40 – Course Introduction and Fundamental Concepts

Reading Material:

Chapter 1

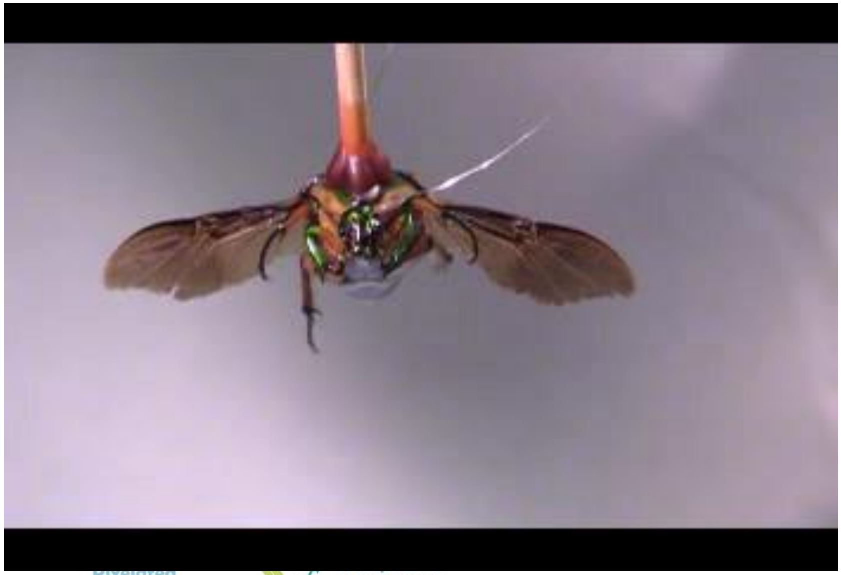
What do I do?

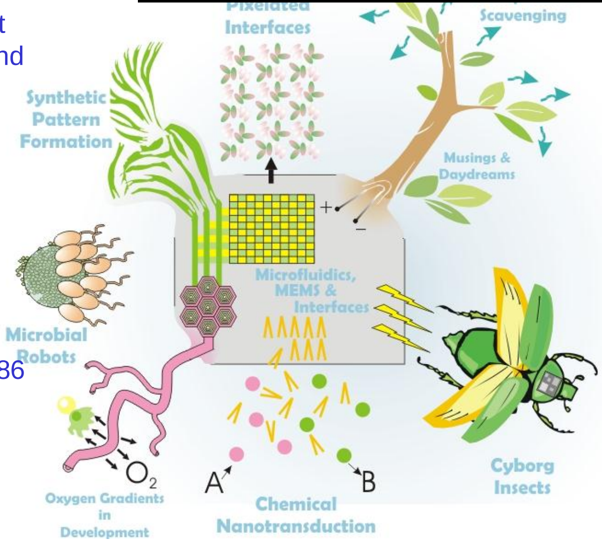
- I build gadgets…

- My obsession is building gadgets that interface with biology

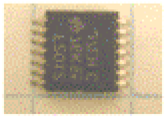
- http://www.eecs.berkeley.edu/~maharbiz/

- See, for example:
  - M.M. Maharbiz and H. Sato "Cyborg Beetles: Tiny flying robots that are part machine and part insect may one day save lives in wars and disasters" Scientific American, Vol. 303, Number 6, 94-99 (2010). [December issue]
  - Sato H, Berry CW, Peeri Y, Baghoomian E, Casey BE, Lavella G, VandenBrooks JM, Harrison JF and Maharbiz MM, "Remote radio control of insect flight," Front. Integr. Neurosci. 3:24, 2009. doi:10.3389/neuro.07.024.2009
  - http://www.plosone.org/article/info:doi/10.1371/journal.pone.0007086





v1.0, cotinis, no radio



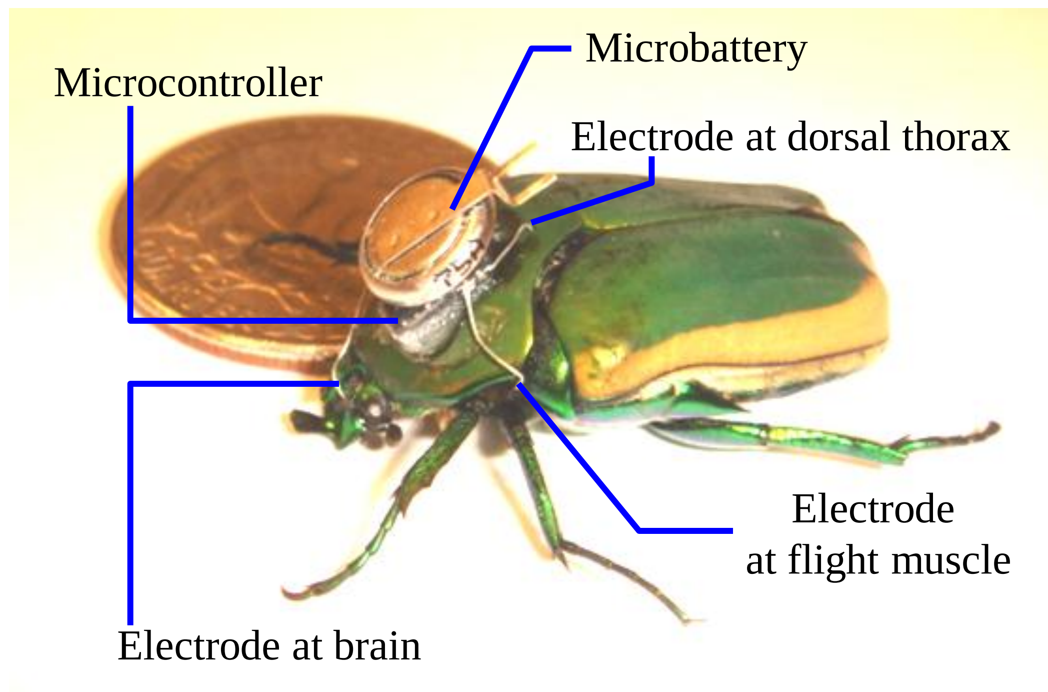
Microcontroller

Texas Instruments, MSP430F2012IPWR,
63 mg, 5.0 mm x 4.5 mm x 1.0 mm

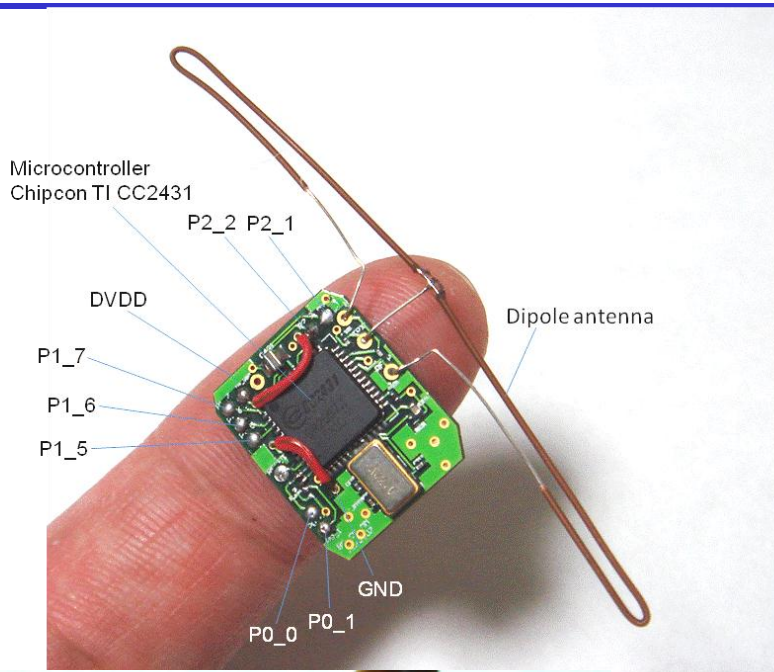
Microbattery

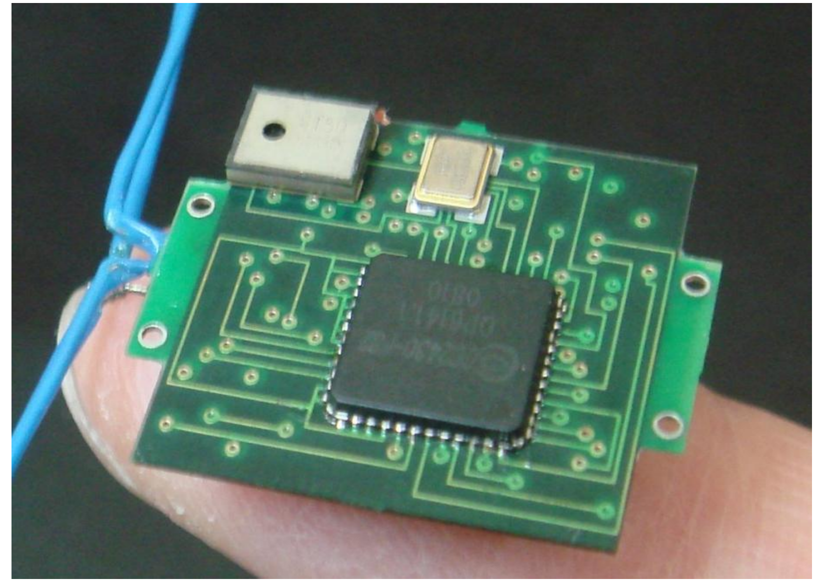
Panasonic, ML614, 3 V, 160 mg,
Ø6.8 mm x 1.4 mm, 3.4 mAh

