Circuit Theory

Asst. Prof. Görkem SERBES

Introduction

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Course Details

- Course Code : BLM1612
- Course Name: Circuit Theory
  (Devre Teorisi)
- Instructor : Görkem SERBES

Assesement

Method	Quantity	(%)
Problem Solving	5	5
Laboratory	5+1	20
Midterm Exam(s)	2	40
Final Exam	1	35

Course Outline

1. Introduction.

Lumped circuit elements, Levels of abstraction, What are the circuits?, Course objectives.

2. Basic Concepts.

Units, Charge, Current, Voltage, Power, Conservation of Energy, Circuit Elements, Networks vs. Circuits, Ohm's Law, .

3. Voltage and Current Laws.

Circuit Terminology, Kirchhoff's Current Law, Kirchhoff's Voltage Law, The Single-Loop Circuit, Conservation of Energy, The Single-Node-Pair Circuit, Series Circuits, Parallel Circuits, Voltage Division, Current Division.

4. Nodal and Mesh Analysis.

Nodal (or "Node-Voltage") Analysis, Nodal Analysis with Supernodes, Mesh (Current) Analysis, Mesh Analysis with Supermeshes, Equivalent Practical Sources.

5. Linearity & Superposition.

Linearity, Superposition, Superposition: Voltage Sources, Superposition: Current Sources, Practical Voltage Sources, Practical Current Sources.

6. Thevenin & Norton Equivalents.

Thevenin Equivalent, Power from a Practical Source, Maximum Power Transfer .

7. The Operational Amplifier.

The Operational Amplifier, Inverting Amplifier, Noninverting Amplifier, Voltage Follower, Summing Amplifier, Difference Amplifier, Op-Amp Cascades, Op-Amp Parameters, Common Mode Rejection, Saturation, An instrumentation amplifier.

Course Outline

8. Capacitors and Inductors.

Capacitance, Capacitor Current & Voltage, Capacitor Characteristics, Inductance, Inductor Current & Voltage, Inductor Characteristics, Inductor Energy Storage, DC Capacitor Circuits, DC Inductor Circuits.

9. Basic RL and RC Circuits.

The Source-Free RL Circuit, The Source-Free RC Circuit, Unit-Step Definition, Driven RL Circuit, Driven RC Circuit.

10. RLC Circuits.

Parallel RLC Circuit, Series RLC Circuit, RLC Solution: Over-damped, RLC Solution: Critically Damped, RLC Solution: Under-damped, The Complete Response Of The RLC Circuit.

11. AC Analysis.

Complex numbers, phasors, impedance, admittance, Sinusoidal steady-state; Ohm's Law, KVL, KCL for AC circuits, Sinusoidal steady-state: Thevenin, superposition, examples.

12. The Frequency Response.

Frequency response: transfer function, logarithms, Bode plots.

Frequency response: resonance, passive & active filter design

13. Laplace Transform.

Laplace: introduction to transforms, inverse transform.

Laplace: theorems, solving differential equations

14. s-Domain analysis

s-Domain analysis: transfer functions, poles, zeroes.

s-Domain analysis: nodal, mesh, additional techniques

COURSE OBJECTIVE

- Students will be able to:
  - Analyze wide range of pure resistive DC circuits using the different techniques covered through-out the course.
  - Gains hands-on experience in DC circuit problem solving tricks and shortcuts.
  - Utilize the Thevenin theorem as a core tool in circuit analysis.
  - Analyze RL, RC, and RLC circuits with the proper tools.
  - Carry power consumption calculation for different components in a DC circuit.
  - Design, simulate, and implement Basic DC circuits.

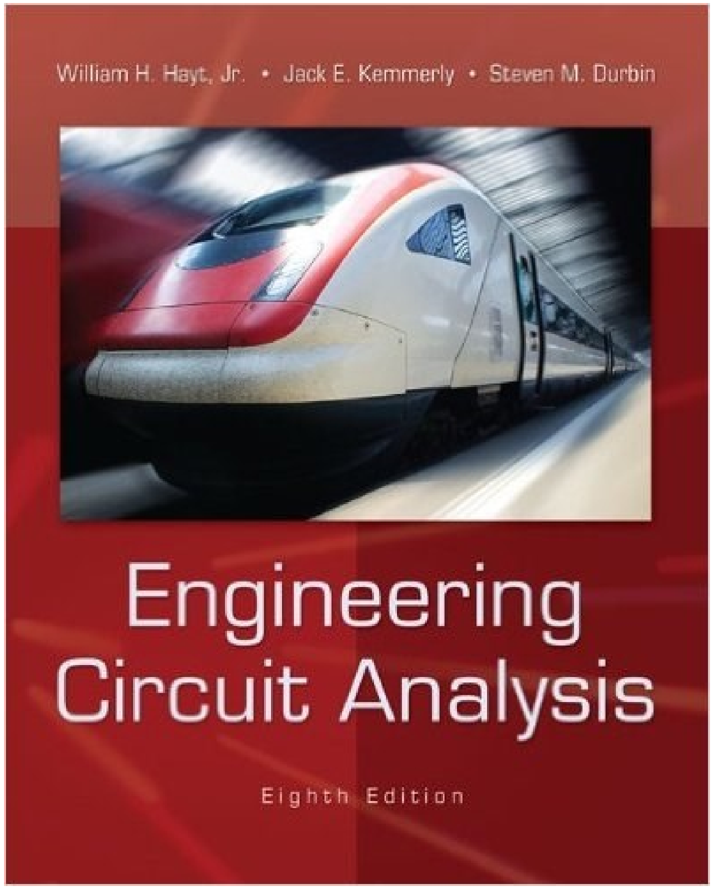
Main course book

Engineering Circuit Analysis

by William Hayt, Jack Kemmerly, Steven Durbin.

Published by McGraw-Hill.

