6.200 Lecture Notes: Foundations and Vocabulary

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Circuit networks are a graphical language that can be used to solve engineering problems. However, before we can use them fully, we need to create a shared vocabulary that we can use to talk about them. In these notes, we introduce and explain that vocabulary.

Some of this content may be familiar to some readers from physics classes, but there are subtle differences, so I would encourage you to pay attention to the fine points, as they are important later. We will try to emphasize these points as they come up.

While these notes introduce circuits primarily as they apply to electronics, keep in mind that there are rich applications for circuits in fields such as mechanical engineering, chemical engineering, optics, thermal systems, and many others. So while you may think of voltage and current in only electrical contexts at first, eventually you will learn that these concepts can be abstracted to apply to a much wider range of applied-physical systems.

Graphs and Circuit Networks

A circuit is described mathematically as a kind of **graph**. It consists of **nodes** (points in space) and **branches** (connections between nodes), as shown in figure 1. This structure forms the basic fabric on which the circuit variables evolve. Branches are typically only counted as distinct if they contain a circuit element. If they do not, one thinks of a series of connected branches as being represented by a single branch, i.e. one typically reduces the number of branches to whatever extent is permitted by the **topology** of the circuit (the number of loops in the circuit), as illustrated in figure 1. In addition, dots are only drawn at nodes if more than two branches intersect at a node.

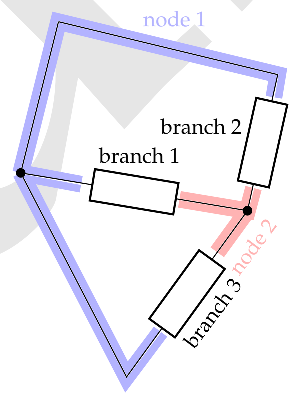


Figure 1: This graph would be described as having three branches and two nodes, despite it being drawn using 6 linear structures, because many of the branches are trivially connected to each other in series, and not all contain circuit elements, drawn here as generic rectangles.

Nodes

Nodes are intersection points where currents can combine and flow between the branches. They have an electrostatic potential (equivalently, a voltage) associated with them that we call the **node potential**. The node voltage can be positive, negative, or zero. When the node potential is zero, we will sometimes introduce a special symbol $\perp$ or ⏚ and refer to this as the ground node. [1]

[1] The choice of ground node can be important in certain types of practical circuits, but is irrelevant in circuit analysis (i.e. in calculations of circuit values). We'll talk more about this situation later in these notes. You can add an arbitrary offset potential to the circuit as long as you add it to all the nodes in the circuit.

As figure 2 illustrates, two circuits can be drawn to look very different, but represent the same underlying circuit. Spend some time

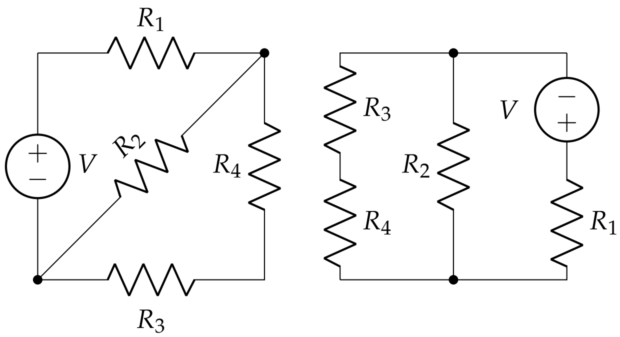
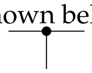


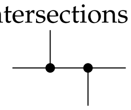
Figure 2: Example of two circuits that may not at first look identical, because they are drawn differently, but that are in fact topologically equivalent.

looking at these two circuits to try to convince yourself that they are indeed the same.

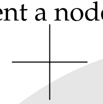
Nodes that connect three branches are drawn as a black dot as shown below.



Nodes with four or more branches are typically not used to avoid confusion with crossing nodes, and are instead broken up into two intersections with three branches each, as shown below.



Finally, crossing branches without connection are simply drawn as a cross, without a dot in the center, and should never be interpreted as being connected in a node. Thus the drawing below does not represent a node.



