Circuit Analysis and Design

Academic year 2019/2020 – Semester 1 – Presentation 1

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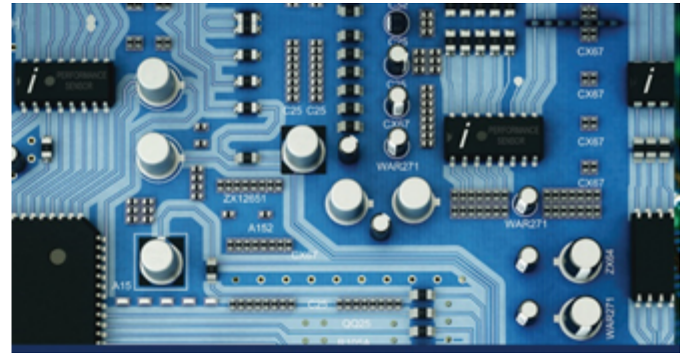
"A good student never steal or cheat"

Agenda



- Introduction
- Logistics
- Syllabus / policies
- What is this course all about and course outcomes?
- International System of Units (SI)
- Charge, voltage, current, and power
- Independent sources
- Summary

Acknowledgement: We would like to thank Cenange learning. These slides are modified version of Cenange learning. J. S Kang, Cengage Learning, 2016

Contact Info

3 Teachers:

Dr. Masood Ur-Rehman,

Dr. Qammer H. Abbasi,

Dr. Guodong Zhao



Office hours: Main building office A1-308 (lunch time, best to confirm with each individual teacher)

The course has 3 **lectures, 1 tutorial** and mandatory 1 **laboratory** per week (at Research Building B216) -> please refer to your own timetable (different for EEE and EEE+Comms programmes)

Course Material

Recommended textbooks:

- Robert Boylestad, Introductory Circuit analysis, 13th Edition, Pearson, 2015.
- James S Kang, Electric circuits, Cengage Learning, 2016.

- Neil Storey, Electronics a System Approach , 5th Edition, Pearson, 2013.
- Artilce M. Davis, Linear Circuit Analysis, Cengage Learning, 2013.
- J David Irwin, R Mark Nelms, (Basic) Engineering Circuit Analysis (10 ed), Wiley, 2011.
- A R Hambley, Electrical Engineering (6 ed), Prentice Hall, 2014.
- J Nilsson and S Riedel, Electric Circuits (10 ed), Pearson, 2014.
- R C Dorf and J A Svoboda, Introduction to Electric Circuits (9 ed), Wiley, 2014.
- Giorgio Rizzoni, Fundamentals of Electrical Engineering, McGraw-Hill, 2009.

-> However numerous books deal with electrical circuit theory, analysis and design, with similar coverage, and you can choose one with a style that you prefer.

This list has been provided by the colleague teaching the 'mirror' course in Glasgow
http://readinglists.glasgow.ac.uk/lists/83D94E61-49DE-0916-8244-8019129BE4D4.html

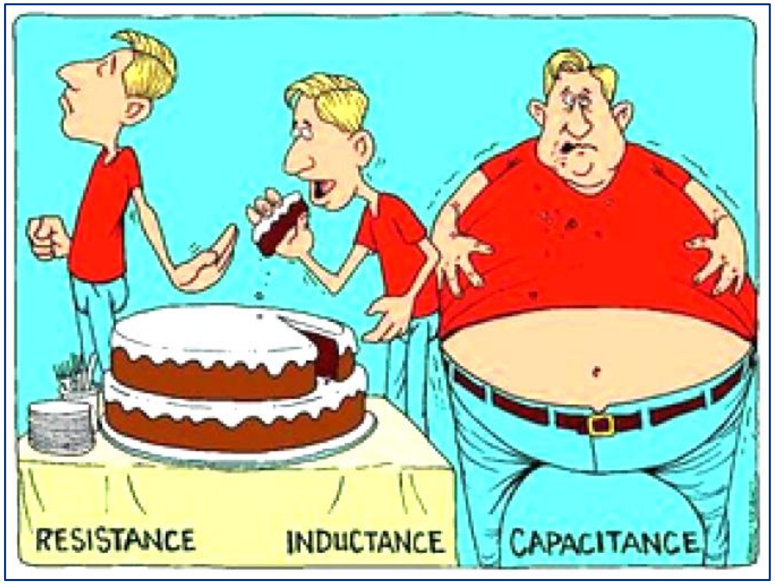
Additional material (lab scripts, lecture notes, exercises) provided in **Blackboard** (BB9) website