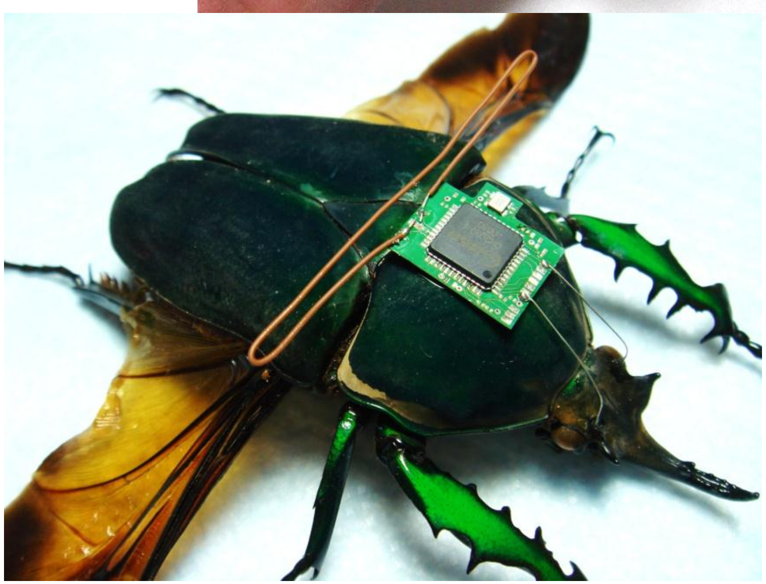
Silver wires were soldered as electrodes.

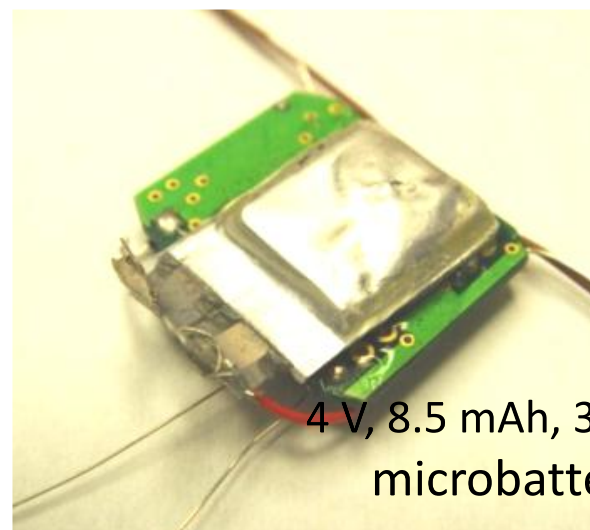


v2.0, 3.0: Mecynorrhina and radio







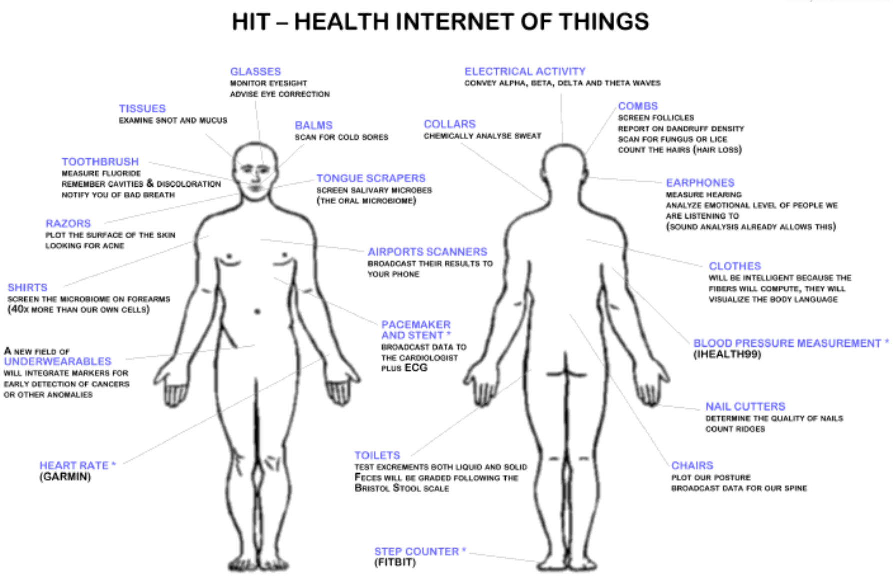


4 V, 8.5 mAh, 350 mg
microbattery

There’s a revolution in “physical hacking” unfolding

- Get excited! Hacking is increasingly not just about software
  - Maker movement
    - http://makezine.com/
    - http://www.makerbot.com/
  - www.shapeways.com
  - the quantified self

www.hackerspaces.org
go! visit! work with others!



Walter de Brouwer, *http://quantifiedself.com/2011/02/hit-%E2%80%93-health-internet-of-things/*

Course Outline / Requirements

- **Professor**
  - Michel M. Maharbiz, EECS
  - 646 Sutardja Dai Hall (SDH)
- **Lecture**
  - Monday, Wednesday, Friday
  - 11 am – 12 pm
  - 10 Evans
- **Office Hours**
  - Monday, Friday after lunch (1 – 2 pm)
  - Or, you can email me for an appointment if you aren’t able to make regular office hours
    - go to http://www.eecs.berkeley.edu/~maharbiz/schedule.htm
    - Pick a free time on my schedule
    - Email me and wait for confirmation

GSI's

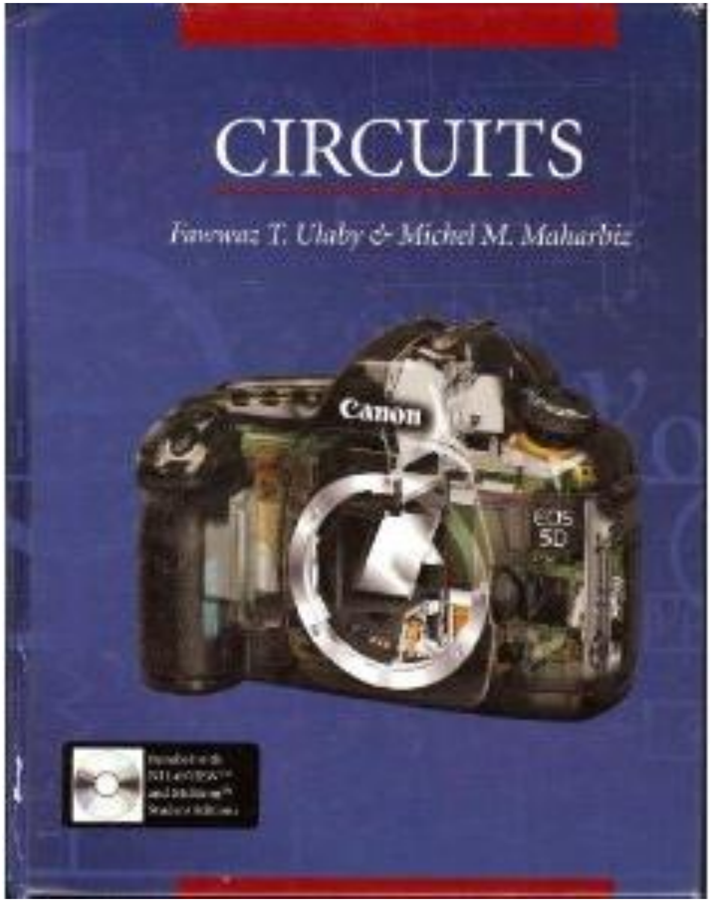
- Subject to change in the first week

- Discussion GSI's:
  - Wenting Zhou, wtzhou@eecs.berkeley.edu
    - OH: Tu 1-2pm at 504 Cory and Wed 5-6pm at 504 Cory
  - Andre Zeumault, azeumault@berkeley.edu
    - OH: TBA

- Lab GSI's:
  - Ibrahim Awwal (head GSI) ibrahim.awwal@berkeley.edu
  - meet the rest at your section

The Textbook

- Circuits
  - By Ulaby and Maharbiz
  - NTS Press
- Why?
  - Good text with lots of real-world examples
  - Cheaper than competitors
  - It’s my book!
  - Coordinates better between EE40/42/100



Course Plan

- We will generally follow the content of the text, but with important additions / subtractions
- The course notes are your primary guide, and they are INTENTIONALLY sparse so you HAVE to attend lecture
- I will sometimes project the slides, other times use the board / tablet
- EE 40
  - Homework: 10 %
  - Midterms (2): 30 %
  - Final Exam: 30 %
  - Labs: 30 %

Policies

- **Tests**
  - Missed exam will only be allowed for medical reasons or research-related travel and HAS TO BE APPROVED BY ME OVER EMAIL three (3) weeks in advance.
- **Homeworks**
  - You can miss 1 HW
  - Else, your lowest score will be dropped
- **Cheating**
  - No excuses; I will seek the maximum penalty and fully follow the department policy (except, I don’t allow repetition of work under *any* circumstance) http://www.eecs.berkeley.edu/Policies/acad.dis.shtml