Branches

Branches are connections between nodes. In electrical circuits, branches always have an orientation (i.e. they have a well-defined "from" and "to" node indicated with a '+' and '-' label respectively) and have two associated values, the current (which can be positive or negative, negative current corresponding to current flowing opposite to the branch orientation) and the voltage difference which we call the **branch voltage**.

One of the most difficult concepts for new students to grasp, and one of the differences from how circuits are taught in physics class, is that in Electrical Engineering, circuit branches always have an orientation, i.e. they connect *from* a node and *to* another node, but the choice of branch orientation never influences the direction of actual current flow in a circuit.

Branches have **constitutive relations** that enforce mathematical relationships between special parameters—current and voltage– associated with them. Branches have current through them and voltage across them.

Again, it is common in physics class to teach students that circuit elements can have two possible constitutive relations differing only by a sign, depending on how the current and voltage are defined on that branch. In Electrical Engineering, we remove this ambiguity by enforcing the a consistent labelling of current and voltage as discussed above breifly, and in more detail below.

Loops

An important topological concept in a circuit is the concept of a loop. A loop consists of a unique path around which current can flow in a circuit. Circuits can have many such loops, and branches can be part of multiple loops in the circuit.

In contrast, a **mesh** is a minimal set of loops that includes each branch at least once. If a set of loops can be reduced in number while still including every branch in at least one loop, it is not a mesh. Illustrated in figure 3 is an example of a set of loops and branches labeled. Choosing any two out of the three loops forms a mesh.

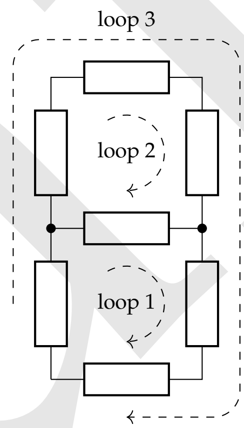


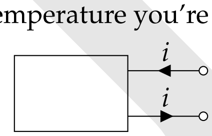
Figure 3: Circuit network with loops labeled. Loops 1 and 2 form a complete mesh for the circuit, even though a third loop exists. Similarly, any other two of the three loops would suffice to define the mesh.

Terminals and Ports

A terminal is a single wire that is intended to make contact to another circuit element. It is typically drawn as a line with an open circle at the end, like this —o.

As we will learn later when discussing supernodes, current that leaves a circuit network must eventually return to it, so it becomes very logical to group terminals together to form ports (pairs of two terminals). We will also talk about “input” and “output” ports, in cases where there is a clear directionality to signal transfer—as there often is.

We draw ports as you might expect: like two terminals side by side. In a port, current out of one terminal must be equal to the current in the other terminal. Any two terminals can in principle be called a “port” but in practice, this is usually done only when the two terminals are associated with a meaningful signal, e.g. the voltage across the port corresponds to an audio signal you’re trying to amplify or a temperature you’re trying to sense.



The rectangle here represents a generic circuit. This could be as simple as one element (e.g. a resistor), or could be a large network. From this, one should correctly conclude that a branch is equivalent to a one-port circuit.

Current

We will use a small rectangle to represent an abstract circuit element (imagine for now it is a resistor, as this is probably the element you're most familiar with from your introductory physics classes).

Because circuits are of broad interest, not just for electronics but also for a wide range of engineering disciplines, we will try to be quite generic when we talk about current and voltage. Current, for our purposes, is thus an abstract quantity defined on a branch with a direction.

You should think of it as representing the transport of another abstract quantity we will call **charge**. In reality, charge can be used as a convenient analog for other things, for example in mechanical systems it represents position or momentum, while in thermal systems, it represents heat. So try not to think about what this means physically yet. [2]

The most important point here is that, unlike in your introductory physics class, the arrow *does not represent the direction of flow of current*. Instead it just represents the direction we define to have positive current, $i > 0$, i.e. positive i. But often, i will be negative, current will flow from B to A even though the arrow points from A to B. [3]

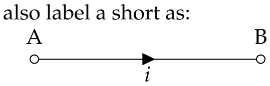
If the point here is not obvious, it is worth going to this website to make sure you really understand it. You'll find a short game you can play there that will test your understanding. You should play the game until you get it right 100% of the time and get bored of it.