Course Description

*Provide a basic understanding of the **behaviour of electrical circuits** containing inductance, capacitance and resistance and the circuits response to DC, steady-state AC, and transient DC voltages and currents. Establish the concept of **impedance and frequency response** of a circuit. Present and design, through simulations and practical experiments, simple circuit systems such as **filters and operational amplifiers**.*

By the end of this course students will be able to:

- **define** the fundamental electrical properties of charge, current, voltage, power and their units;
- **apply** the fundamental laws of circuits analysis, including Ohm's law, Kirchhoff's laws for current and voltages, and Thévenin's and Norton's theorems, to circuits containing resistors, capacitors, inductors, and operational amplifiers;
- **employ** the concepts of phasors and impedances in the analysis of linear steady-state AC electrical circuits;
- **analyse** the behaviour at transients of 1^{st} order and 2^{nd} order DC electrical circuits;
- **design** and characterise passive and active filters; and
- **practice** and apply the concepts acquired in class to laboratory experiments involving the use of basic equipment such as multimeters, DC power supplies, digital oscilloscopes, and waveform generators



(Tentative) lectures Plan

Week	Lecture Topics	Laboratory Topics
1,2	Nomenclature and circuital representation, complex numbers and related math	Familiarise with lab and its equipment
3,6	Ohm’s and Kirchhoff’s laws, voltage dividers, series and parallel components	DC circuits with PSpice and Thevenin theorem
8,9	Mesh and nodal analysis, calculation of the bias point of a circuit, Equivalent circuits (Thevenin and Norton),	Transients and time constants
10,11	Review of part 1, transients (1st and 2nd order)	AC circuits and filters
12,13	Review of transients, AC circuit analysis (phasors and impedance), Application to filter analysis	Operational Amplifiers
14,15	concept of RMS values for power calculations, Operational amplifiers, final review pre-exam	Lab Report Work

Assessment and Requirements

Formative assessment (helping you check your progress and understanding)

- Exercises in class at lectures
- GTAs formative comments at the end of each laboratory session

Summative assessment (contributing to your final grade)

- 75% final written **examination**
- 25% **laboratory** activities
  - There are 6 laboratory sessions to attend (we would encourage you to read the lab script before attending the lab if possible)
  - An individual laboratory report on an open problem to be written and submitted on Moodle

Students **must attend** the timetabled classes, including the laboratory sessions. If you attend less than 75% you will be awarded a CW (Credit Withheld). This will prevent to progress in your degree until cleared.

Any student who misses an assessment or a significant number of classes because of illness or other good cause should **report** these to teaching office (counsellor) and adviser of study as soon as possible.

Let us start!

First of all some quick reference words…

The list in the next slide tries to provide the translation of a few words used in the course from English to Chinese characters… It is intended to be a reference for the students for quick checking.

Many thanks to Dr Keliang Zhou, whose slides provided the inspiration for this, and to Dr Bo Tan and Qingchao Chen for their help.

If you spot any mistake, please let me know ☺

行为 or 性能	behaviour
电感值	inductance value
电容值	capacitance value
电阻值	resistance value
瞬态响应	transient response
微分方程	differential equations
时域	time domain
频域	frequency domain
稳态响应	steady-state response
相量	phasor
阻抗	impedance
运算放大器 / 运算放大器	operational amplifier
开关	switch
电源	power supply/source
叠加原理	superposition principle
无源的	passive
有源的	active
耗能元件	dissipative element
储能元件	energy storage element
基氏电流定律	Kirchhoff current law
基氏电压定律	Kirchhoff voltage law
等效	equivalent
元件串并联 / 串并联元件	series and parallel components
戴维宁 定理	Thevenin’s theorem
诺顿 定理	Norton’s theorem

线性电路	linear circuit
电荷	electric charge
电势	potential -> voltage
连续性	continuity
n-阶常微分方程	N-order differential equation
单位阶跃函数	unit step function
特征方程	characteristic equation
过阻尼	over-damped
临界阻尼	critically damped
欠阻尼	under-damped
强迫响应 / 强制响应	forced response
自然响应	natural response
欧拉等式	Euler’s equation
导纳	admittance
电阻	resistance
电抗	reactance
电导	conductance
电纳	susceptance
倒数	reciprocal
分贝	decibel
共轭	conjugate