Isbn: 0073529575



Rules of the Conduct

- No eating /drinking in class
  - *except water*
- Cell phones must be kept outside of class or switched-off during class
  - *If your cell-phone rings during class or you use it in any way, you will be asked to leave and counted as unexcused absent.*
- No web surfing and/or unrelated use of computers,
  - when computers are used in class or lab.

Rules of the Conduct

- You are responsible for checking the class web page often for announcements.
- Academic dishonesty and cheating will not be tolerated and will be dealt with according to university rules and regulations
  - *Presenting any work, or a portion thereof, that does not belong to you is considered academic dishonesty.*
- University rules and regulations:
  - http://www.ogi.yildiz.edu.tr/category.php?id=17
  - https://www.yok.gov.tr/content/view/544/230/lang,tr_TR/

Attendance Policy

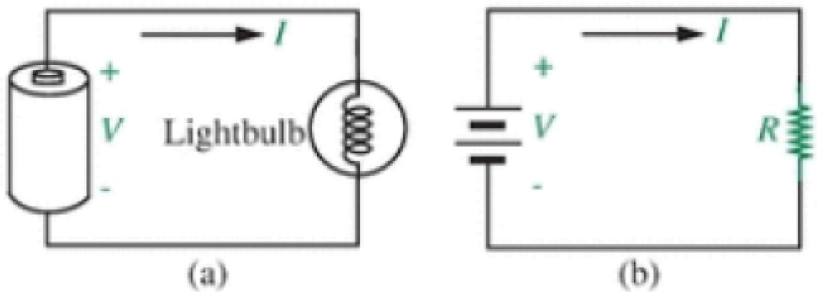
- The requirement for attendance is **70%**.
  - *Hospital reports are not accepted to fulfill the requirement for attendance.*
  - *The students, who fail to fulfill the attendance requirement, will be excluded from the final exams and the grade of* F0 *will be given*.

Abstraction

- We have electromagnetic phenomena and this data can be expressed by using Maxwell's equations. (Scientific part)
- Electrical engineers create a new abstraction layer on top of Maxwell's equations called the lumped circuit abstraction.
- By using this lumped circuit abstraction electrical and computer systems can be designed.

Lumped circuit element

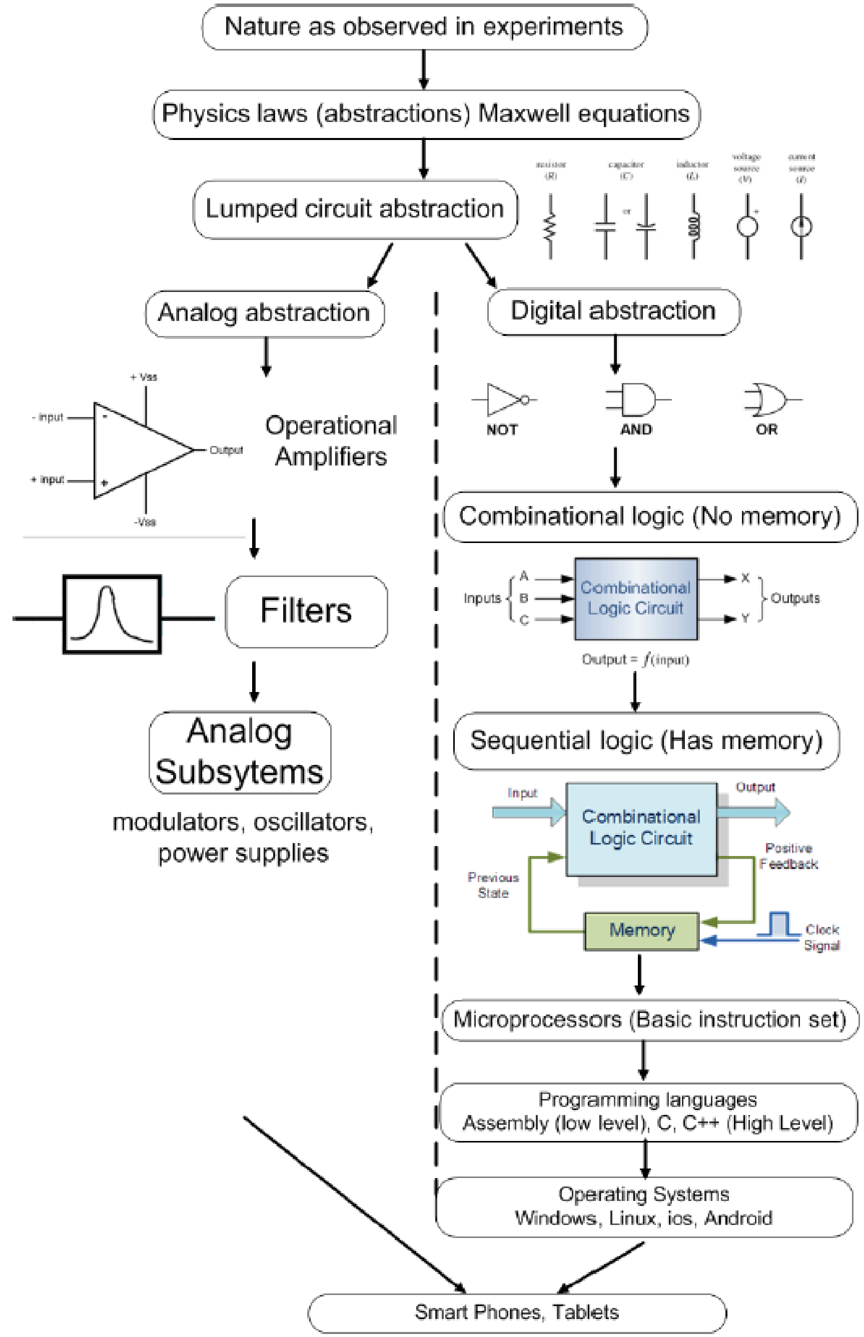
- A lumped circuit element is often used as an abstract representation or a model of a piece of material with complicated behaviour.



