Limits of Lumped Parameter Circuit Theory

The purpose of this laboratory experience is to introduce the students to the limits of lumped parameter circuit theory. The study will consist of the observation of voltage measurements that cannot be predicted by using KVL and KCL and the given terminal equations relating voltages and currents in a lumped parameter circuit. Rather, the measurements must be described by using field concepts and be analyzed by applying Maxwell's equations to the situation. Students will have the opportunity to learn the knowledge needed for this type of analysis in the courses on transmission lines and electromagnetic theory, EE 313/353, EE 334, and EE 401.

To introduce the student to the phenomena, students will perform the procedure in section 3 interference signals and section 4 ground loops in Experiment 3 of the EE 241 manual. In addition, the instructor will give a demonstration of transmission line effects on circuit response, and will discuss the precautions that are necessary to reduce electrostatic discharge effects on electronic parts. The phenomena of electromagnetic radiation from a circuit will not be addressed, but could be added in the future. This is a preliminary draft, and may be revised on Wednesday.

Read the EE 241 manual version of Experiment 3 for background for these instructions. As the student knows from physics, energy is stored in electric and magnetic fields and is dissipated through the conductance of the media. In circuit theory, the storage of energy in an electric field is modeled by a lumped parameter capacitor, the storage of energy in a magnetic field is modeled by a lumped parameter inductor (and mutually coupled inductors), and the energy dissipated is modeled by a lumped parameter resistor. Through the mechanism of Faraday's law, voltages can be induced in circuit closed paths by a time-varying magnetic field thereby invalidating KVL. Through the mechanism of Maxwell's displacement current, currents can be induced in a closed surface of a circuit by a time-varying electric field thereby invalidating KCL. The procedures in section 3 will provide an opportunity to observe both phenomena. In addition, the procedures in section 4 on ground loops will provide an opportunity to observe the effect of "hidden" parts of a circuit that allow voltages to be induced by time-varying magnetic and electric fields.

When the dimensions of a circuit are greater than the wavelength of the signals (voltages or currents) being processed, then a lumped parameter model cannot be used to analyze the response. Rather, a transmission line, or distributed, model must be used to predict performance. PSPice has a transmission line model element that can be used to simulate the response for this situation. Note that in free space, light travels about one foot in one nanosecond, and on a printed circuit board, the distance that a voltage or current signal travels will be about six inches or 15 centimeters. So with typical printed circuit board dimensions and clock signals of 1 GHz or higher, wave propagation must be considered, and transmission line effects must be included in the analysis of circuit responses. The instructor will provide a demonstration of the transmission line effects on the response of a simple RC circuit to that the student can observe this phenomena.

Electronic circuits must be protected from the effects of electrostatic discharge, or ESD. This phenomena is familiar to anyone who has received a shock from touching a "grounded" surface after walking on a carpet, or sliding out of a car seat, on a day with low humidity. This collection of charge on our body causes a voltage to be induced between our body and the "ground" (think of our bodies as one conductor of a two conductor capacitor). The same phenomena can be observed in the creation of lighting bolts by clouds accumulating charge and producing a voltage between the cloud and the ground - when the voltage becomes large enough its electric field causes the air to ionize, and hence the lighting bolt. ESD can damage electronic chips, in particular, MOS devices and their gate capacitors. Therefore, ground strips and grounded workspaces are used to insure that there will be no buildup of static charge on electronic workers. It is a good practice to insure that you are "grounded" before you handle sensitive electronic chips to prevent their damage through ESD.

In addition, if a time varying current in a circuit and the electric field that it produces are in phase, then there can be radiation of electromagnetic energy, i.e., an electromagnetic wave is created. Most electronic systems must satisfy FCC regulations that attempt to limit this unintended radiation of electromagnetic energy. You can observe this effect by placing an AM radio near your computer when it is running; there will be a "noise" signal produced on the AM radio from the radiation of electromagnetic energy from the computer circuits.

Procedure:
1. Section 3 Interference Signals: do all procedures and answer the questions.
2. Section 4 Ground Loops: do all procedures and answer the questions.
3. Wednesday: observe the demonstration on transmission line effects by the instructor, and record the observations in your notebook.
4. At home: observe the effect of electromagnetic radiation from your computer using an AM radio.

Note: The laboratory final will be this Friday 6/7/02; same format as before - bring your lab notebook and calculator.