Introduction

- The seven base units of the International System of Units (SI) along with derived units relevant to electrical and computer engineering are presented.
- A voltage source with voltage V_s provides a constant potential difference to the circuit connected between the positive terminal and the negative terminal. If the voltage from the voltage source is constant with time, the voltage source is a direct current (dc) source. If the voltage from the voltage source is a sinusoid, the voltage source is an alternating current (ac) voltage source.
- A current source with current I_s provides a constant current of I_s amperes to the circuit connected to the two terminals. If the current from the current source is constant with time, the current source is a direct current (dc) source. If the current from the current source is a sinusoid, the current source is an alternating current (ac) current source.
- The voltage or current on the dependent sources depends solely on the controlling voltage or controlling current.
- Elementary signals that are useful throughout the text are introduced.

International System of Units (SI)

- The SI system is founded on seven base units for the seven quantities assumed to be mutually independent.
- The meter (m) is defined as the length of a path traveled by light in a vacuum during a time interval of 1/299,792,458 ($\approx 1/(3 \times 10^8)$) of a second.
- The kilogram (kg) is equal to the mass of the international prototype of the kilogram.
- The second (s) is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
- The ampere (A) is the constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newtons per meter of length.
- The kelvin (K) is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

International System of Units (Continued)

- The mole (mol) is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.
- The candela (cd) is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} Hertz and that has the radiant intensity in that direction of 1/683 watt per steradian.

SI Derived Units with Special Names and Units

Derived Quantity	Name	Symbol	Expression in terms of other SI units
Frequency	hertz	Hz	–
Energy	joule	J	N·m
Power	watt	W	J/s
Electric charge	coulomb	C	–
Electric potential difference	volt	V	W/A
Capacitance	farad	F	C/V
Electric resistance	ohm	Ω	V/A
Electric conductance	siemens	S	A/V
Magnetic flux	weber	Wb	V·s
Magnetic flux density	tesla	T	Wb/m^2
Inductance	henry	H	Wb/A

SI Prefixes

Prefix	Symbol	Magnitude	Example
pico	p	10^{-12}	1 pF = 10^{-12} F
nano	n	10^{-9}	1 nF = 10^{-9} F, 1 ns = 10^{-9} s
micro	μ	10^{-6}	1 μF = 10^{-6} F, 1 μs = 10^{-6} s
milli	m	10^{-3}	1 mA = 10^{-3} A, 1 mm = 10^{-3} m
centi	c	10^{-2}	1 cm = 0.01 m
deci	d	10^{-1}	1 dB = 0.1 Bel
deka	da	10	1 dam = 10 m, 1 daL = 10 L
hecto	h	10^{2}	1 hL = 100 L
kilo	k	10^{3}	1 kHz = 1000 Hz, 1 kΩ = 1000 Ω
mega	M	10^{6}	1 MHz = 10^{6} Hz
giga	G	10^{9}	1 GHz = 10^{9} Hz
tera	T	10^{12}	1 THz = 10^{12} Hz

From Electric Circuits by James S. Kang (Cenange Learning)

Electric Charge

- Atoms are the basic building blocks of matter. The nucleus of atoms consists of protons and neutrons. The electrons orbit around the nucleus. The protons are positively charged and the electrons are negatively charged. The neutrons are electrically neutral.
- The amount of **charge** on the proton is given by

  $e = 1.60217662 \times 10^{-19}$ C
- The amount of charge on the electron is given by

  $-e = -1.60217662 \times 10^{-19}$ C
- Notice that the charge is quantized as the integral multiple of e. Since there are equal number of protons and electrons per atom, the atoms are electrically neutral.
- When a plastic rod is rubbed by fur, some electrons from the fur are transferred to the plastic rod. Since the fur lost electrons, it is positively charged and the plastic rod is negatively charged. When the fur and the plastic rod are placed in proximity, they attract each other. Opposite charges attract and like charges repel.

