01.6 intro.ele Electronic elements

1 We now review a few lumped-parameter elements for electronic systems. Let a **current** i and **voltage** v be input to a port in an electronic element. Since, for electronic system, the power into the element is

$$P(t) = i(t)v(t) \tag{1}$$

we call i and v the **power-flow variables**. Voltage is always understood to be between two points in a circuit. If only one point is included, the voltage is implicitly relative to a reference voltage, called **ground**.

2 The **magnetic flux linkage** λ is

$$\lambda(t) = \int_0^t v(\tau)d\tau + \lambda(0). \tag{2}$$

Similarly, the **charge** is

$$q(t) = \int_0^t i(\tau)d\tau + q(0). \tag{3}$$

3 We now consider two elements that can store energy, called **energy storage elements**; an element that can dissipate energy to a system's environment, called an **energy dissipative element**; and two elements that can supply power from outside a system, called **source elements**.

Capacitors

4 Capacitors have two terminal and are composed of two conductive surfaces separated by some distance. One surface has charge q and the other $-q$. A capacitor stores energy in an *electric field* between the surfaces.

5 Let a capacitor with voltage v across it and charge q be characterized by the parameter **capacitance** C, where the constitutive equation is

$$q = Cv. \tag{4}$$

6 The capacitance has derived SI unit **farad (*F*)**, where $F = A \cdot s/V$. A farad is actually quite a lot of capacitance. Most capacitors have capacitances best represented in μF, nF, and pF.

7 The time-derivative of this equation yields the v-i relationship (what we call the "elemental equation") for capacitors.

$$\frac{dv}{dt} = \frac{1}{C} i \tag{5}$$

8 Capacitors allow us to build many new types of circuits: filtering, energy storage, resonant, blocking (blocks dc-component), and bypassing (draws ac-component to ground).

9 Capacitors come in a number of varieties, with those with the largest capacity (and least expensive) being **electrolytic** and most common being **ceramic**. There are two functional varieties of capacitors: **bipolar** and **polarized**, with circuit diagram symbols shown in Figure ele.1. Polarized capacitors can have voltage drop across in only one direction, from **anode** (+) to **cathode** (−)—otherwise they are damaged or may **explode**. Electrolytic capacitors are polarized and ceramic capacitors are bipolar.

10 So what if you need a high-capacitance bipolar capacitor? Here's a trick: place identical high-capacity polarized capacitors **cathode-to-cathode**. What results is effectively a bipolar capacitor with capacitance *half* that of one of the polarized capacitors.

Inductors

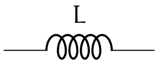
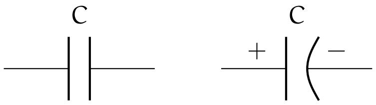


Figure ele.2: inductor circuit diagram symbol.



(a) bipolar capacitor.

(b) polarized capacitor

Figure ele.1: capacitor circuit diagram symbols.

11 A **pure inductor** is defined as an element in which **flux linkage** λ—the integral of the voltage—across the inductor is a monotonic function of the current i. An **ideal inductor** is such that this monotonic function is linear, with slope called the **inductance** L; i.e. the ideal constitutive equation is

$$\lambda = Li \tag{6}$$

12 The units of inductance are the SI derived unit **henry (*H*)**. Most inductors have inductance best represented in mH or μH.
13 The elemental equation for an inductor is found by taking the time-derivative of the constitutive equation.

$$\frac{di}{dt} = \frac{1}{L}v \tag{7}$$

14 Inductors store energy in a *magnetic field*. It is important to notice how inductors are, in a sense, the *opposite* of capacitors. A capacitor's current is proportional to the time rate of change of its voltage. An inductor's voltage is proportional to the time rate of change of its current.
15 Inductors are usually made of wire coiled into a number of turns. The geometry of the coil determines its inductance L.
16 Often, a **core** material—such as iron and ferrite—is included by wrapping the wire around the core. This increases the inductance L.
17 Inductors are used extensively in radio-frequency (rf) circuits, which we won't discuss in this text. However, they play important roles in ac-dc conversion, filtering, and transformers—all of which we will consider extensively.
18 The circuit diagram for an inductor is shown in Figure ele.2.

Resistors

Figure ele.3: resistor circuit diagram symbol.

19 Resistors *dissipate* energy from the system, converting electrical energy to thermal energy (heat). The **constitutive equation** for an ideal resistor is

$$v = iR. \tag{8}$$

This is already in terms of power variables, so it is also the **elemental equation**.

Sources

20 Sources (a.k.a. supplies) supply power to a circuit. There are two primary types: *voltage sources* and *current sources*.

Ideal voltage sources

21 An ideal voltage source provides exactly the voltage a user specifies, independent of the circuit to which it is connected. All it must do in order to achieve this is to supply whatever current necessary.

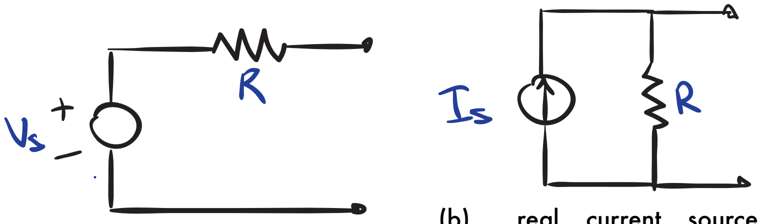
Ideal current sources

22 An ideal current source provides exactly the current a user specifies, independent of the circuit to which it is connected. All it must do in order to achieve this is to supply whatever voltage necessary.

Modeling real sources

23 No real source can produce infinite power. Some have feedback that controls the output within some finite power range. These types of sources can be approximated as ideal when operating within its specifications. Many voltage sources (e.g. batteries) do not have internal feedback controlling the voltage. When these sources are "loaded" (delivering power) they cannot maintain their nominal output, be that voltage or current. We model these types of sources as ideal sources in series or parallel with a resistor, as illustrated in Figure ele.4.

24 Most manufacturers specify the nominal resistance of a source as the "output resistance." A typical value is $50\ \Omega$.



(a) real voltage source model.

(b) real current source model.

Figure ele.4: Models for power-limited "real" sources.