a) A simple light bulb circuit b) The lumped circuit represantation

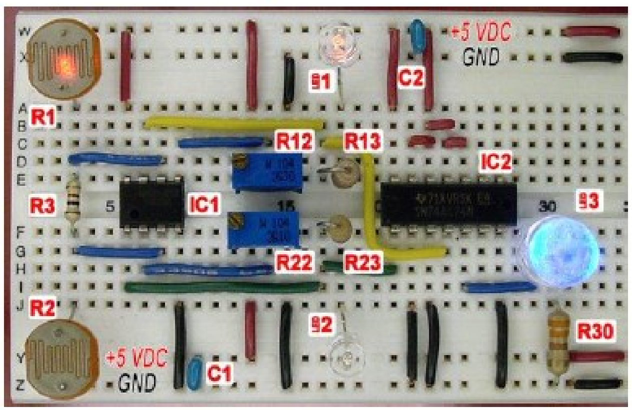
- *R* is a lumped element abstraction for the bulb.
- A lumped element is described by its *v-i* (voltage - current) relation.

Levels of abstraction

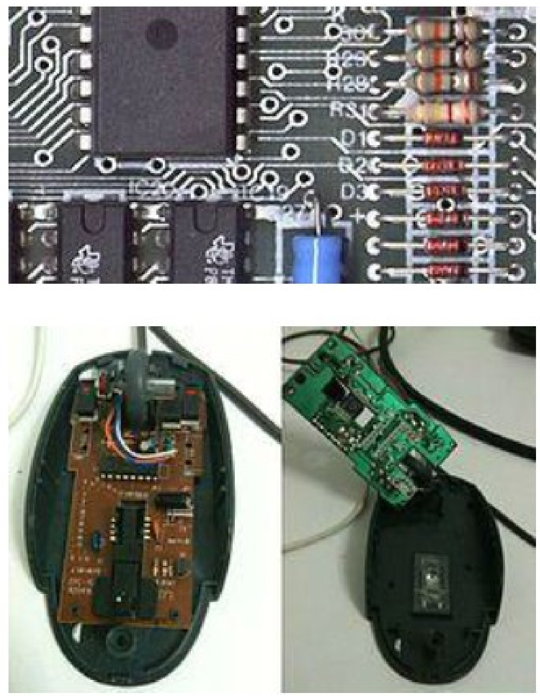


What are the circuits?

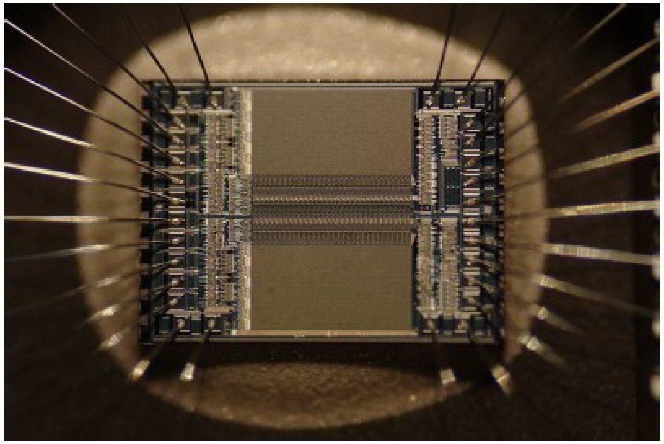
- A *circuit* consists of electrical or electronic components interconnected with metal wires.
- Every electrical or electronic device is a circuit.



Breadboard



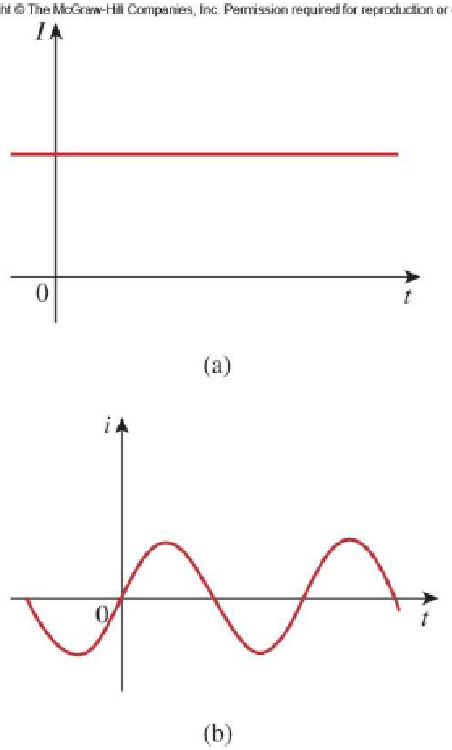
Printed Circuit Boards (PCBs)



Integrated Circuits (ICS)

Course objectives

- (1) to understand the electromagnetic concepts of charge, voltage, current, power, and energy



a) DC, b) AC

	Alternating Current (AC)	Direct Current (DC)
Amount of energy that can be carried	Safe to transfer over longer city distances	Voltage of DC cannot travel very far until it begins to lose energy
Frequency	The frequency of alternating current is 50Hz or 60Hz	The frequency of direct current is zero
Direction	It reverses its direction while flowing in a circuit	It flows in one direction in the circuit
Obtained from	A.C Generator	Cell or Battery
Magnitude	Magnitude varying with time	Constant magnitude