Coulomb's Law

- According to Coulomb's law, the magnitude of force between two charged bodies is proportional to the charges Q and q and inversely proportional to the distance squared:

$$F = \frac{1}{4\pi\varepsilon}\frac{Qq}{r^2}$$

where ε is permittivity of the medium. The permittivity of free space, ε_0, is given by

$$\varepsilon_0 = \frac{1}{4\pi c^2 10^{-7}}\left(F/m\right) = 8.8541878176\times10^{-12}\left(F/m\right)$$

where c is the speed of light in the vacuum, given by c = 299,792,458 m/s ≈ 3 x 10^8 m/s.

- The unit for the permittivity is farads per meter (F/m). The direction of the force coincides with the line connecting the two bodies. If the charges are of the same polarity, the two bodies repel each other. On the other hand, if the charges are of the opposite polarity, they attract each other.

Electric Field and Voltage

- The presence of the point charge creates a field around it where charged particles experience force. This field is called an **electric field**.
- If an object with charge q is placed in the presence of electric field E, the object will experience a force

  F = qE
- For a positive point charge Q, E is as below (where ar indicates the direction of the field)

$$\boldsymbol{E} = \frac{1}{4\pi\varepsilon}\frac{Q}{r^2}\boldsymbol{a}_r$$

- We then define **voltage** the work to do per unit of charge in order to move this from one point to another in the presence of an electric field. This is measured in Volt -> 1 V = 1 Joule / 1 Coulomb

$$v = \frac{dw}{dq}$$

Current

- In the absence of electric field, the free electrons in the conduction band of conductors such as copper wire make random movements. When an electric field is applied along the copper wire, the negatively charged electrons will move toward the direction of higher potential.
- The **current** is defined as the flow of charge through a cross-sectional area as a function of time, or the time rate of change of the charge. The formula is given below. The unit for the current is coulombs per second or amperes (A).
- If the amount of charge crossing the area changes with time, the current is defined as

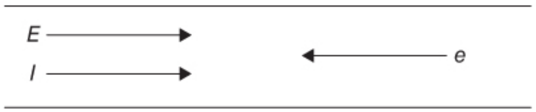
$$i(t) = \frac{dq(t)}{dt}$$

- The direction of current is defined as the direction of positive charges. Figure 1.2 shows the direction of the electric field, current, and electron inside a conductor.
- The charge transferred between time t_1 and t_2 can be obtained by integrating the current from t_1 and t_2, that is,

$$q = \int_{t_1}^{t_2} i(\lambda)\, d\lambda$$

FIGURE 1.2

The directions of E, I, and e.



EXAMPLE 1.1 and EXAMPLE 1.2

- The charge flowing into a circuit element for t ≥ 0 is given by

  $$q(t) = 2\times10^{-3}\left(1-e^{-1000t}\right)\ coulomb$$

  Find the current flowing into the element for t ≥ 0.

  $$i(t) = \frac{dq(t)}{dt} = 2\times10^{-3}\times1000e^{-1000t}\ \mathrm{A} = 2e^{-1000t}\ \mathrm{A}\ \ \text{for t} \geq 0$$

- EXAMPLE 1.2 The current flowing into a circuit element is given by i(t) = 5 sin(2π10t) mA for t ≥ 0. Find the charge flowing into the device for t ≥ 0. Also find the total charge entered into the device at t = 0.05 s.

$$q(t) = \int_0^t i(\lambda)\,d\lambda = \frac{5\times10^{-3}}{2\pi10}\left[1-\cos(2\pi10t)\right] = 7.9577\times10^{-5}\left[1-\cos(2\pi10t)\right]$$

- At t = 0.05 s, we have

  $$q(0.05) = 1.5915\times10^{-4}\left[1-\cos(2\pi10\times0.05)\right] = 1.5915\times10^{-4}\ \mathrm{C}$$

Power

- Power is the change in energy as a function of time, defined as below.

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

- If the voltage and the current are time-varying, the power is also time-varying. Thus, we have p(t) instantaneous power:

$$p(t) = i(t)v(t)$$

- Energy is the capacity to do work, so the integration of power over time

$$w = \int_{t_1}^{t_2} p\,dt = \int_{t_1}^{t_2} v\,i\,dt$$

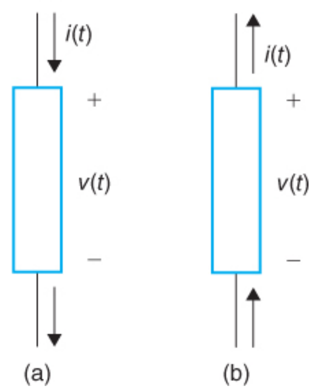
- Units for energy are kWatt/hour, which is what the electric company measures on your electric meter to send you a bill (1kW/h = 3.6 MJ).

