ELEC 326

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1 Objectives

The circuits studied in this course are examples of electrical systems. Therefore, these notes will primarily

- provide an introduction to the general properties and characteristics of electrical systems,
- explain the role of system models in the analysis and synthesis of electrical systems, and
- give a brief introduction to digital systems.

I encourage all of you to read Chapter 1 in the textbook. This is a general introduction to the area of digital design that should be viewed as introductory material augmenting these notes.

1.1 What is a system?

A *system* is a collection of devices assembled to perform a useful transformation of information.

- Information is presented to a system's input terminals in the form of time-varying signals.
- Changes in a system's input signals can produce changes in its output signals after some delay (controlling this delay is at the core of all system design).
- Systems may contain internal memory used to save information for future use.
- The value of a system's output signal is determined by the values of the system's input signals and the information in its internal memory.
- The values of the output signals are determined by some rule or algorithm that can be physically implemented.
- If a system has memory, it can have two or more different output values for the same input value.

1.2 System models

A system *model* is a simplified description of one or more properties of a system.

- Models predict how a system will react to changes in its input signals.
- Models predict system behavior without building a physical instance of the system.
- A single model never represents all of the physical properties of a system, and therefore cannot exactly predict a system's behavior.
- While in theory we could represent everything about a system, the result would be a model that is at least as complex as the system it models.
- We use simple models that can answer questions about certain system properties of interest, and may have to use different types of models to answer questions about other properties.

1.3 Structural vs. behavioral models

There are two types of models that you will encounter in this course. One is used to describe how a system is built and the other to describe what it does.

A *structural* model describes how a system is built (i.e., its internal structure).

- It usually takes the form of a diagram showing how the component parts of the system are interconnected.
- It could also take the form of one or more lists of components and connections (e.g., the input to a computer simulation program).
- Structural models show how to build a system, but are not usually very good for predicting its behavior.
- Even structural models leave out some detail to make them manageable (e.g., the physical positioning of wires and components).

A *behavioral* model describes what a system does by defining the transformation of input signals into output signals by the system (i.e., its external behavior).

- Behavioral models usually do not provide any information about how the system is built (i.e., its internal details).
- Completely different physical systems can have the same behavior, so a behavioral model does not describe a unique system.

In the past, most models of physical systems were based on mathematical equations. Recall simple systems of equations that you solved in your mechanics and basis EE classes. In recent years, the use of computer simulation models has become widespread.

1.4 Analysis, synthesis, & verification of systems

- *Analysis*: Derive a system's behavior from a description of its physical structure, i.e., derive a behavioral model for the system from its structural model.
- *Synthesis*: Build a system that has a given behavior, i.e., derive a structural model for the system from its behavioral model.
- Usually we want to optimize one or more parameters when we synthesize a system, e.g., speed, power, cost, reliability.
- Automating synthesis with computer-aided design tools (CAD) tools to map the behavioral model into a structural model. Three main companies that do this – Synopsys, Mentor Graphic, Cadence.

1.5 Hierarchical system organization

Hierarchically organized systems have the following properties:

- A hierarchical system consists of building block modules interconnected in some way.
- The modules themselves are constructed from interconnected simpler modules.
- Internal module design detail is hidden from and independent of systems built from them.
- Without this hierarchical approach we cannot build complex systems.
- For the hierarchical approach to work, the models for a module's behavior must remain valid when they are connected to other modules, i.e., connecting modules must not affect the behavior of those modules.

2 Digital systems

Some basic characteristics of all digital systems follow

- Signals can assume only a discrete number of values, usually two.
- For two-valued systems, it is usual to designate the two signal voltages as L and H (for *low* and *high*) instead of referring to them by the actual voltages of the signals.
- Advantages of two-valued signals:
  - Noise immunity
  - Unlimited precision: use multiple signals
  - Simple, cheap, and stable circuits
  - Easy to detect one of two values – using the notion of thresholds
- Digital system models are based on discrete math and algorithms, e.g., Boolean algebra, graphical state transition graphs, algorithms (flow charts, programs).
- Digital systems are behaviorally or structurally described using hardware description languages (HDLs). Examples include Verilog, which we will study in reasonable depth in this course, and VHDL.

2.1 Combinational vs. sequential systems

- *Combinational* systems have no memory, so input signals uniquely determine output signals. If the inputs signals are the same at two different times, the outputs at those times will be the same.
- *Sequential* systems have memory, so past input signals can affect current output signals. The same input signals at different times can produce different output signals. Sequential systems are built by adding memory to combinational systems. The memory in a sequential circuit can cause its outputs to depend on past inputs as well as current ones.

2.2 Exercise:

For each of the following system descriptions indicate whether it can be realized as a combinational system or whether a sequential system must be used. Indicate the reasons for your choice.

- The system has two 4-bit input terminals and one 5-bit output terminal, and the values on these three sets of terminals are treated as binary numbers. The system adds the two input numbers and puts their sum on the output terminal.
- This system has one input terminal and one output terminal. A sequence of 1's and 0's is applied to the input terminal, and the output terminal has value 1 if the number of 1's applied to the input is odd, and value 0 otherwise.
- This system is similar to the previous one but the output is 1 if the number of 1's in the most recent four inputs is odd.
- This system has four input terminals and one output terminal which has value 1 if the number of input terminals that have value 1 is odd.
- This system has 32 input terminals used to represent a 32-bit binary number and 33 output terminals used to represent a 33-bit binary number. The number on the output is to be equal to the number on the input multiplied by 2.

2.3 The digital system hierarchy

Digital systems can be thought of as organized into levels, using the abstraction mechanisms that you have already encountered in ELEC 220.

- Systems (e.g., computers)
- Functional units (e.g., registers, memories, arithmetic units.)
- Gates and flip-flops
- Electronic circuits
- Components (e.g., transistors, resistors, capacitors)
- ELEC 326 is primarily concerned with the design of the functional units using gates and flip-flops as the basic building blocks.