Practical Considerations

Electrical current is measured by a device known as an ammeter, which must be placed in series with the branch being studied, and has units of amperes (coulombs of charge per second) or amps [A]. This unit can have prefixes added according to the International System of units (SI) such as μA for microamps (10^{-6} A), mA for milliamps (10^{-3} A) etc..

[2] In case you were wondering, yes, electrical engineers use the same definition of positive charge as physicists (so electrons have negative charge), so the current and charge we talk about is the same one that you learned about in your physics classes.

[3] It doesn't matter if the branch has a device on it, or is just a short, so one can also label a short as:



and i would still be well defined, and again, we know nothing about the direction of current in this circuit until we know the value of i, specifically whether the sign of i is positive or negative.

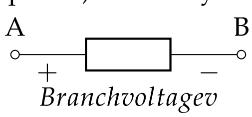
Typical current values in common real-world devices range in magnitude between microamps and amps, although applications exist which deal with currents ranging from picoamps (e.g. electron and ion microscopes) to megaamps (e.g. lightning).

Voltage

Voltage is sometimes defined in different ways, so you have to be a bit careful when working with it, or speaking about it. A **branch voltage** is the voltage *drop* across a circuit element, from the + terminal to the - terminal.[4] On the other hand, the term voltage is sometimes used to refer to **node potential**, which refers to the value of the electrostatic potential at a given node. This potential must always be defined relative to arbitrarily chosen 0 potential (typically the **ground**).

[4] For a simple connection, i.e. a short circuit, branch voltage is always zero, but for most real-world circuit elements (except for a not-time-varying current flowing in a superconductor) there will always be some small voltage across a wire.

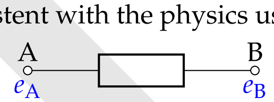
For purposes of building intuition about voltage, imagine a set of hiking trails connecting to each other on a hilly landscape. Think of the branch voltage as representing drop in altitude along one of the trails. Voltage is positive as you "go downhill" and is negative when you "go uphill." Branch voltages are local quantities, you only need to know what's going on on your local section of the "trail" (between its endpoints) to know your branch voltage.



In the sketch above, v is the branch voltage. It represents the drop in potential traveling from the positive label (in this case A) to the negative label (in this case B). Just as with the current definition, the drawing above tells us nothing about the actual value of the branch voltage, i.e. whether voltage drops from A to B or from B to A. It simply states that if $v > 0$, then the voltage drops from A to B. If $v < 0$, then the voltage drop would be negative (i.e. the potential of B would be larger than the potential of A).

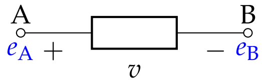
A **node voltage** or, more commonly, **node potential** (or just **potential**) is a number associated with a node. Node potentials are chosen carefully so that the difference between node potentials across a branch yields the node voltage. In these notes, we will always use the term "potential" to refer to a node, and "voltage" to refer to a branch, just to avoid confusion. This choice of terminology is also more consistent with the physics usage.[5]

[5] A good intuitive way to think about potential is to imagine it as altitude. To know the altitude, you need a reference (sea level, analogous to "ground") and you need the big picture (i.e. you need to know the overall map). In comparison, a branch voltage is a local parameter, and you only need to know if the trail you're on is going up or down to determine it.

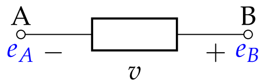


where e_A and e_B are the node potentials. The node potential is related to the branch voltage in different ways depending on the labeling.

Here we show a case where, $v = e_A - e_B$.



But now, we change the label and so the definition of v so that $v = e_B - e_A$.



When node potentials are used, a zero value of the node potential must always be defined. As mentioned above, this is called the ground node.

Thus, always take care to label the device terminals with a '+' and '-' sign on each branch whenever analyzing a circuit problem, otherwise the branch voltages and node potentials are not well defined.

Node potentials are more commonly used in circuit analysis than branch voltages, but the constitutive relation (see below) is always written in terms of branch voltage, so it is important to understand both these concepts.

Practical Considerations

Voltage is measured in units of volts, and like current, can have prefixes added (millivolts or mV for 10^{-3} V, etc.). In common household and laboratory electronic circuits, voltages range from millivolts to a few 10s of volts. Larger appliances and power systems deal with higher voltage, with some power transmission systems even operating at the megavolt (MV $= 10^6$ V level).