Passive Sign Convention

- In the passive sign convention, if the direction of current is from the positive terminal of a device, through the device, to the negative terminal of the device as shown in Figure 1.3(a), the power is positive. The device absorbs/consumes/dissipates power.
- On the other hand, if the current leaves the positive terminal of a device, flows through the rest of the circuit, and enters the negative terminal of the device as shown in Figure 1.3(b), the power is negative. The device releases/generates power.

FIGURE 1.3

(a) Power is positive.
(b) Power is negative.



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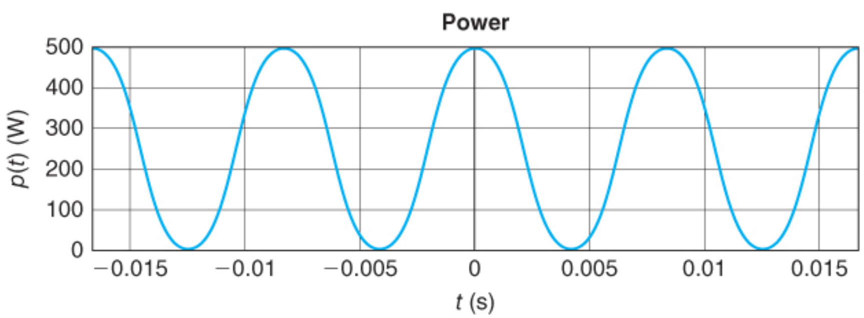
EXAMPLE 1.3

- Let the voltage across an element be $v(t) = 100 \cos(2\pi 60t)$ V and the current though the element from positive terminal to negative terminal be $i(t) = 5 \cos(2\pi 60t)$ A for $t \geq 0$. Find the instantaneous power $p(t)$ and plot $p(t)$.

- $p(t) = i(t)v(t) = 5 \cos(2\pi 60t) \times 100 \cos(2\pi 60t) = 500 \cos^2(2\pi 60t) = 250 + 250 \cos(2\pi \times 120t)$ W.
- The instantaneous power $p(t)$ is shown in Figure 1.4. Since $p(t) \geq 0$ for all t, the element is not releasing power any time. One the average, the element absorbs 250 W of power.

FIGURE 1.4

Plot of $p(t)$.



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Independent Sources

- A voltage source with voltage V_s provides a constant potential difference to the circuit connected between the positive terminal and the negative terminal. The circuit notations for voltage source are shown in Figure 1.6.
- If a positive charge Δq is moved from the negative terminal to the positive terminal through the voltage source, the potential energy of the charge is increased by $\Delta q V_s$.
- If a negative charge with magnitude Δq is moved from the positive terminal to the negative terminal through the voltage source, the potential energy of the charge is increased by $\Delta q V_s$.
- A current source with current I_s provides a constant current of I_s amperes to the circuit connected to the two terminals. The circuit notation for current source is shown in Figure 1.7.

FIGURE 1.6

Circuit symbols for voltage sources.

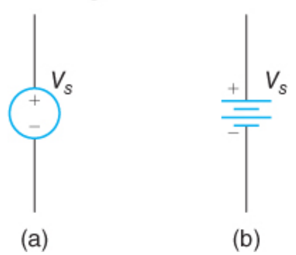
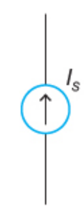


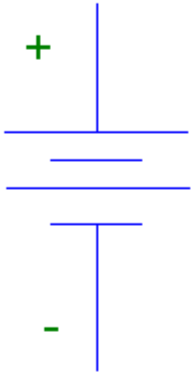
FIGURE 1.7

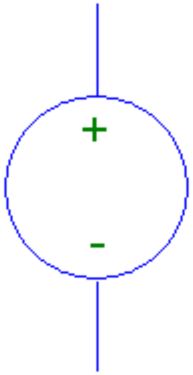
A circuit symbol for the current source.