Labs and Final Project

- In pairs, you will build a working EEG!
- http://openeeg.sourceforge.net/doc/
- http://www.neurosky.com/

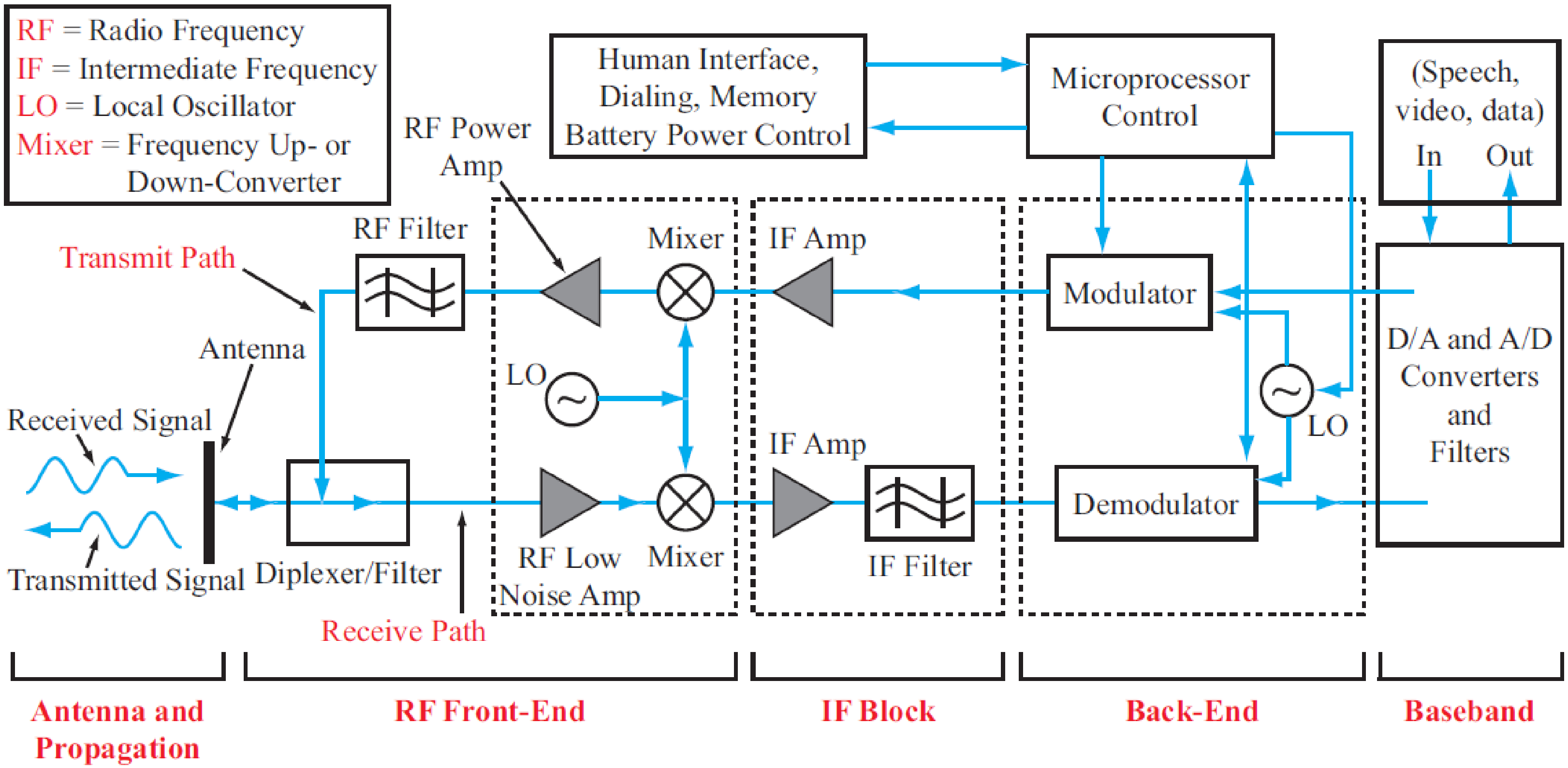
Labs and Final Project

Soldering	23 Jan M-F
Resistors	30 Jan M-F
Amplification I - sim amp	6 Feb M-F
Amplification II - instr amp	13 Feb M-F
No labs (also, Midterm 1)	week of 20 Feb
RLC / oscillators	27 Feb M-F
Filters	5 March M-F
ADC	12 March M-F
Project design, SPICE, breadboard	19 March M-F
Breadboard testing and debug	2 April M-F
PCB layout (also Midterm 2)	9 April M-F
No labs (PCB FAB)	16 April M-F
Solder / build	23 April
Check off - put EEG on my head	One day, week of 30 April

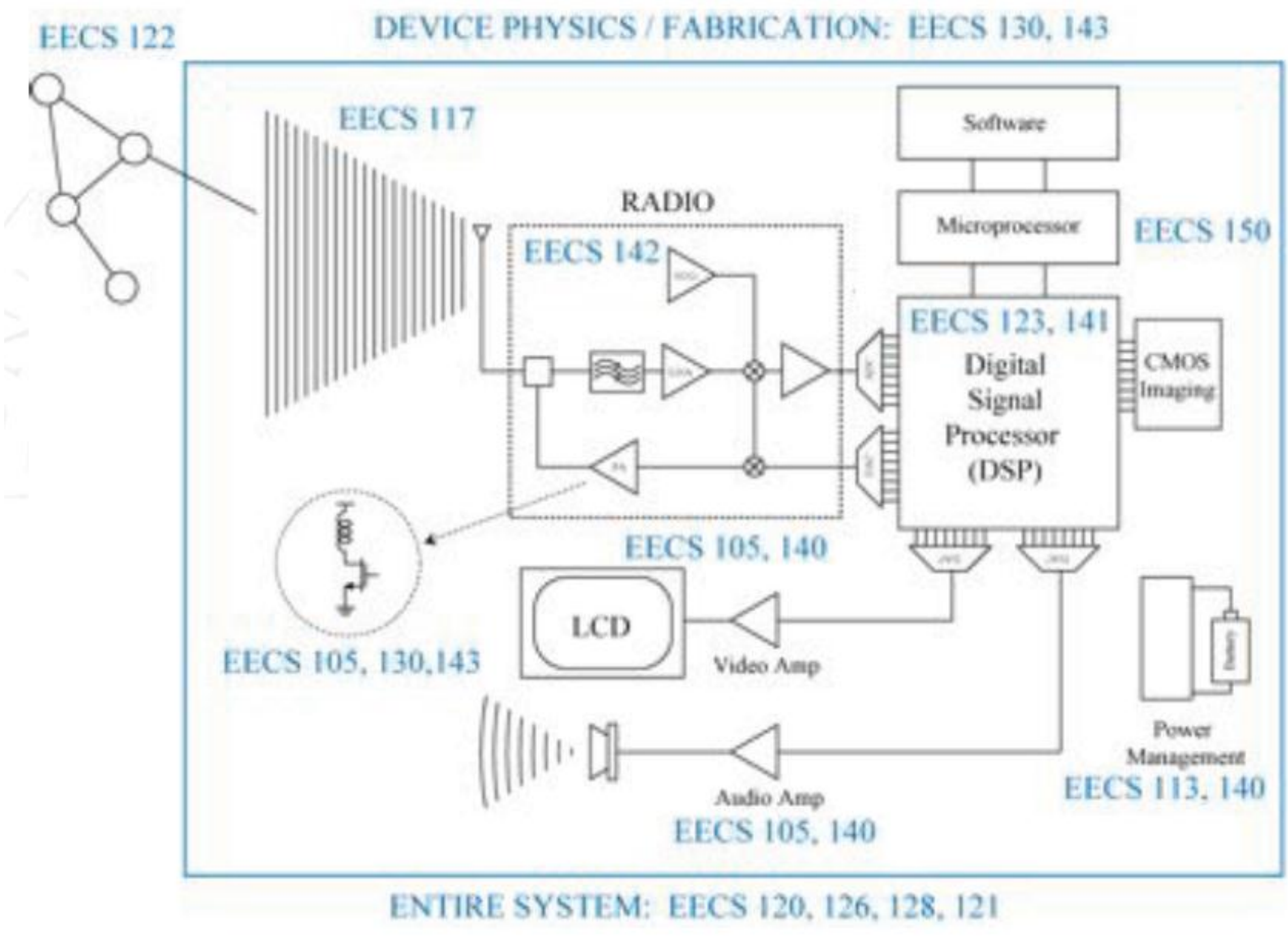
Peek inside a cell phone

- Lot’s of “chips” (Integrated Circuits)

Cell phone architecture



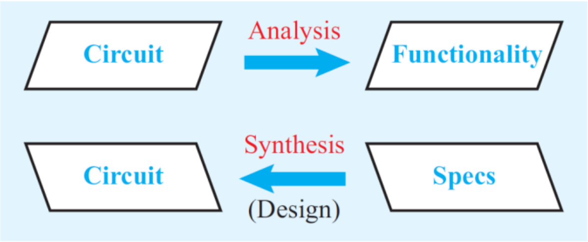
Cell phone by EE courses



EE "Layers"

- Devices
  - You can "touch and feel" devices
  - Semiconductors are materials of choice, properties can be engineered
  - Information is ultimately represented by electrons (and 'holes') and/or photons
- Circuits
  - Any interconnection of devices that performs a useful function
  - Digital circuits, analog circuits, "RF" and microwave
- Systems
  - The theory behind EE systems. A model for the system that includes noise, non-linearity, feedback, and dynamics.
  - Most often digital signal processing algorithms used.

