are optional; they need only be included as necessary for clarification.

<div align="center">

u(t) ⟶ **S<sub>e</sub>** —— e(t) ——⊣                    u(t) ⟶ **S<sub>f</sub>** ⊢———— 
                                                                                    f(t)

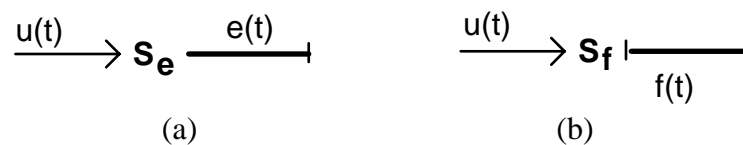(a)                                                     (b)
</div>

Figure 3.24:   Bond graph symbols for modulated power sources with signal flow and power flow explicitly represented. (a): Modulated effort source. (b): Modulated flow source.

Explicit representation of the signal flow path is not essential, especially if the source of the input signal is not included. In that case, the modulating input, u(t), may be written next to the symbol for the ideal power source as shown in figure 3.25.

<div align="center">

u(t): **S<sub>e</sub>** —— e(t) ——⊣                    u(t): **S<sub>f</sub>** ⊢————
                                                                                    f(t)

(a)                                                     (b)
</div>

Figure 3.25:    Bond graph symbols for modulated power sources without signal flow explicitly represented.  (a): Modulated effort source.  (b): Modulated flow source.