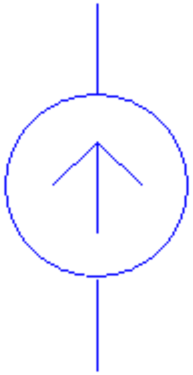
Independent Power Sources

- Independent voltage source outputs a voltage, either dc or time varying, to the circuit no matter how much current is required.





- Independent current source outputs a dc or ac current to the circuit no matter how much voltage is required.



DC Sources and AC Sources

- If the voltage from the voltage source is constant with time, the voltage source is called the direct current (dc) voltage source. Likewise, if the current from the current source is constant with time, the current source is called the direct current (dc) current source.
- If the voltage from the voltage source is a sinusoid as shown in Figure 1.8, the voltage source is called alternating current (ac) voltage source. Likewise, if the current from the current source is a sinusoid, the current source is called alternating current (ac) current source.
- A circuit notation for ac voltage source and ac current source are shown in Figure 1.9.

FIGURE 1.8

Plot of a cosine wave with period T, amplitude V_m, and phase zero.

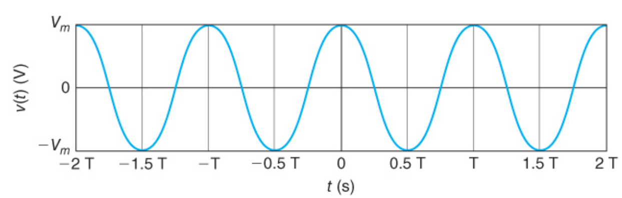
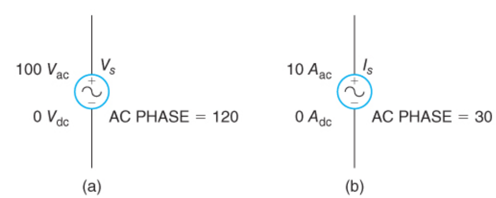


FIGURE 1.9

Circuit symbols for (a) ac voltage source; (b) ac current source.



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Equivalent Voltage Source and Equivalent Current Source

- When dc voltage sources are connected **in series**, they can be combined into single equivalent dc voltage source as shown in Figure 1.10.
- $V_3 = V_1 + V_2 = 4.5\ V + 7.5\ V = 12\ V$
- When dc current sources are connected **in parallel**, they can be combined into single equivalent dc current source as shown in Figure 1.11.
- $I_3 = I_1 + I_2 = 3\ A + 5\ A = 8\ A$

FIGURE 1.10

An equivalent voltage source.

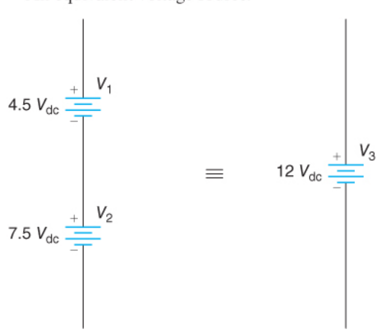
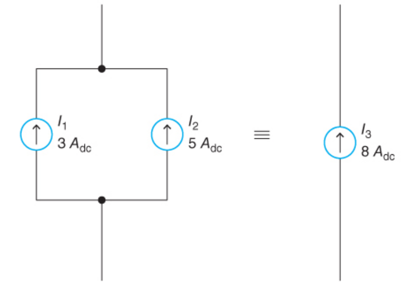


FIGURE 1.11

An equivalent current source.