Analysis vs. Synthesis



Some history to lead us to our first topics

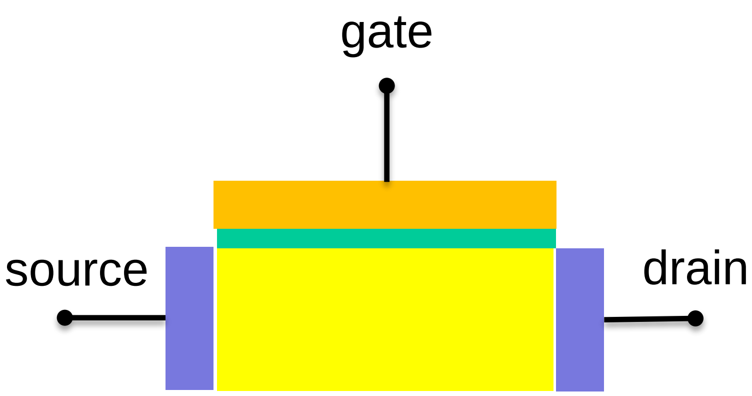
Transistors

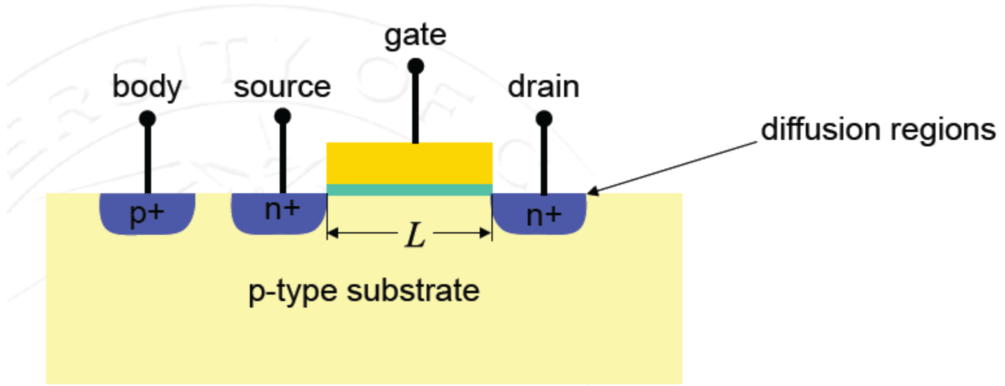
- Invented at Bell Laboratories on December 16, 1947 by William Shockley (seated at Brattain's laboratory bench), John Bardeen (left) and Walter Brattain (right)
- Inventors awarded Nobel Prize

Early transistor-based systems

- Bell labs was the research lab of a telephone company. As such the importance of the transistor was not recognized by many of the business folks at AT&T.
- Device was flaky and low power compared to vacuum tubes, the workhorse device of the time (for sig amplification)
- In 1952 first transistorized radios appear. Compared to vacuum tube, transistors were compact.
- Transistor radio was a revolutionary battery operated device.

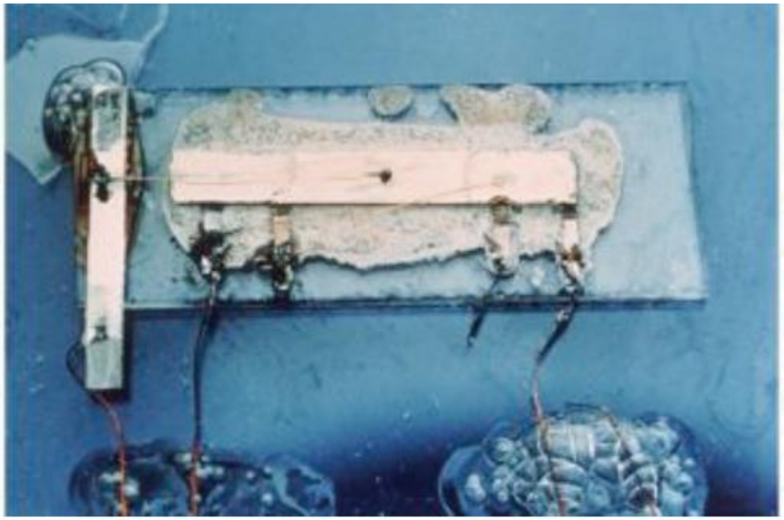
How does a transistor work?





- Metal-Oxide-Semiconductor sandwich. Usual structure is actually polysilicon, silicon dioxide, silicon. (Note that the original transistor fabricated was not an MOS device.)
- A "channel" for current flow can be setup between the drain/ source.
- The channel conduction (between drain and source) is controlled by the gate voltage.

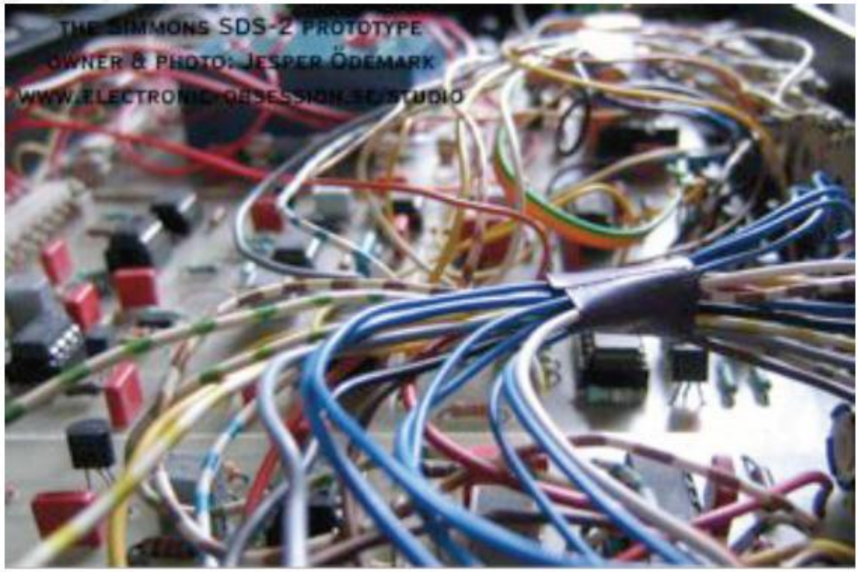
The Integrated Circuit



- First IC is invented by Jack Kilby of Texas Instruments and Robert Noyce of Fairchild Semiconductor (later founded Intel)
- In his patent application of February 6, 1959, Kilby described his new device as “a body of semiconductor material ... wherein all the components of the electronic circuit are completely integrated.” (2000 Nobel Prize in Physics)

Why are IC’s important?

- When building a complex circuit, most of the failures occur in the wiring and connections → spaghetti of wires
- Printed circuit boards help improve reliability but they are physically large and discrete components are fairly expensive
- ICs: Low cost mass production, monolithic, includes transistors and interconnect.



State of the art IC's

- Easily integrate millions to *billions* of transistors on a single chip.
- Patterns printed once and can be used again and again to make copies of IC.
- High yields through careful manufacturing tolerances.
- Dimensions have gone from sub mm to sub micron. Today the gate length and oxide of a transistor is ~10 nm (about ten layers of atoms)

Circuits

- When devices are interconnected to perform some useful function, we say that thing is a circuit
- Examples:
  - A light bulb/switch, spark generator in internal combustion engine, a radio, a cell phone, a computer
- A typical "circuit" may contain millions of devices. How do we deal with this level of complexity?
  - Hierarchy: Divide and conquer
  - A large circuit is broken up into my sub-blocks
  - Sub-blocks are broken up into sub-blocks …

Analog Circuits

- Analog circuit represent the signal as an electrical current/ voltage
- Typical analog circuits:
  - Amplify signals (weak signal picked up by microphone)
  - Filter signals (remove unwanted components, interference, noise)
  - Perform mathematical operations on waveform
    - Multiplication, differentiation, integration
- Circuits very susceptible to noise and distortion
- Analog circuits are “hand crafted” by analog “designers”
- Attempts to automate analog design (Computer Aided Design or CAD) have largely failed

Digital Circuits

- Represent quantities by discrete voltages, “1” and “0” (e.g. 1V and 0V) – “bits”
- Digital circuits perform “logic” operations on the signals (AND, OR, XOR) – “combinatorial logic”
- Mathematical operations can be performed using logic operations (XOR is a 1-bit adder)
- Digital memory created using capacitors (dynamic memory) or through latches/flip-flops (regenerative circuits)
- Digital circuits are robust against noise (signal levels are regenerated to “0” and “1” after digital functions)
- Digital circuits often “clocked” to simplify design

Computers

- ENIAC was the first general purpose computer
- Used by Army to calculate artillery firing tables. Later used for calculations related to the hydrogen bomb.
- Early computers filled up entire rooms and were very unreliable.
- First “bug” was a moth causing a circuit fault.
- First programmer was Ada Lovelace (~ 1840!!!)

