Modeling and Simulation

Lecture 1

INTRODUCTION
Objectives

- Understanding the concepts of M&S
- The Mathematical Model of a system
- Using MATLAB for circuit analysis implementation
- Using LabView Control Design & Simulation toolbox for circuit analysis implementation
- Results validation using the RLC Circuit Analysis MATLAB interface
Understanding the concept of M&S

- We will analyze an electrical system (simple circuits in our case) by means of mathematical calculations. This is the “modeling” process. We will obtain the **Mathematical Model of a system (MM)**.
- Using dedicated programs (Matlab, LabView, NI Multisim) we will **simulate** the behavior of the system using several test input signals. We will characterize the system using time and frequency domain calculations.

**Reasons**

“Experts have estimated that board designers dictate 75% of the cost of final printed boards solely based on design choices before the designs leave the CAD stations.”

*Institute for Printed Circuits report, 2008*
In which area would you most benefit from greater productivity?*

- **Simulation**: 29%
  - All best-in-class companies use simulation in design**
- **Design verification**: 40%
- **Part evaluation**: 22%
- **Layout and routing**: 8%

* Results based on the *2005 Integrating Design and Test* survey conducted by NI and Tektronix Aberdeen Group Analysis

** Aberdeen Group Analysis
The Mathematical Model (MM) of a system

- If the circuit has **zero initial conditions** it means that the inductor current and capacitor voltage are both 0 when starting the simulation.

**Step response**: the behavior of the circuit after the sudden application of a DC voltage or current.

**Natural response**: the behavior of the circuit after the DC voltage or current source is suddenly disconnected.

For this particular case we are interested in representing:
- capacitor voltage
- inductor current
The Mathematical Model (MM) of a system

• 2nd order circuit.
• The **state variables** are:
  Voltages over Capacitors
  Currents through Inductors
• The **test signal** is:
  The Step input

![RLC filtering circuit]

\[i(t) = i_R(t) = i_C(t) = i_L(t)\] - Series connection

\[u_{in}(t) = u_R(t) + u_L(t) + u_C(t) = R \cdot i(t) + L \frac{di(t)}{dt} + u_C(t)\] (1.1)

\[i(t) = i_C(t) = C \frac{du_C(t)}{dt}\] (1.2)

\[u_{in}(t) = L \cdot C \frac{d^2u_C(t)}{dt^2} + R \cdot C \frac{du_C(t)}{dt} + u_C(t)\] (1.3)
The Mathematical Model (MM) of a system

**Mathematical Model (or Circuit Model):** a mathematical relation between the input and output variables. The model describes the evolution of the output variable as a function of the input variable.

\[
\begin{align*}
    u_{in}(t) &= L \cdot C \cdot \frac{d^2 u_c(t)}{dt^2} + R \cdot C \cdot \frac{du_c(t)}{dt} + u_c(t) \\
\end{align*}
\]

**We assume that:** \( R = 4 \Omega, \ L = 2H, \ C = 2F \) and that we have found a solution for \( u_c(t) \).

**MM:** \( u_{in}(t) = 4 \cdot \frac{d^2 u_c(t)}{dt^2} + 8 \cdot \frac{du_c(t)}{dt} + u_c(t) \)

\[
\begin{align*}
    u_c(t) &= 1 + 0.077 \cdot e^{-1.866t} - 0.928 \cdot e^{-0.134t} \\
\end{align*}
\]

**Using MATLAB:** using dedicated MATLAB functions we can create programs (m-files) which help us implement complicated mathematical calculations.
clear all;
% define a time vector for Uc(t) calculation
 t = [0:0.1:100];
% define a time vector for Il(t) plotting
 t2 = t(1:(length(t)-1));
% Define Uc(t) as presented in relation (1.4)
 Uc = 1+0.077*exp(-1.866*t)-0.928*exp(-0.134*t);
% Calculate Il(t)
 Il = 2*diff(Uc);
% Plotting Uc – the capacitor voltage
 figure(1); clf;
 set(gcf,'Color',[1,1,1]);
 subplot(211);
 plot(t,Uc,'-b');grid on; axis tight;
 title('Uc(t) evolution');
 xlabel('Time [s]'); ylabel('Amplitude [V]');
% Plotting Il – the inductor current
 subplot(212);
 plot(t2,Il,'-b');grid on; axis tight;
 title('Il(t) evolution');
 xlabel('Time [s]'); ylabel('Amplitude [A]');
Using LabView Control Design & Simulation toolbox for circuit analysis implementation

**Using LabView**: using Labview models we get familiar with graphical programming and we learn how to analyze a system starting from the mathematical model.

A possible solution (not the only one) is to separate the term with the 2nd derivative from the rest of the terms and divide everything by the constant of the isolated term.

\[
L \cdot C \cdot \frac{d^2 u_c(t)}{dt^2} = u_{in}(t) - R \cdot C \cdot \frac{du_c(t)}{dt} - u_c(t) \quad \text{=:} \quad L \cdot C
\]  

\[
\frac{d^2 u_c(t)}{dt^2} = \frac{1}{L \cdot C} \cdot (u_{in}(t) - R \cdot C \cdot \frac{du_c(t)}{dt} - u_c(t))
\]

We think of the left side of the equation as being constructed from a sum of three elements and a multiplication with a constant.

Access the Control Design & Simulation palette and use the dedicated sub-VIs.
Using LabView Control Design & Simulation toolbox for circuit analysis implementation

Block Diagram for the implementation of the RLC circuit

Step response.
Using LabView Control Design & Simulation toolbox for circuit analysis implementation

Front Panel for the implementation of the RLC circuit Step response.
Results validation using the RLC Circuit Analysis MATLAB interface

Access the interface by typing the `rlc_gui` command in the MATLAB Command Window.
Select the desired circuit connection and set the values for the components. This tool can be used for checking if the MM which we obtained offers the correct relation between the input and output parameters of interest.
Using the circuit schematics and NI Multisim for circuit analysis implementation

Using NI Multisim: learn how to implement several analysis procedures starting from the circuit setup.
Using the circuit schematics and NI Multisim for circuit analysis implementation.

The common details concerning the way in which this program can be operated (saving files, placing components, wiring the circuit, etc.) depends on the experience of the user.