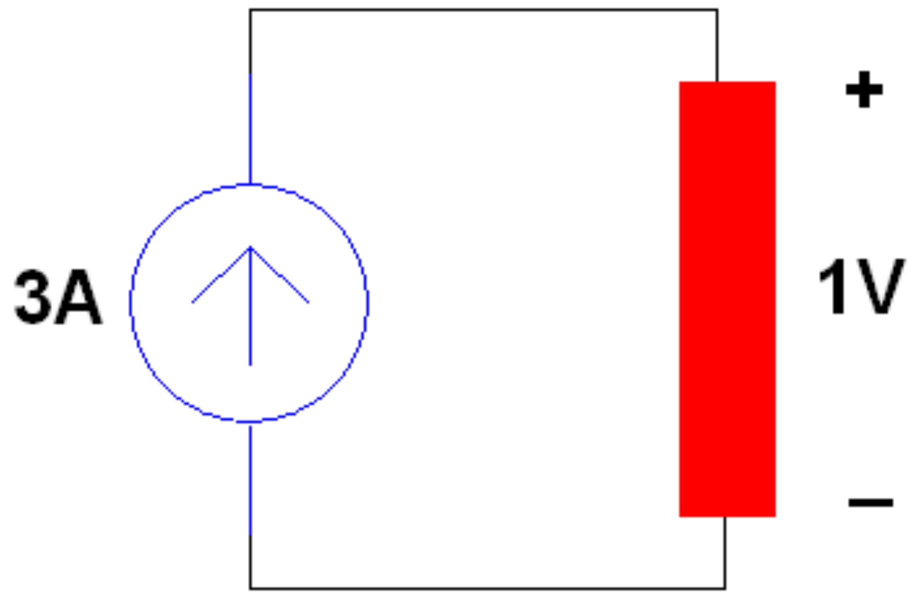


Remember that:

- Current can flow in and out of an independent voltage source, but the polarity of the voltage is determined by the voltage source.

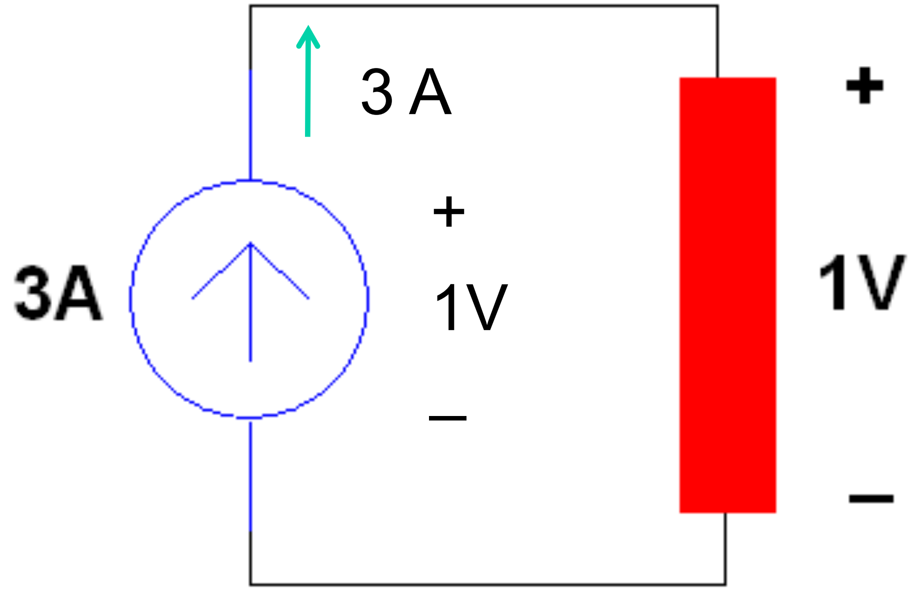
- There is always a voltage drop across the independent current source and the direction of positive current is determined by the current source.

Example 1



1V is dropped across some element (in red) and the wires to that element are connected directly to the independent current source.