Programmers Betty Jean Jennings (left) and Fran Bilas (right) operate the ENIAC's main control panel at the Moore School of Electrical Engineering. (U.S. Army photo from the archives of the ARL Technical Library) [Wikipedia]

Units, Multiples, Notation

Table 1-1: Fundamental SI units.

Dimension	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol

Table 1-2: Multiple and submultiple prefixes.

Prefix	Symbol	Magnitude
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}

As a general rule, we shall use:

- A lowercase letter, such as i for current, to represent the general case:

  i *may or may not be time varying*

- A lowercase letter followed with (t) to emphasize time:

  $i(t)$ *is a time-varying quantity*

- An uppercase letter if the quantity is not time varying; thus:

  I *is of constant value (dc quantity)*

- A letter printed in boldface to denote that:

  $\mathbf{I}$ *has a specific meaning, such as a vector, a matrix, the phasor counterpart of* $i(t)$, *or the Laplace or Fourier transform of* $i(t)$

Charge and Current

- A conductor is a material where chargers are free to move about. Even in “rest", the charge carriers are in rapid motion due to the thermal energy. Typical carriers include electrons, ions, and “holes" (in semiconductors).
- Current is charge in motion. When positive charges move in the positive direction, we say the current is positive. If negative charges move in the same direction, we say the current is negative. flux. In other words, the current flowing through a surface is defined as

$$I = \frac{\text{Net charge crossing surface in time } \Delta\text{t}}{\Delta t}$$

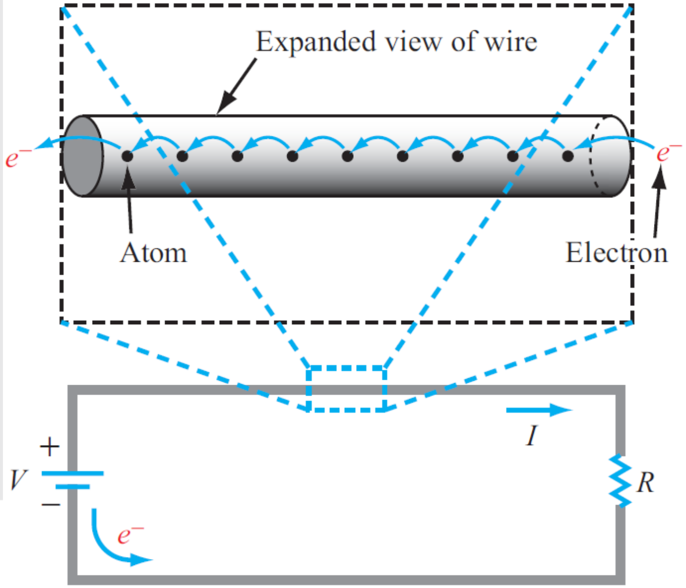
where Δt is a small time interval. The units of current are [I] = [C/s] = [A], or ampere (after André-Marie Ampère).

Charge & Current

- Unit of charge = coulomb

$$e = 1.6 \times 10^{-19} \qquad \text{(C)}$$

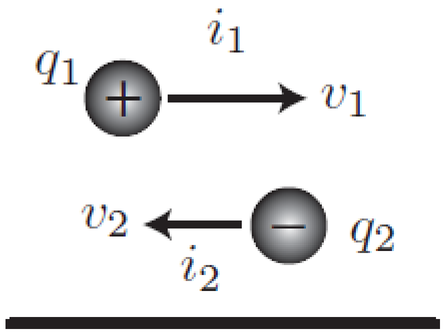
1. Charge can be either positive or negative.
2. The fundamental (smallest) quantity of charge is that of a single electron or proton. Its magnitude usually is denoted by the letter e.
3. According to the law of conservation of charge, the (net) charge in a closed region can neither be created nor destroyed.
4. Two like charges repel one another, whereas two charges of opposite polarity attract.



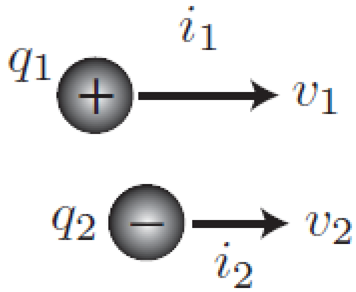
$$i = \frac{dq}{dt} \qquad \text{(A)},$$

Charge and Current

- When both positive and negative charge are moving, the net charge motion determines the overall current.

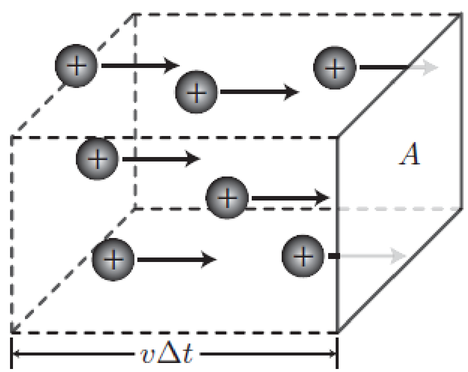


Net current is $i = i_1 + i_2$



Net current is $i = i_1 - |i_2|$

Counting Charge



- Suppose that the charge carriers each have a charge of q. Let's count the number of charges (c) crossing a surface in time Δt and multiply by the electrical charge

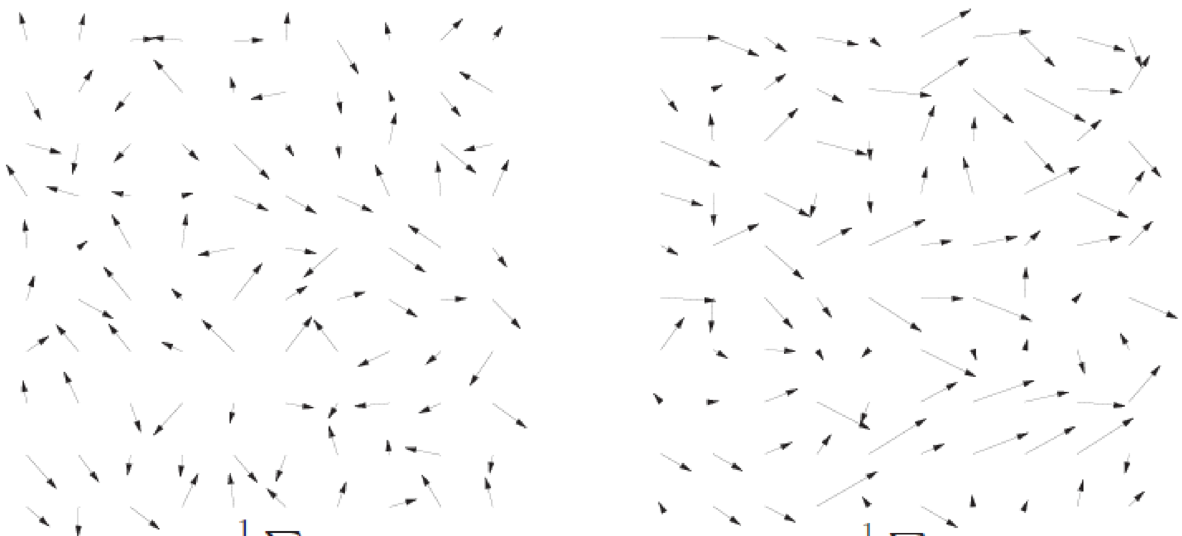
$$I = q\frac{c}{\Delta t}$$

- To find c, let's make the simple assumption that all the charges are moving at a speed of v to the right.
- Then the distance traversed by the charges in time Δt is simply $v\Delta t$, or in other words if we move back from the surface this distance, all the charges in the volume formed by the cross-sectional surface A and the distance $v\Delta t$ will cross the surface in time Δt. This means that

$$I = q\frac{v\Delta t N A}{\Delta t} = q(NA)v$$

where N is the density of electrons per unit volume.

Motion of Charge

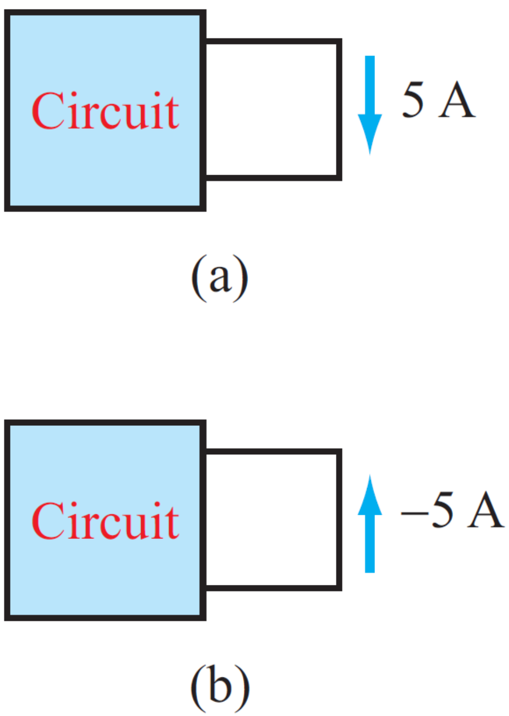


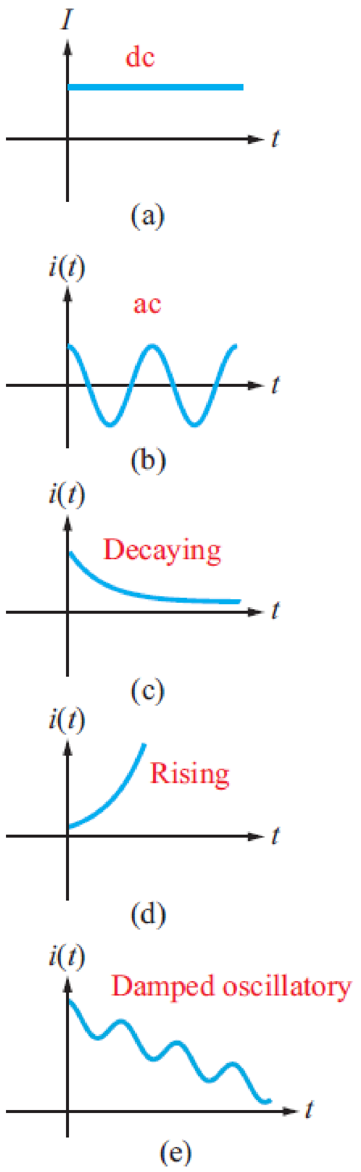
$$\bar{v} = \frac{1}{N}\sum_i \mathbf{v_i} = 0$$