Ground is typically referenced to the physical ground (the one underneith our feet), but only through some wires, thus locally in a building the "ground" potential can actually vary a bit from the earth ground, and vary further from grounds in other parts of a building, depending on the resistance of the grounding wires and the amount of current flowing through them. Furthermore, equipment bring the earth ground to a chassis and defines a new ground to which all the local components of the equipment is referenced. Finally, on an integrated circuit or printed circuit board, a signal ground is typically defined. These grounds all have different symbols and different uses (power transfer, safety, and signal precision, for example).

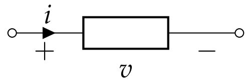
Constitutive Relations

Constitutive relations relate the current and voltage (or equivalently charge and flux)[6] across a device or a port.

A circuit element with a constitutive relation can be conceptualized

[6] Current i is the rate of change of charge q, so $i = dq/dt$ and voltage v is the rate of change of flux Λ, so $v = d\Lambda/dt$. If you're not familiar with flux, you can think of it as what a voltage delivers to a circuit, just like current delivers charge.

as sketched below:



where we have been *very careful* in the labelling so that the current is defined as positive if it flows into the voltage terminal labeled with the "+" symbol. This choice is known as the **Passive Signs Convention.**

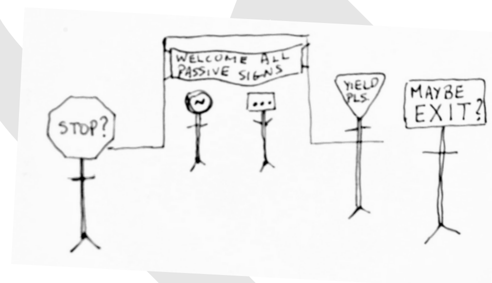


Figure 4: Attendees enjoy the "Passive-Signs Convention."

Passive Signs Convention

By convention (the "Passive Signs Convention") the positive current direction is from the '+' labelled side of the branch to the '-' labelled side of the branch.

This convention is necessary in order for proper book-keeping of current and voltage signs. When performing circuit analysis (as opposed to talking about a circuit casually), we do not expect current to travel in the direction of the arrow label, nor do we expect potential to decrease from the '+' to '-' label. Rather these are just labels that help us keep track of which way current would flow *if current happens to be positive* and which way potential would drop *if the voltage happens to be positive*.

This labelling is essential to ensure that power dissipation is associated with the formula $p = iv$ (and not $p = -iv$) and that Ohm's law (see below) is $v = iR$ (and not $v = -iR$). Unfortunately, introductory physics classes do not typically choose a convention, and so you may find yourself confused by this labeling requirement at first. In this case, you may find yourself at an advantage if you didn't pay close attention in your physics class...

Power and energy

The device power as mentioned above can be estimated from its terminal parameters (branch current and voltage). Thus $p = iv$. Note that in general i and v are time-dependent quantities, so more precisely one should write $p(t) = i(t)v(t)$.[7]

When using the passive-sign convention, passive devices (i.e. devices that dissipate or absorb power like resistors and voltage sources supplying current to a circuit) have positive power.[8]

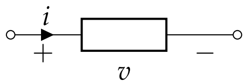
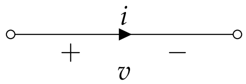
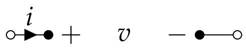
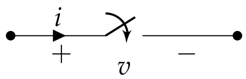
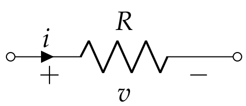
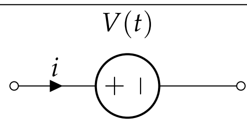
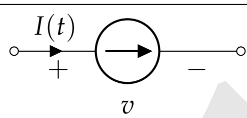
We will learn later that the total power in a circuit must sum to zero. Until we start to learn circuit analysis, we can't do much with this fact, so we'll just leave it at that for now.

[7] Remember, from your physics classes, that energy is the integral of power, so from the fundamental theorem of calculus, $E(t) = \int_{-\infty}^{t} p(t')dt'$

[8] I like to think of this in the hiking analogy as hikers going downhill, i.e. lowering their potential energy. If the hikers are traveling uphill (say with a chair lift), then the power will be negative.