Course objectives

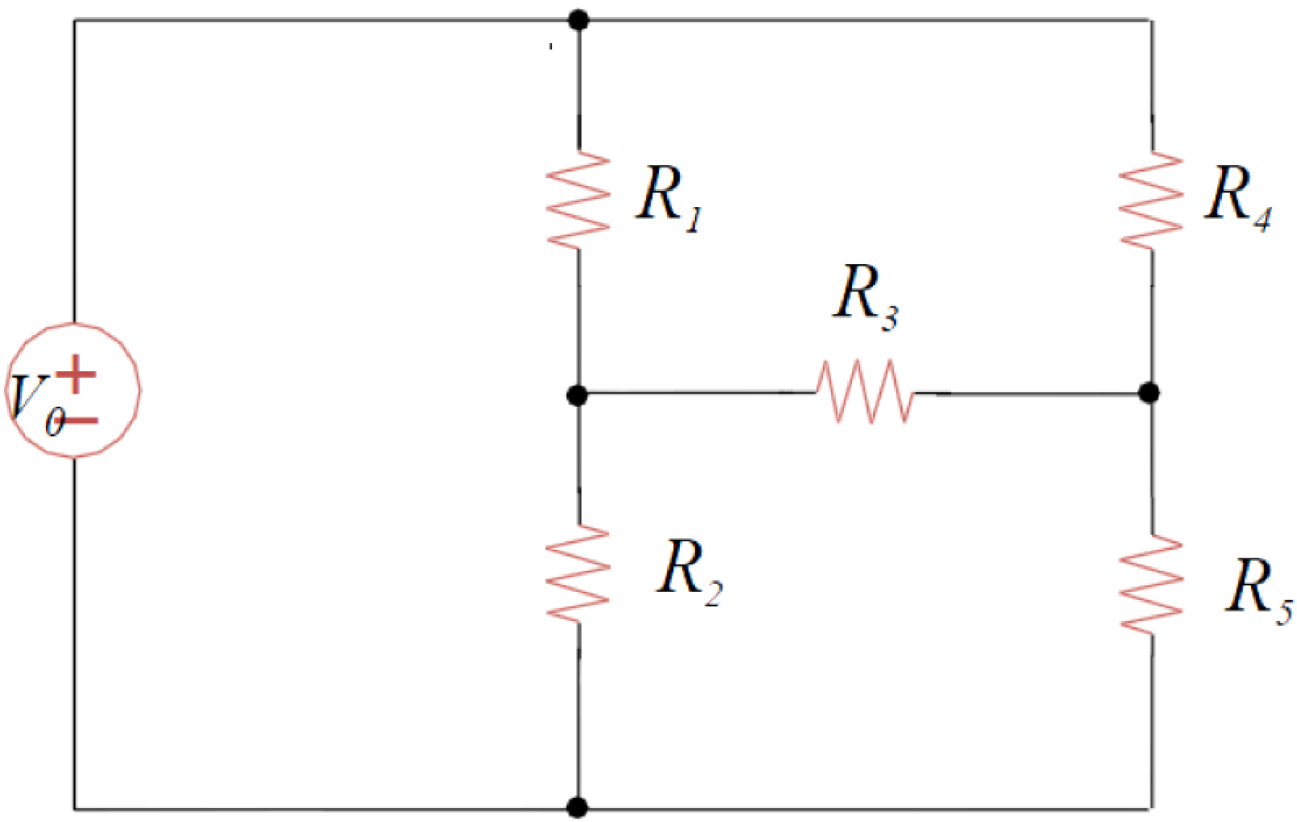
- (2) to understand the function of linear circuit elements (e.g. resistors, inductors, capacitors, voltage sources, current sources, operational amplifiers)

  - a linear circuit is an electric circuit in which circuit parameters (Resistance, inductance, capacitance) are constant.

  - a nonlinear circuit is an electric circuit whose parameters are changing with respect to current and voltage (diodes, transistors)

Course objectives

- (3) to understand and apply circuit theory (e.g. Ohm's Law, Kirchoff's Voltage & Current Laws)