Example 1

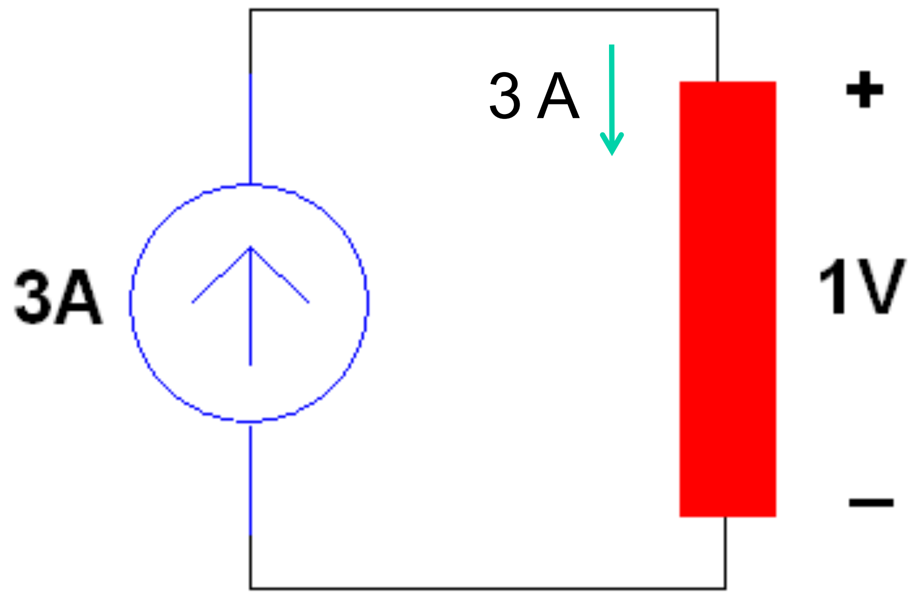


This means that 1V is also dropped across the independent current source. Therefore, the current source is generated 1 V(3 A) = 3 W of power.

Passive sign convention: When current leaves the + side of a voltage drop across the independent current source, the power associated with the current source is:

$$p = -3\text{ A}(1\text{ V}) = -3\text{ W}$$

Example 1



Conservation of energy means that the other element in red must be dissipating 3 W of power.

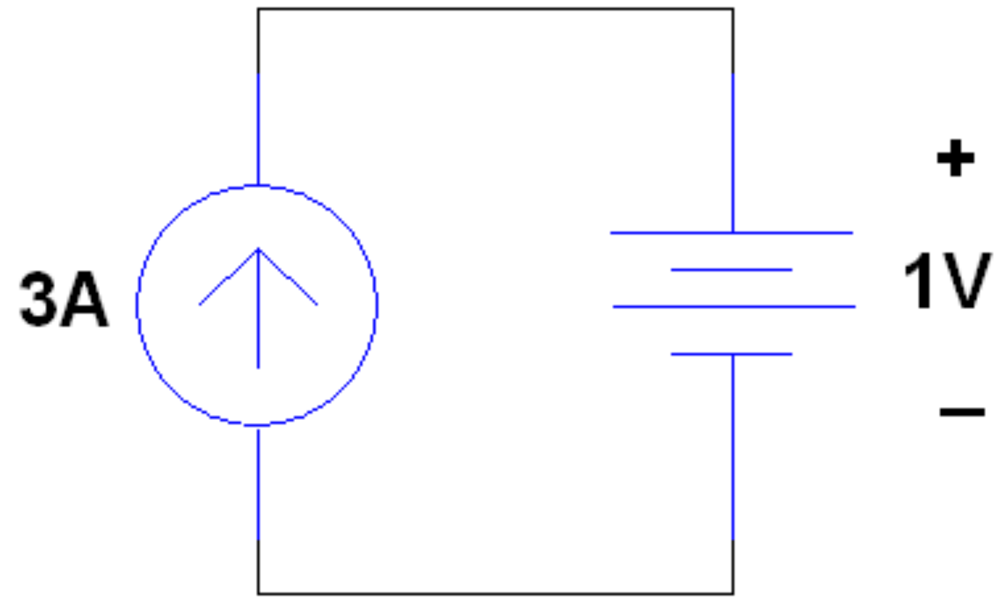
$$\sum p = p_{current\ source} + p_{red\ \mathrm{element}} = 0$$

$$p_{current\ source} = -3\ \mathrm{W;\ therefore,}\ p_{red\ \mathrm{element}} = 3\ \mathrm{W}$$

Passive sign convention: When current enters the + side of a voltage drop across the element in red, the power associated with this element is:

$$p = 3\ \mathrm{A}(1\ \mathrm{V}) = 3\ \mathrm{W}$$

Example 1



Suppose the red element was an independent voltage source. This means is that the independent current source happens to be supplying power to the independent voltage source, which is dissipating power. This happens when you are charging a battery, which is considered to be an independent voltage source.

Passive Elements

- The magnitude of the voltage drop and current flowing through passive devices depends on the voltage and current sources that are present and/or recently attached to the circuit.
  - These components can dissipate power immediately or store power temporarily and later release the stored power back into the circuit.

Passive Components

Component	Symbol	Basic Measure (Unit)
Resistor		Ohm (Ω)
Inductor		Henry (H)
Capacitor		Farad (F)

Summary

- Course contents
- Grading policy
- Course is all about and its outcome
- Introduction
- Si Units
- Voltage, current, electric field, power
- Sources
- Passive elements
- What will we study in next lecture.