$$\bar{v} = \frac{1}{N}\sum_i \mathbf{v_i} \approx \hat{\mathbf{x}} v_d$$

- The above result emphasizes that current is associated with motion. In our simple example, we assumed all carriers move at a velocity v. In reality, as you may know, electrons move very rapidly in random directions due to thermal motion $(mv^2 \sim kT)$ and v is the net *drift velocity*.

Time dependence of Current



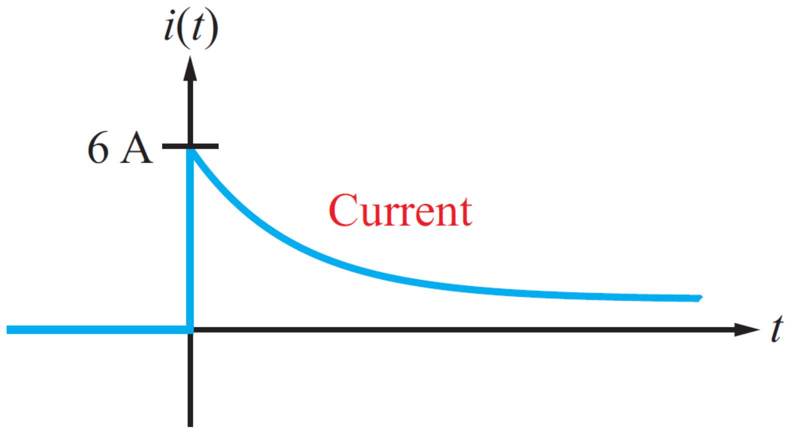


Example: Charge Transfer

- Given:

Solution

$$i(t) = \begin{cases} 0 & \text{for } t < 0, \\ 6e^{-0.2t} \text{ A} & \text{for } t \geq 0. \end{cases}$$



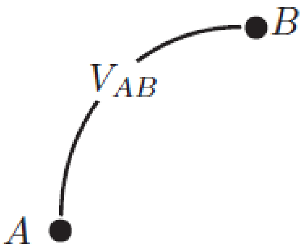
Determine: (a) $q(t)$

(b) $\Delta Q(1, 2)$

Example: Charge Transfer (cont.)

(b)

Voltage

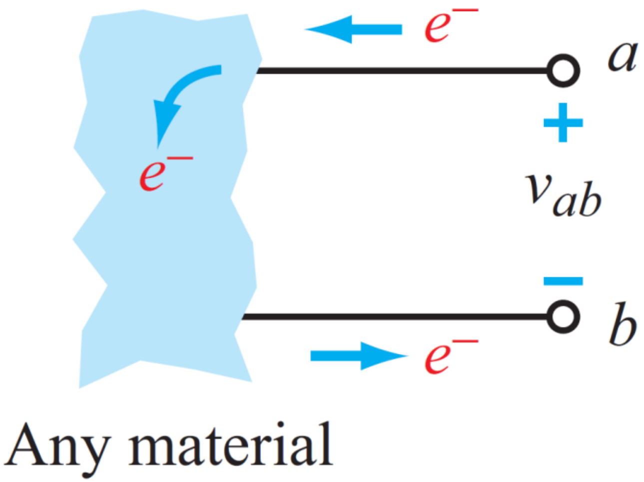


- The voltage difference V_{AB} between A and B is the amount of energy gained or lost per unit of charge in moving between two points.
- Voltage is a relative quantity. An absolute voltage is meaningless and usually is implicitly referenced to a known point in the circuit (ground) or in some cases a point at infinity.
- If a total charge of Δq is moved from $A \rightarrow B$, the energy required is

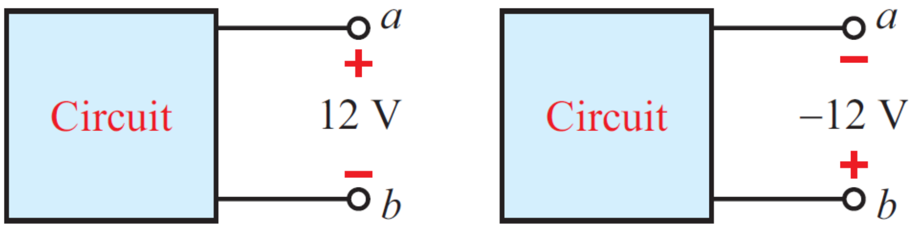
$$E = \Delta q V_{AB}$$

- If the energy is positive, then by definition energy is gained by the charges as they move “downhill". If the energy is negative, then energy is must be supplied externally to move the charges “uphill".
- The units of voltage are Volts (after the Italian physicist Alessandro Volta), or Joules/Coulomb.

Voltage



$$v_{ab} = \frac{dw}{dq}$$

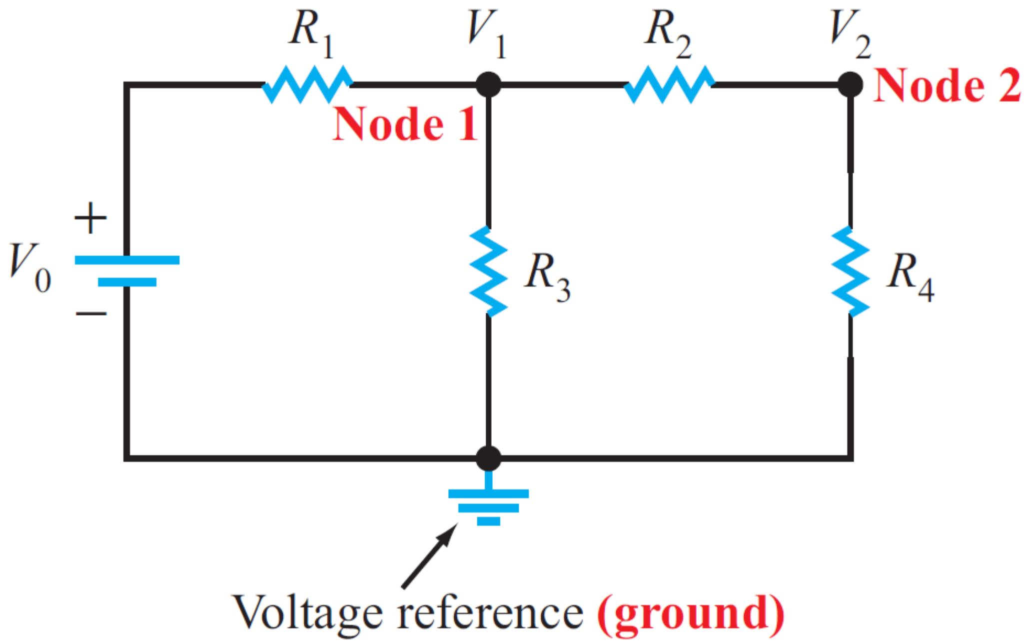


$$V_{ab} = -V_{ba}$$

The voltage between location ***a*** and location ***b*** is the ratio of ***dw*** to ***dq***, where ***dw*** is the energy in joules (J) required to move (positive) charge ***dq*** from ***b*** to ***a*** (or negative charge from a to b).