Bestiary of Electronic Devices

Here we list a wide variety of single-port circuit elements, from the very basic to the very complex, along with their constitutive relations.

Name	Symbol	Parameter	Constitutive Relation
Generic		n/a	$i = f(v, i)$ or $v = g(i, v)$
Short circuit		n/a	$v = 0$
Open circuit		n/a	$i = 0$
Switch		state (open/closed)	$i = 0(open)$ $v = 0(closed)$
Resistor		R resistance	$v = iR$
Voltage source		V strength	$v = V$
Current source		I strength	$i = I$

Sources/Constraints

Ideal voltage sources and current sources are somewhat misnamed... they aren't really *sources* as much as they are electrical machines that maintain a certain current or voltage. Thus we also use the term "constraints" sometimes to describe them, because they can be thought of as mathematical constraints imposed on the circuit. As one might expect from the adjective "ideal" that describes them, no such sources exist in the real world. An ideal voltage source can maintain a precise voltage across it no matter the current through it. Similarly an ideal current source can maintain a precise current through it no matter the voltage across it and so again, it cannot exist in the real world. We use these here because they are mathematically and conceptually useful as models and, as long as they are applied for small enough voltages and currents, they approximate real-world devices relatively well. [9]

You will general simplify your life by aligning the '+' label with the '+' terminal of your voltage source and aligning your i label with

[9] Current sources and voltage sources need not be constant in time The current and voltage they maintain can vary in time, but it cannot vary in response to the external circuit (later we will discuss special types of sources that break this rule). This behavior is somewhat weird and thus the term "constraint" does seem more natural for it.

the direction of your current source. Thus the i arrow should always point *into* any voltage source, perhaps counter-intuitively. Only by sticking to this convention will the power correctly be negative when the device is supplying power, and positive when it is absorbing power. [10]

[10] Often students struggle with the idea of a source absorbing power—but it happens all the time: every time you charge your phone, its battery (which can be approximately modeled as a source) is absorbing power.

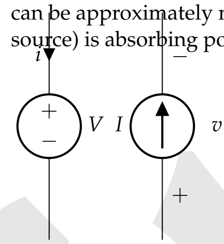


Figure 5: Note that we did not have to label v on the voltage source or i on the current source because we used the passive signs convention, meaning by implication $v = V$ and $i = I$.

Notice that for a voltage source, the strength or constraint V is a device parameter, and the constitutive relation (assuming you choose your labels correctly) is trivial so $v = V$. However i is unconstrained, so i is determined only by what the circuit is connected to.

Similarly, for a current source the strength or constraint I is a parameter, and equal to the variable i (again, assuming the labels are set correctly). In this case v is unconstrained.

One good way to visualize the voltage constraint imposed by a supply is through an *i*-*v*curve. However, this just gives you the range of possible i and v values. At any moment, only one value of i and v is permitted in classical circuits (quantum mechanics breaks this rule, but is beyond the scope of this class). Figure 6 shows the *i*-*v*curve of a voltage source, which is always just a vertical line as can be deduced from its constitutive relation.

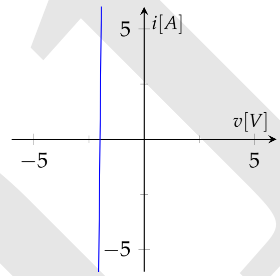


Figure 6: *i*-*v*curve of a -2 V voltage source. Ideal voltage sources will always form vertical lines on *i*-*v*plots. Similarly, current sources will always form horizontal lines.

Ideal sources can have any value of power p, $p > 0$, $p < 0$ or $p = 0$ and there is no way to know which it will be without knowing what the source is connected to. The constitutive relation on its own cannot tell you because it only constrains i *or* v, while to know p you need to know both.

One convenient way we keep track of when a device is absorbing ($p > 0$) or supplying ($p < 0$) power is which quadrant of the *i*-*v*plot the current and voltage coordinate is found. In quadrants I and III, the power is positive (because $i \cdot v > 0$) while in quadrants II and IV, the power is negative (because $i \cdot v < 0$). Obviously, if either i or v is zero, then $p = 0$, so along the axes and at the origin no power is being generated or consumed.