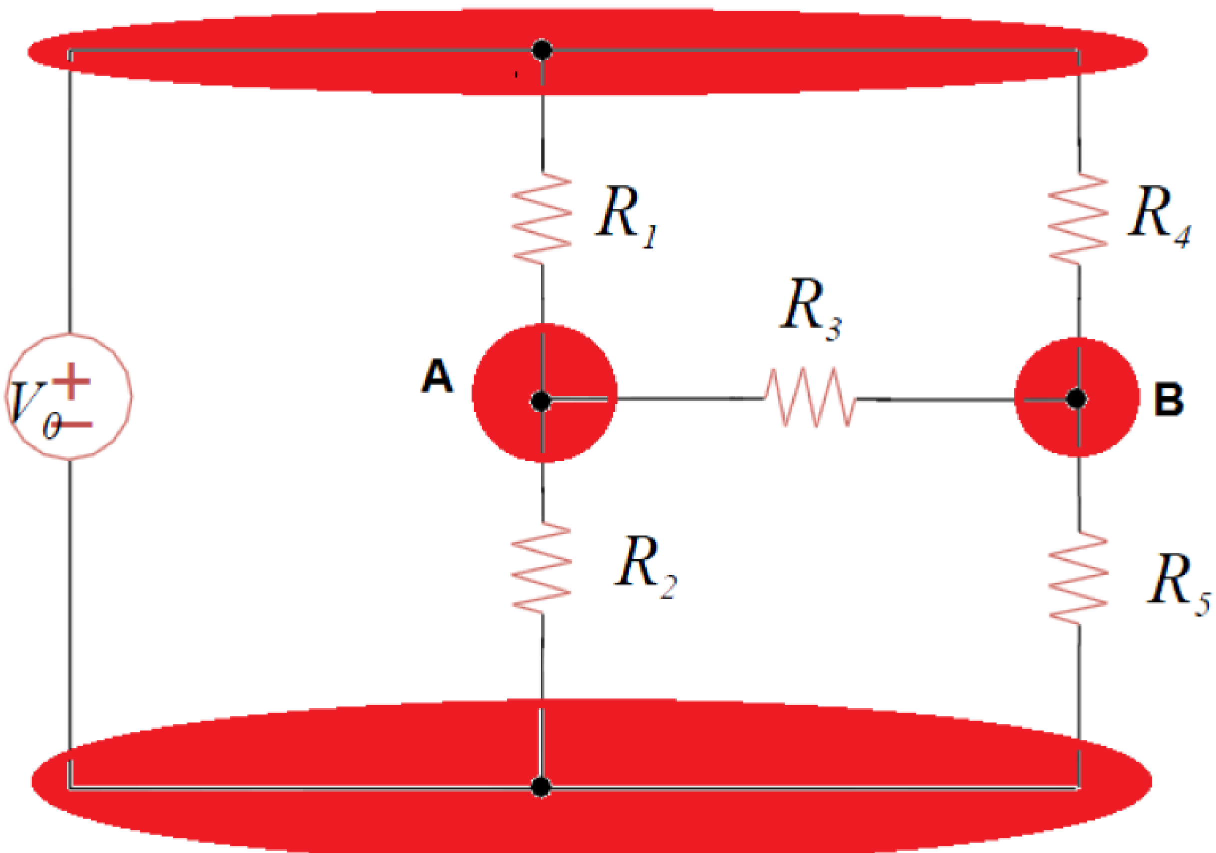


-A simple circuit can be analysed with KVL and KCL but lots of equations must be solved.

- So, easier methods are needed.

Course objectives

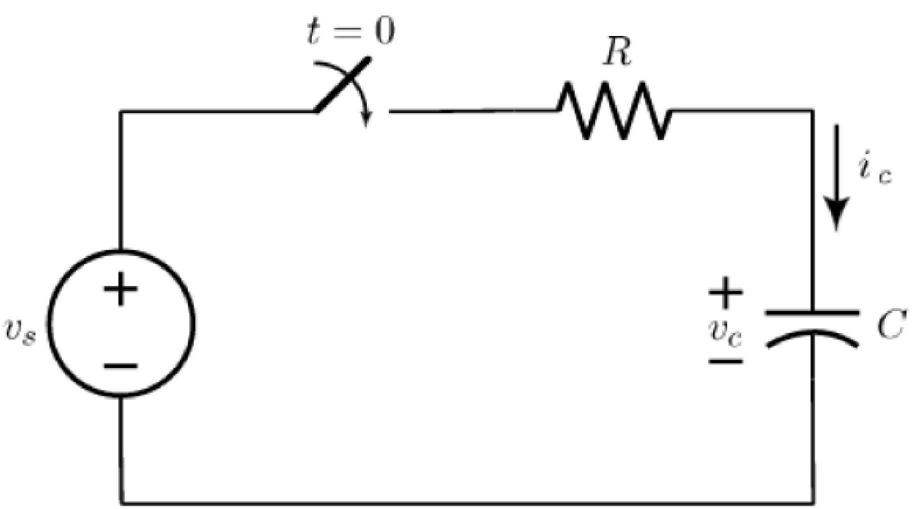
- (4) to apply linear analysis techniques (nodal, mesh, superposition, source transformation, Thevenin & Norton equivalents) to compute Direct Current circuit responses



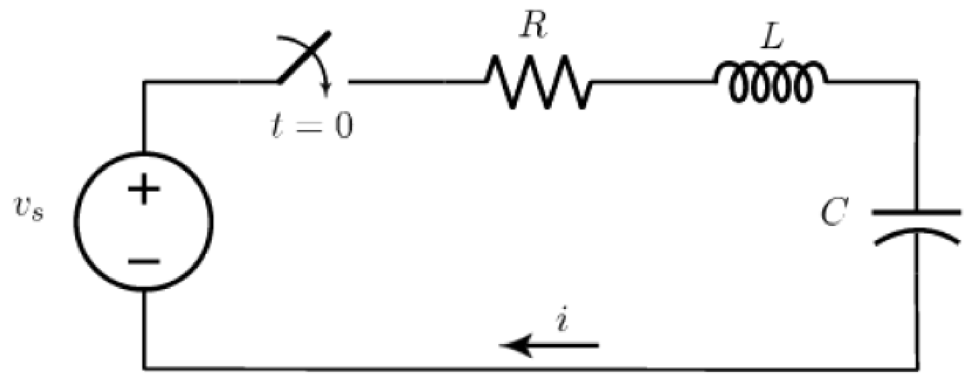
- In nodal analysis, same circuit can be solved by using two node equations (A, B)

Course objectives

- (5) to compute the transient and steady-state responses of first- and second-order linear circuits