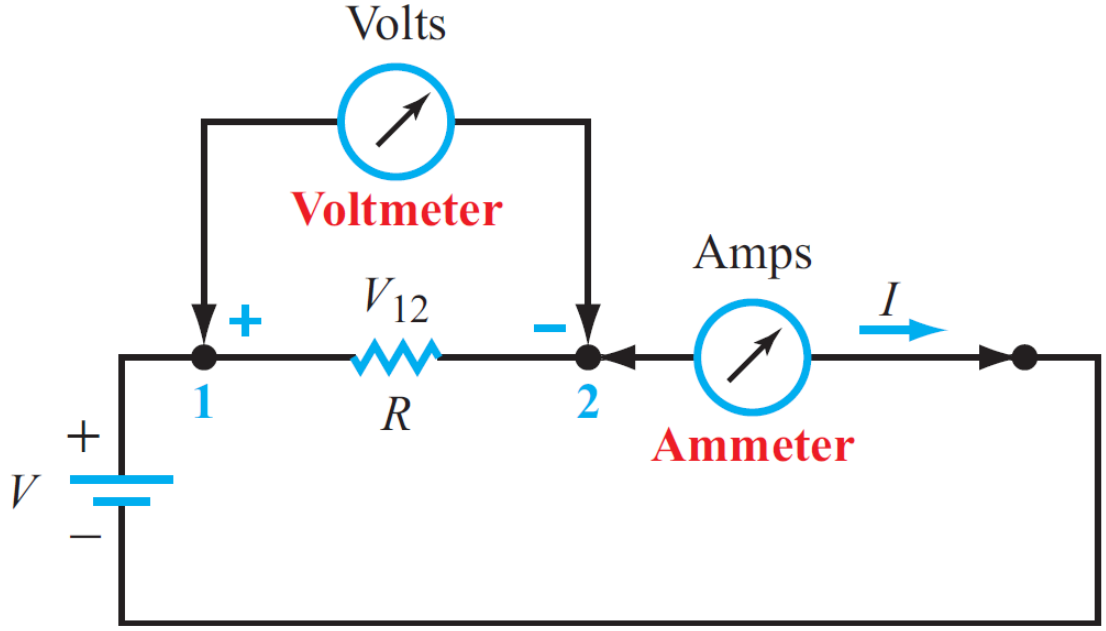
Reference/Ground

- Choose reference point for potential
- Assign potential at reference = 0, called ground
- Now all potentials are relative to ground terminal



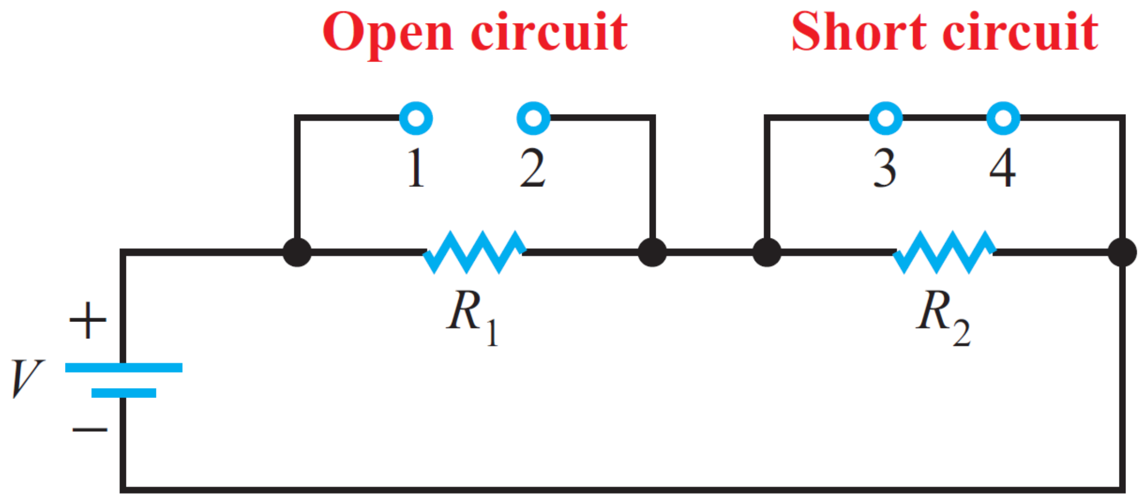
Measuring Voltage & Current

- Voltmeter: measures voltage without drawing current
- Ammeter: measures current without dropping voltage



Open Circuit & Short Circuit

- Open circuit: no path for current flow ($R = \infty$)
- Short circuit: no voltage drop ($R = 0$)



Power

Rate of expending or absorbing energy

$$P = \frac{dw}{dt} = \frac{dw}{dq}\frac{dq}{dt} = vi$$

$$\sum P = 0$$

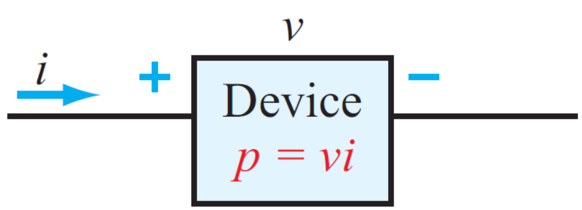
Energy conservation

Units: watts

One watt = power rate of one joule of work per second. 1 W = 1 A x 1 V

!!!!!Passive Sign Convention!!!!!

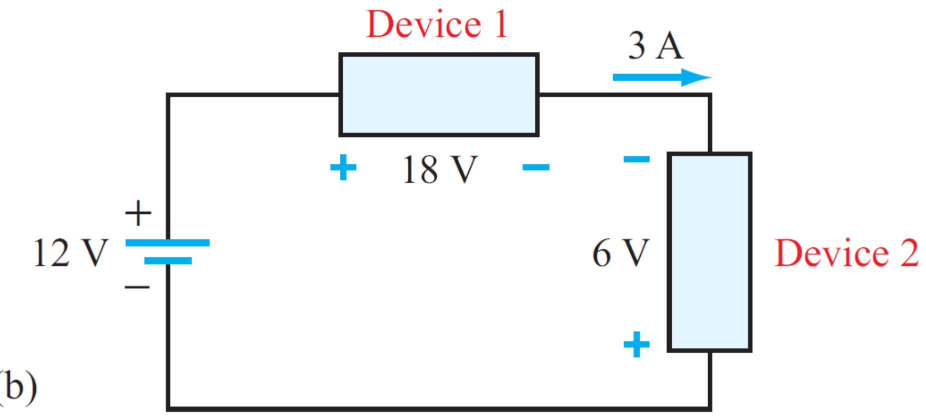
Passive Sign Convention



$p > 0$ power delivered to device

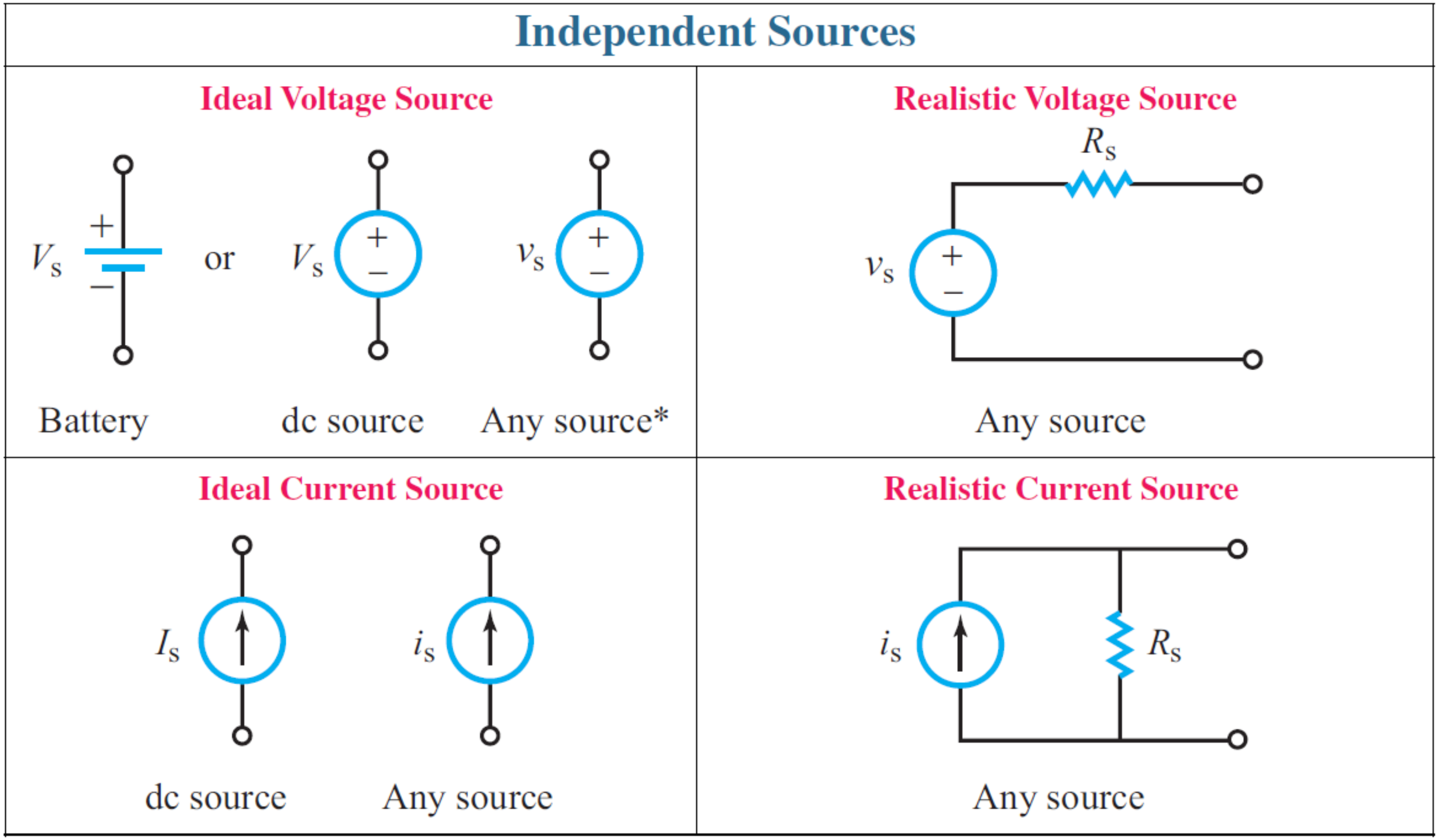
$p < 0$ power supplied by device

*Note that i direction is defined as entering (+) side of v.