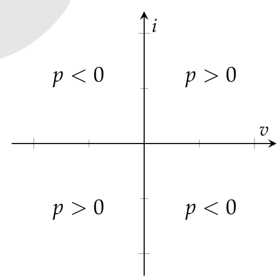


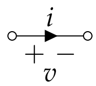
Figure 7: Power sign in various quadrants of an *i*-*v*plot.

Practical Considerations In reality, a lab voltage *supply* (which is a physical piece of equipment you can buy) struggles to supply current beyond certain specified limits. So do not confuse the ideal voltage source with an actual lab voltage supply, and vice versa.

One particular subtlety is that there's a huge difference between a zero-strength source and a source that is "off". A zero-strength source is actually very much "on" in the sense that it is enforcing a constraint on the circuit. In contrast, a lab power supply that is powered off will in all probability just act like an open circuit. That's equivalent to a zero-strength current source, but it is quite different from a zero-strength voltage source (which acts like a short), as we shall see now.

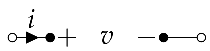
Shorts and Opens: A Special Source/Constraint

A short circuit is a special kind of branch that connects two nodes with the same potential and allows current to flow freely. Typically we just draw it as a straight line connecting the nodes.



In effect, then, this branch is just part of the node, as it shares equal potential everywhere, and the constituitve relation must be $v = 0$.

Open circuits are special branches that cannot conduct current, as shown below.



Opens thus have a constitutive relation of and $i = 0$.[11]

[11] Notice the terminal dots of the open are filled in: these are not connections, they are disconnected from any other circuit element.

Shorts and opens are special cases of ideal sources. A short circuit is thus identical to a voltage source with constraint $V = 0$ and an open circuit is identical to a current source with constraint $I = 0$.

This equivalence will be essential later when we introduce some advanced methods of circuit analysis.

Because shorts and opens always have either i or v equal to zero, they neither supply nor consume power.

Resistors

Resistors are circuit elements that cause the potential to drop across them in proportion to the current through them.

The constitutive relation that defines a resistor is known as **Ohm's law** and is $v = iR$ where v and i are defined according to the passive sign convention and R is the parameter known as **resistance**. This relation is also written $i = Gv$ where G is called **conductance** and $G = 1/R$.

While we have introduced the resistor here for the first time, it is a good chance to mention one misconception many students are taught in their physics classes. While it is true that there is not such a thing as a negative resistor (i.e. a resistor with $R < 0$), it is routine in circuit analysis to encounter a situation where resistance is nonetheless negative. This apparent contradiction occurs because we often use simple circuit elements (like a resistor) to model far more complex circuits. While there is no *single* element with resistance less than zero, complicated circuits can act like a negative resistor when viewed from a port. Thus you should not be surprised to encounter a problem in which $R < 0$ in a circuit analysis situation, even though you cannot buy such a resistor from a catalog.

For a resistor, the i-$v$curve is a simple straight line through the origin.

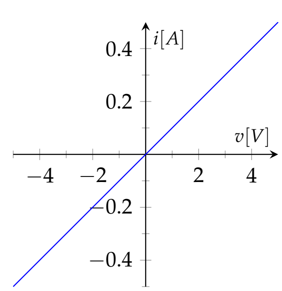


Figure 8: i-$v$curve of a 10 Ωresistor. Resistor i-$v$curves are straight lines that pass through the origin with slope equal to the conductance, i.e. $1/R$, in this case 0.1 Ω.

If $R > 0$ (as it always is for an actual physical resistor, but not for resistors used as models in analysis), then the slope of the i-$v$curve is positive and equals the conductance $G = 1/R$ (because from Ohm's law $i = 1/R \cdot v$, and i is the y axis while v is the x axis). That means that if $R > 0$ the sign of i and v must always be the same, and so $p > 0$ and power is always dissipated in a positive resistor. This situation is illustrated in figure 8.

A resistor with resistance of 0 has constitutive relation $v = i \cdot R = i \cdot 0 = 0$ which is the same as the constitutive relation of a short circuit. Resistors with zero resistance are thus just short circuits.

Similarly, an infinite resistance corresponds to a constitutive relation of $i = v/\infty = 0$ which matches an open circuit. Infinite resistors are thus, intuitively enough, open circuits.