A first order RC circuit

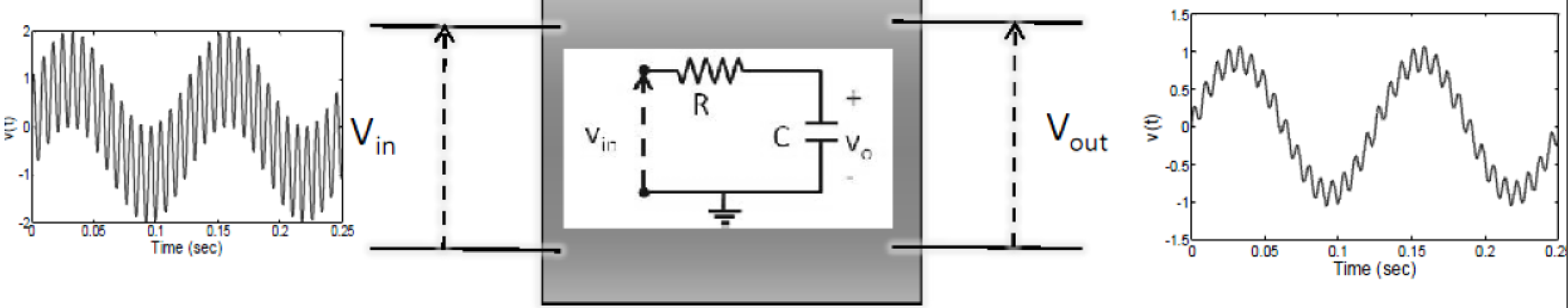


A second order RLC circuit

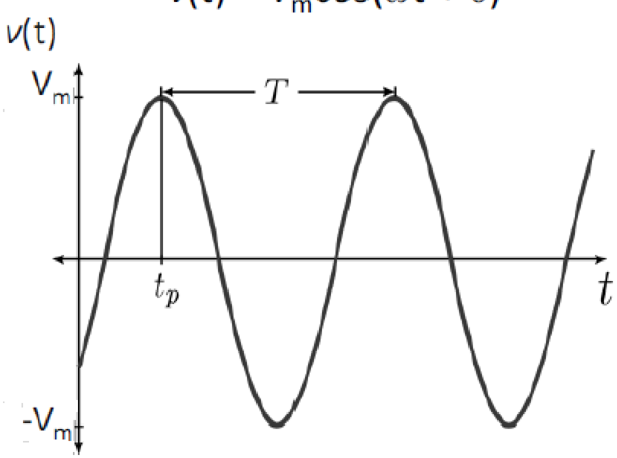
Course objectives

- (6) to determine the linear steady-state responses of Alternating Current circuits using phasors

Time Domain



$v(t) = V_m \cos(\omega t + \theta)$



Amplitude: V_m

Period: T sec

Frequency (Hz): $f = \frac{1}{T}$

Frequency (rad/sec): $\omega = 2\pi f$

Phase Angle: $\theta = -2\pi \frac{t_p}{T}$

Linear vs. Nonlinear

- Linear problems are inherently more easily solved than their nonlinear counterparts.

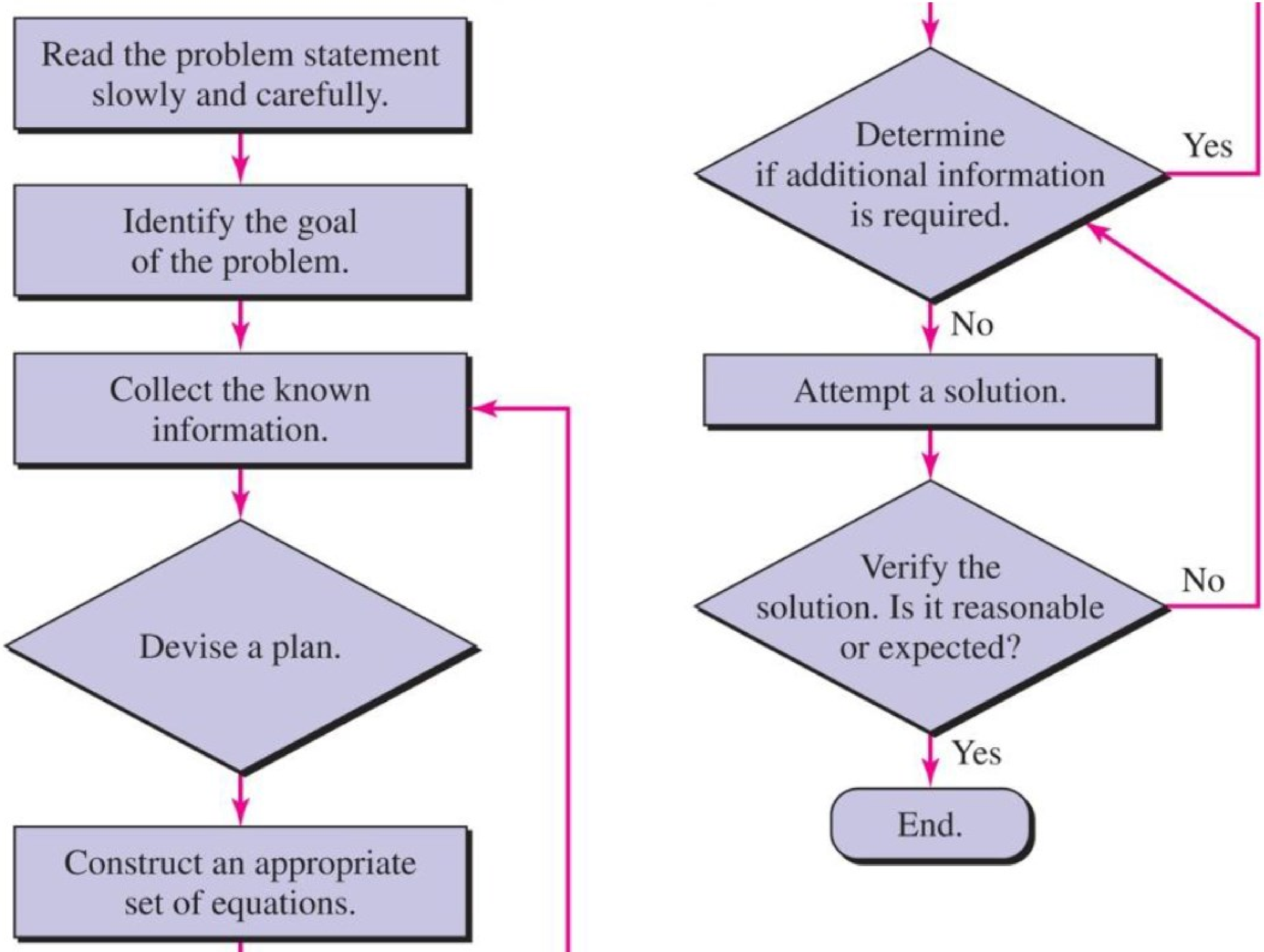
- For this reason, we often seek reasonably accurate linear approximations (or *models) to* physical situations.

- The linear models are more easily manipulated and understood which makes **analysis** and **design** a more straightforward process.