(b)

Circuit Elements: Independent Sources



Example 1-4: Energy Consumption

- Given: Resistor consuming 20 W before switch turned off at t = 0.

  Also $v(t) = 100e^{-2t}$ V for $t \geq 0$

- Determine: Total energy consumed by resistor after t = 0.

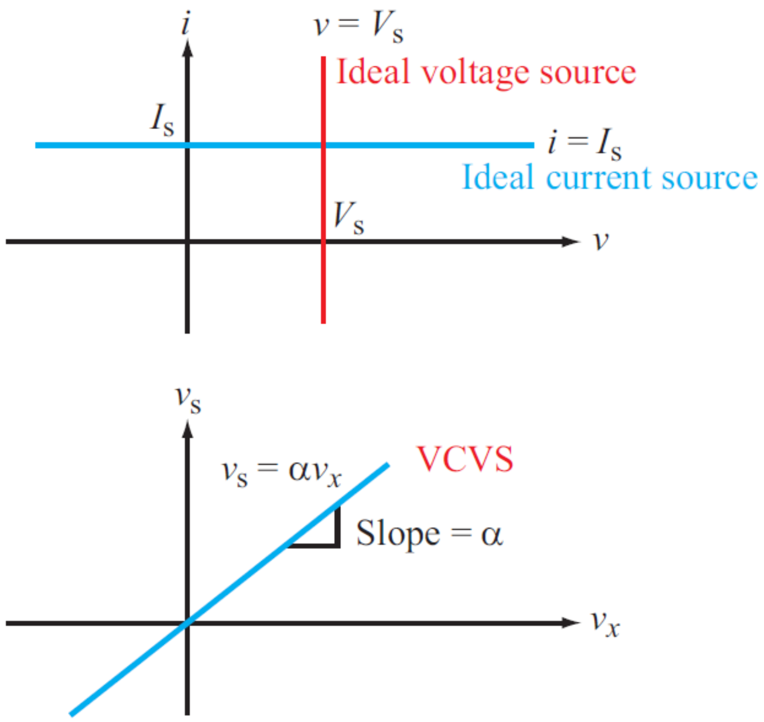
- Solution:

Circuit Elements: Dependent Sources

Dependent Sources	
Voltage-Controlled Voltage Source (VCVS)  $v_s = \alpha v_x$	**Voltage-Controlled Current Source (VCCS)**  $i_s = g v_x$
Current-Controlled Voltage Source (CCVS)  $v_s = r i_x$	**Current-Controlled Current Source (CCCS)**  $i_s = \beta i_x$
Note: α, g, r, and β are constants; v_x and i_x are a specific voltage and a specific current elsewhere in the circuit. *Lowercase v and i represent voltage and current sources that may or may not be time varying, whereas uppercase V and I denote dc sources.	

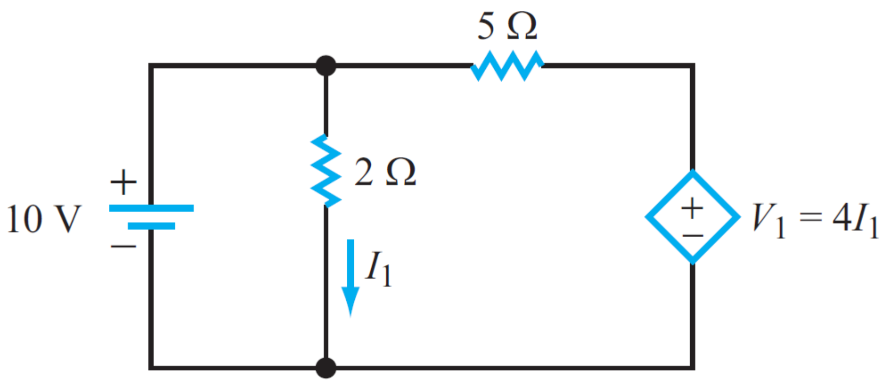
I-V for Sources

- Current/voltage fixed for independent sources
  - What does a non-ideal source look like?
- Dependent sources vary with reference voltage/current
  - What are units for slope?



Example: Dependent Source

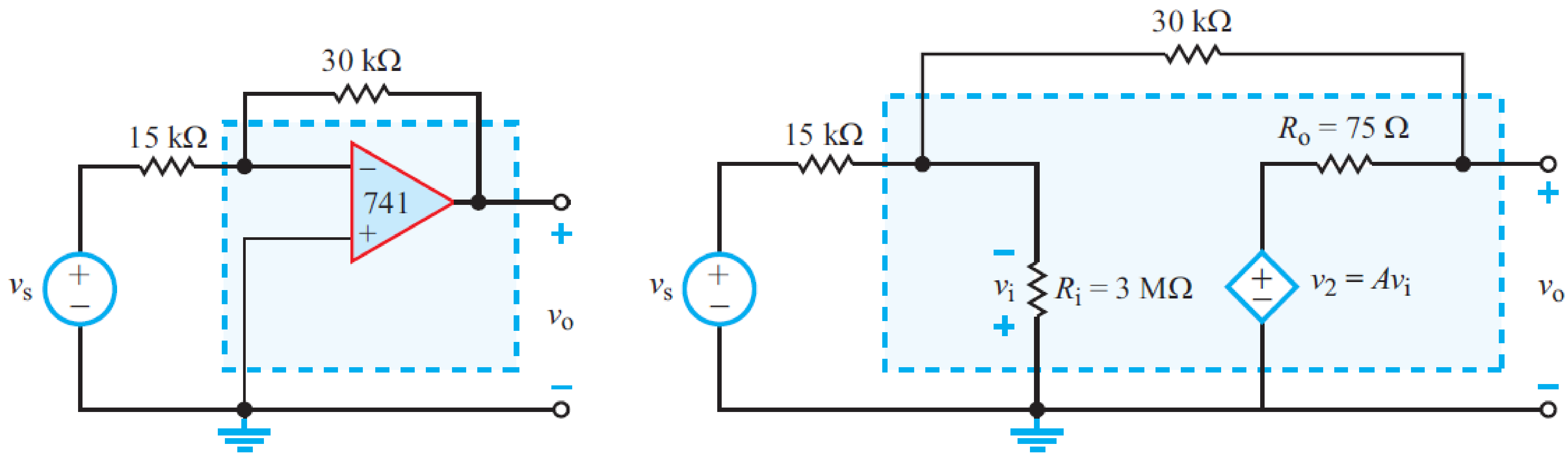
- Given:



Source is CCVS

Determine: V_1

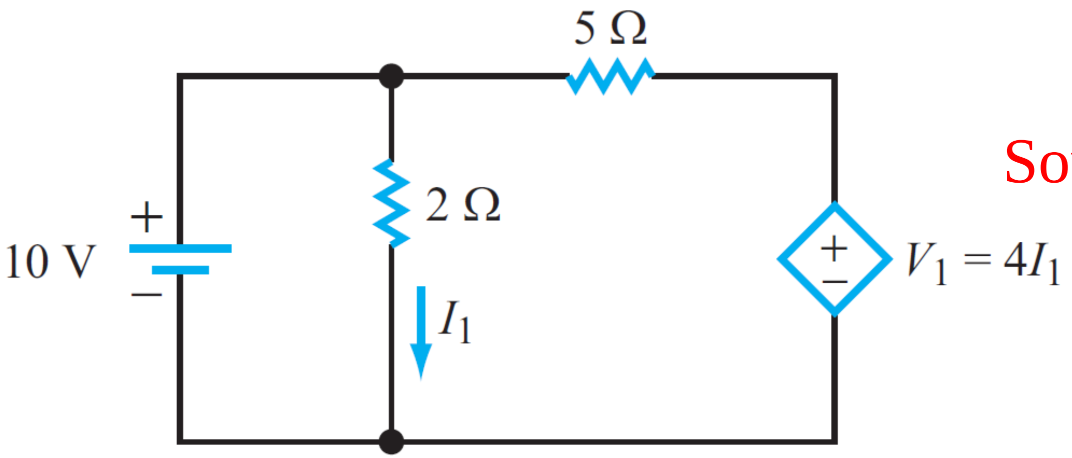
Equivalent Circuit Using Dependent Source



(a) Op-amp circuit (b) Equivalent circuit with dependent source

Example 1-5: Dependent Source

- Given:



Source is CCVS

Determine: V_1

Summary

Chapter 1 Relationships

Ohm's law $i = v/R$

Current $i = dq/dt$

Direction of i = direction of flow of (+) charge

Charge transfer $q(t) = \int_{-\infty}^{t} i\, dt$

$$\Delta Q = q(t_2) - q(t_1) = \int_{t_1}^{t_2} i\, dt$$

Voltage = potential energy difference

Passive sign convention Direction of i is into $+v$ terminal of device

Power $p = vi$

If $p > 0$ ➡ device absorbs power

If $p < 0$ ➡ device delivers power

i–v relationships

Resistor	$v_R = Ri_R$
Capacitor	$i_C = C\, dv_C/dt$
Inductor	$v_L = L\, di_L/dt$