Practical Considerations Resistors can only be purchased in certain values that approximate a geometric series separated approximately by a constant factor. The common E12 series steps in values by a factor of ∼21% between values, resulting in 12 values of resistors across a factor of 10. Here is the standard series: 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, and 82. These values are available from about 1 Ωto about 1 GΩ (so, for example, 12 kΩ, 330 Ω, and 5.6 MΩ resistors are all available). Resistance values take the usual SI prefixes, e.g. kΩ (kiloohm) for 10^3 Ω, and MΩ (megaohm) for 10^6Ω. Resistors above 1 GΩ (= 10^9 Ω) are less common and more of a specialty product because a number of practical factors interfere with their use and reliability.

Resistors are typically specified with a precision (for E12 about 10 %), and with a power-handling ability (1/4 W or 1/2 W is common). When operated above their power ratings, resistors act more like a party poppers than resistors. Wear your safety glasses if you want to see for yourself.

Conclusions

One thing to keep in mind is that all of these constitutive relations and behaviors are heavily idealized. When working with real resistors, real laboratory voltage and current supplies (often called "power supplies") and even real short and open circuits, non-idealities will creep in. We introduce these components here only because they can be used to approximate real-world behavior, not because they match it perfectly.

We now have developed three self-consistent methods for representing some idealized circuit components: (1) schematic drawings of the components that can be placed on a graph with nodes and branches; (2) equations that relate current and branch voltage; and (3) *i*-*v*curves that illustrate relations between current and voltage in devices.

Now that we have established some shared vocabulary and conventions, we will learn how to combine these concepts to perform the first steps of circuit analysis.

Glossary and Definitions

circuit variable Current on a branch or voltage across a branch are circuit variables. For reasons I can't quite explain yet, I do not refer to node potentials as "a variable", although it certainly also varies. Note the variability is with respect to the connections and parameters of the circuit (i.e. the fabric of the circuit) not necessarily with respect to time. So values that dot not vary in time are also considered to be "variables" in a circuit.

circuit parameters Values in constitutive relations that set how circuit variables relate to each other. For example source strengths and resistances are parameters.

branch Connections between nodes in a graph.

branch voltage Voltage drop across a circuit branch.

branch variables Current through a branch or voltage across a branch.

conductance Reciprocal of resistance, often represented with the letter G.

constraint synonym to strength of a voltage or current source.

constitutive relation Equation or system of equations that defines the circuit element's behavior mathematically.

current Rate of flow of charge through a branch.

graph Combination of nodes and branches to form a network.

label '+', '-' or arrow indicating direction in which positive voltage is chosen to drop and positive current is chosen to flow. The label does not impact the actual current or voltage on the circuit, only how it is represented mathematically.

network Collection of nodes and branches that defines a circuit's topology

node Intersection point of branches in a graph.

node potential Voltage with reference to a ground (with zero voltage).

node voltage See node potential (preferred).

Ohm's law Constitutive relation for a resistor, relating i and v across the resistor.

open Circuit element that does not allow current to flow through it.

parameter See circuit parameters.

passive signs convention labelling convention for circuit elements in which the current arrow always points into the '+' labelled terminal. At MIT, we have sometimes called this the Associated Variables Convention.

port A pair of disconnected circuit terminals, typically intended to carry a meaningful signal represented as a voltage across them or as a current into one and out the other terminal. Current in one terminal must equal current out the other.

resistance Parametric constant of proportionality relating current and voltage in a resistor. $v = iR$.

resistor Circuit element obeying Ohm's law, so that $v = iR$ when v and i are defined according to the passive signs convention.

terminal A single disconnected node of a circuit. An open circle at the terminal indicates an implied connection exists.

topology For our purposes, we just mean the layout of the circuit, neglecting simply connected short circuits.

short Circuit element through which current can flow freely, without voltage developing across it.

strength The strength of a voltage or current source refers to the value imposed at its terminals. The strength can be positive, negative, or time varying. Also called "constraint."

voltage Unfortunately a slightly ambiguous term. Typically refers to branch voltage, but can also refer to node potential depending on context. All such representations are fundamentally specific instances of a measure of electrostatic potential energy.

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