Analysis and Design

- ***Analysis*** is the process through which we determine the scope of a problem, obtain the information required to understand it, and compute the parameters of interest.
- ***Design*** is the process by which we synthesize something new as part of the solution to a problem.
- A crucial part of design is analysis of potential solutions!

Problem-Solving Strategies



Solving Linear Equations

Assume that we must solve a system of equations:

$$\boxed{\begin{array}{rcrcrcr} 7v_1 & - & 3v_2 & - & 4v_3 & = & -11 \\ -3v_1 & + & 6v_2 & - & 2v_3 & = & 3 \\ -4v_1 & - & 2v_2 & + & 11v_3 & = & 25 \end{array}}$$

- could solve these equations by systematic elimination of variables
- quicker way: using matrices, let a computer/calculator perform the required operations

MatLab can be used.

Matrix solution to linear equations

Step 1: Identify the coefficients and variables…

$$G = \begin{bmatrix} 7 & -3 & -4 \\ -3 & 6 & -2 \\ -4 & -2 & 11 \end{bmatrix} \qquad B = \begin{bmatrix} -11 \\ 3 \\ 25 \end{bmatrix} \qquad V = \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix}$$

coefficients variables

Step 2: Write the equations in matrix form…

$$G \cdot V = B \qquad \begin{bmatrix} 7 & -3 & -4 \\ -3 & 6 & -2 \\ -4 & -2 & 11 \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} -11 \\ 3 \\ 25 \end{bmatrix}$$

Step 3: Perform the required operations…

$$G \cdot V = B$$
$$G^{-1} \cdot G \cdot V = G^{-1} \cdot B$$
$$V = G^{-1} \cdot B$$

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} 7 & -3 & -4 \\ -3 & 6 & -2 \\ -4 & -2 & 11 \end{bmatrix}^{-1} \begin{bmatrix} -11 \\ 3 \\ 25 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$$

$$\boxed{v_1 = 1\ \mathrm{V},\ v_2 = 2\ \mathrm{V},\ v_3 = 3\ \mathrm{V}}$$

Matrix inversion

$$V = G^{-1} \cdot B$$

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} 7 & -3 & -4 \\ -3 & 6 & -2 \\ -4 & -2 & 11 \end{bmatrix}^{-1} \begin{bmatrix} -11 \\ 3 \\ 25 \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 3 \end{bmatrix}$$

A matrix multiplied by its inverse equals the **identity matrix** (ones on the main diagonal, zeroes off the diagonal).

$$G^{-1} \cdot G = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

We will use Matlab to solve for G^{-1}.

$$G^{-1} = \begin{bmatrix} .325 & .215 & .157 \\ .215 & .319 & .136 \\ .157 & .136 & .173 \end{bmatrix}$$

MatLab Procedure

```
>> G = [7 -3 -4;-3 6 -2;-4 -2 11]

G =

     7    -3    -4
    -3     6    -2
    -4    -2    11

>> G^-1

ans =

    0.3246    0.2147    0.1571
    0.2147    0.3194    0.1361
    0.1571    0.1361    0.1728
```

MatLab Procedure

```
>> B = [-11;3;25]

B =

   -11
     3
    25

>> V = G^-1 * B

V =

    1.0000
    2.0000
    3.0000
```

Examples

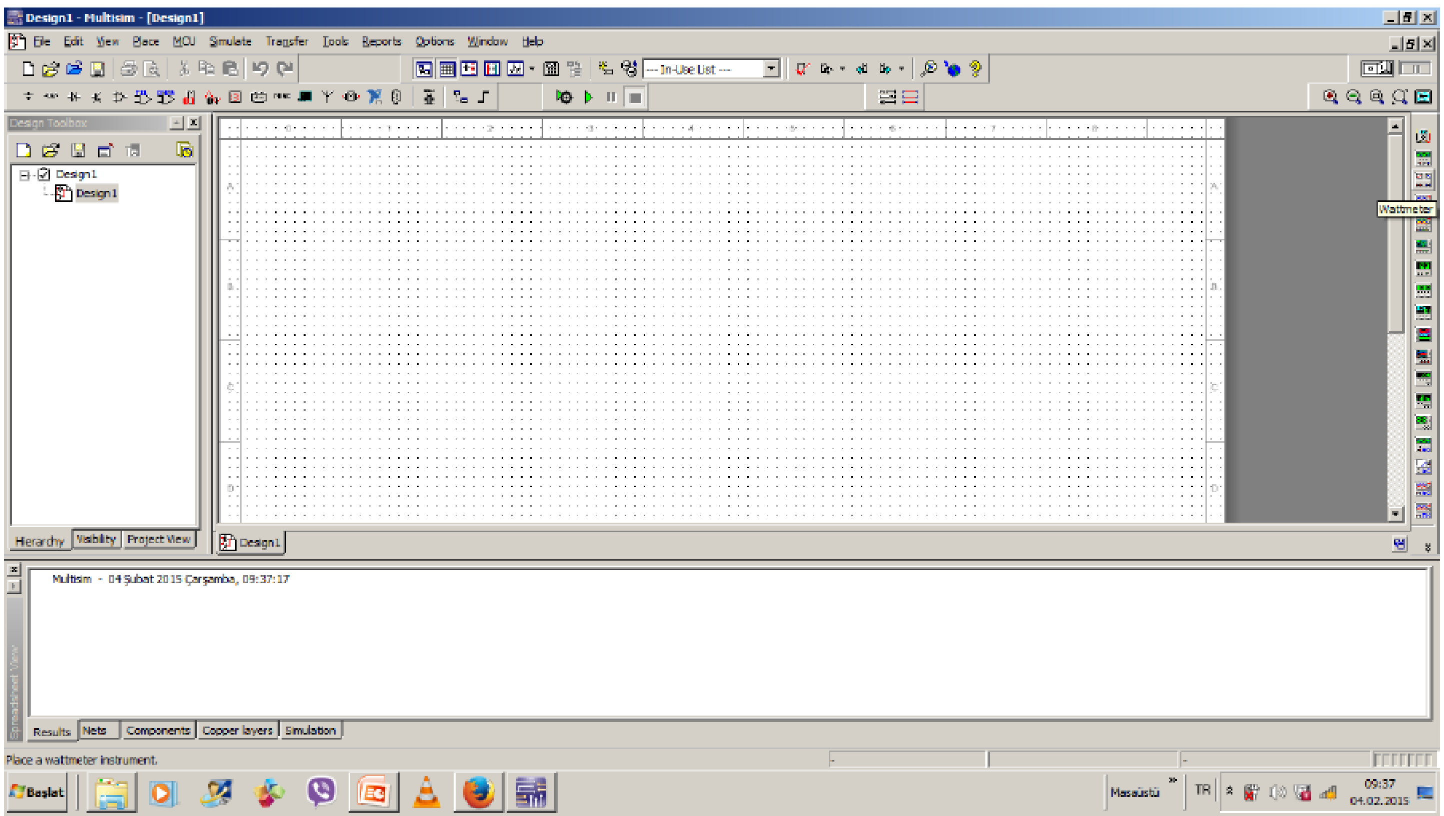
Rewrite the following systems of equations in matrix format and solve:

(b) $$\begin{aligned} 300I_1 - 250I_2 - 400I_3 &= 10 \\ -250I_1 + 375I_2 - 125I_3 &= 0 \\ -400I_1 - 125I_2 + 725I_3 &= 7.5 \end{aligned}$$

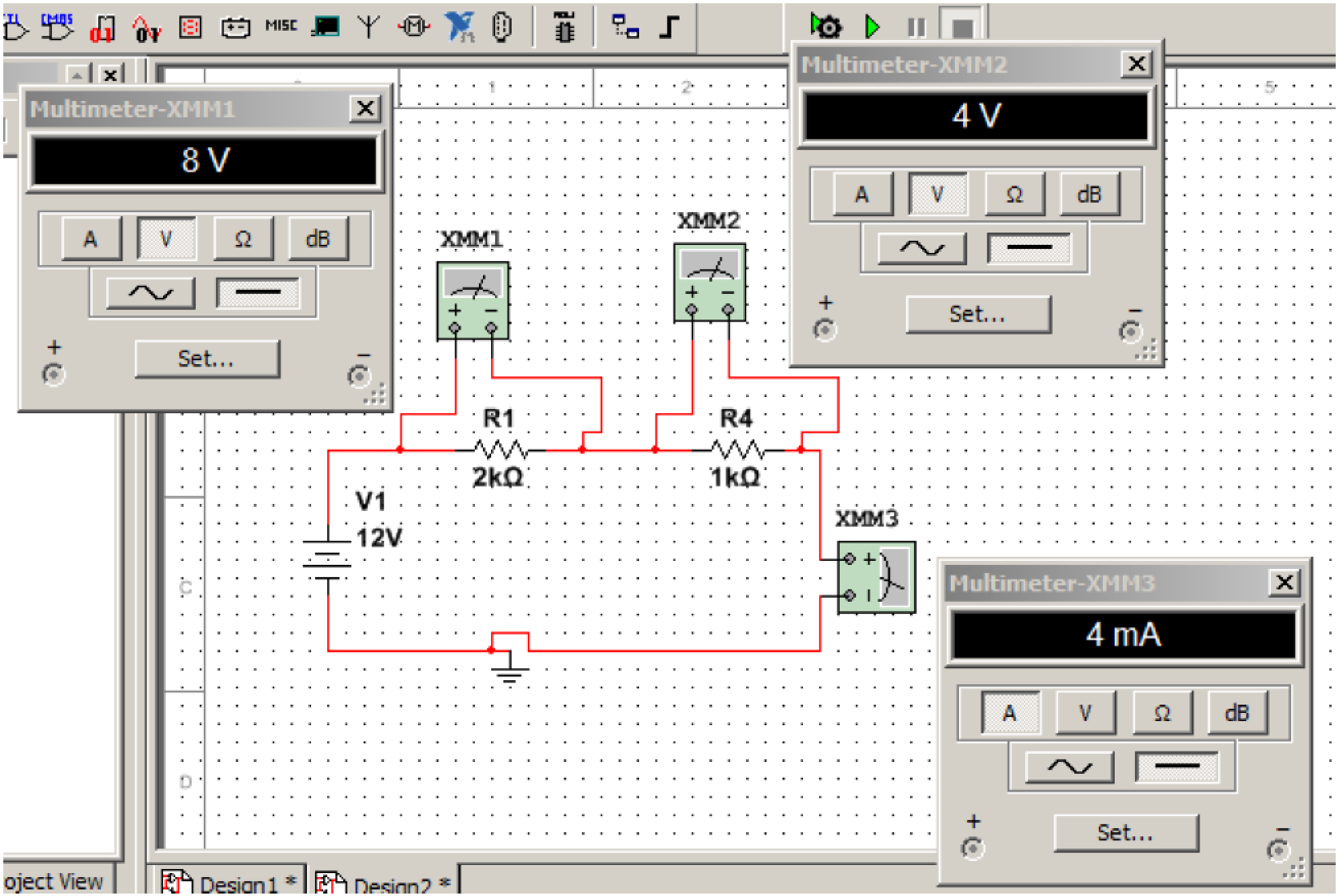
```
>> G = [                ; ...
                       ; ...
                       ];
>> B = [  ;   ;     ];
>> I = G^-1 * B

I = -0.0734
    -0.0626
    -0.0409
```

Multisim

- Multisim is a powerful **schematic capture** and **simulation** environment that engineers and students can use to simulate electronic circuits and prototype Printed Circuit Boards (PCBs).



Multisim Examples



Multisim Examples