EEL 3003, INTRODUCTION TO ELECTRICAL ENGINEERING – SUMMER 2013

Lecture Notes – Lecture #1, Introduction

<u>Lecture Outline:</u>

Today's lecture had 3 major parts:

1) Overview of EE
   a) Major subfields of EE
   b) Example applications: Senior Design projects with ECE involvement
2) Go over syllabus
   a) List of topics
   b) Grade breakdown, letter grade scale
   c) Additional policies
3) First technical lesson
   a) Basic concepts of electrical physics
   b) Basic circuit terms & notation
   c) Basic circuit laws

Parts 1 & 2 are covered in the PowerPoint slides posted on Blackboard.

<u>Part 3: First technical lesson</u>

3a) Basic concepts of electrical physics.

This material should hopefully be review, since you've all taken college physics up through electromagnetism. Of course, electrical engineering is all about engineering systems utilizing physical principles of electricity and magnetism (which have been unified and seen as different aspect of one phenomenon since the days of Maxwell – late 1800s).

i.) What is electricity?

What is electricity? As we know today, typically, electric currents (both in nature – lightning, electric eel attacks – as well as in most engineered systems) result from the motion of the subatomic particles known as electrons, the negatively charged particles that orbit atomic nuclei. (There are a few exceptions, such as holes as charge carriers in semiconductors, and beams of protons or muons in particle accelerators, or flows of ions in chemical systems – in general, any motion of charged bodies (of any size!) carries a current. But in this course, we will mainly focus on electrons, which are convenient for engineering purposes due to their low mass and ready availability.)

ii.) What is an electron?

What is an electron? In modern physics terms, an electron is the quantum of excitation of the electron field, a type of quantum field, as that term is understood in quantum field theories such as quantum electrodynamics (which is incorporated within today's standard model of particle physics). However, for purposes of this course, we will ignore most of the quantum-mechanical properties of the electron, and treat it as a classical particle. Nevertheless, you should be aware that there is today an emerging research field known as quantum electronics, in which researchers develop and study devices that harness quantum properties of the electron, such as single-electron transistors (switched by the presence or absence of a single electron on a very small (several nm) gate electrode), and quantum interference transistors – where the electron wavefunction is made to interfere with itself to switch current along different branches of a single molecule. In the future, such devices may become important in widely-used technologies. But today, even the smallest transistors that are widely used in industry are not much smaller than virus-sized (tens of nm), and their switching involves the movement of at least thousands (if not millions) of electrons. So, in most electronic devices today, we still treat electrons as a "bulk" material, and rely on their statistical behavior, rather than working with them individually and relying on their detailed quantum mechanical behavior.

iii.) Properties of the electron.

However, it's important still to be aware of some of the basic properties of the electron, since they may affect the behavior of some devices. One may ask, how big is an electron? We could imagine answering this question in several ways; for example, by giving its size, mass, or charge.

In terms of size, the electron is treated, in modern physics, as really being a (zero size or infinitesimal) point in space; or at least, if it has a nonzero size, it is too small to measure with modern equipment. Of course, quantum mechanically, although the electron itself is modeled as having zero size, its position is typically spread out due to quantum uncertainty over some volume of space. We know from Heisenberg's uncertainty principle that the more tightly you confine an electron wavefunction in space, the greater the uncertainty in its momentum, so although in principle you could confine an electron into any size space, however small; for very small confinement, this requires a lot of energy; *e.g.* if you tried confining an electron to spaces less than a few hundredths of an Ångstrom, its velocity uncertainty would approach the speed of light. In any case, for most real-world engineering purposes, the concept of the "size" of an electron is unimportant, and we will not consider it further.

How about mass? The electron does have a nonzero mass, specifically $9.10938291 \times 10^{-28}$ g. To get a sense of scale, a major-league baseball has a mass of about 145 g, so it would take about 160,000 *trillion trillion* electrons to equal the mass of a baseball. For most engineering purposes, the mass of the electron is so small as to not be very important for most purposes, although it does come into play in some important phenomena such charge carrier mobility in semiconductors, and the deflection of electron beams (cathode rays) in vacuum tubes.

Finally, in terms of its electric charge, the charge of an electron is $(-)\ 1.60217657 \times 10^{-19}$ C (coulomb). So in other words, $(-)$ 1 coulomb of charge (carried by electrons) would be about 6 ¼ *billion billion* electrons worth of charge. If you could strip *all* of the electrons from all of the atoms in one cc of water, that would be about 334,000 coulombs' worth. But a coulomb is really quite a large amount of charge, if isolated. Two 1-coulomb charges 1 meter apart from each other would push each other apart, by Coulomb's Law, with about a million tons of force! Fortunately, isolated charges in nature tend to very quickly accumulate opposite charges to themselves, and so most macro-scale objects end up being approximately electrically neutral. When we talk about "charging up" a battery with many coulombs worth of charge, be aware, the battery as a whole always remains electrically neutral! "Charging" a battery typically involves just separating that amount of charge in ionic solutions across thin membranes, spread out over a large internal surface area, so that the forces involved are more modest. However, while it is "discharging," the battery may, over time, deliver many coulombs worth of charge through a electrical circuit, from the battery's negative (source) terminal to its positive (drain) terminal.

But, the overall electric charge of the battery always remains the same (neutral).

iv.) Electric current.

That brings us to a discussion of electric current. By analogy with a water current, which is a flow of water, an electric current is a flow of electric charge (usually carried by electrons). We measure any current in terms of its *intensity*, or the rate of flow of material per unit time; for a water current, we might express its intensity in terms of, say, the number of cubic feet of water per second that cross through a cross-section of a pipe; for an electric current, what we care about is the quantity of *charge* that passes through a cross-section of a wire (or other conductor) per second. As a formula, we write:

$$I = Q/t, \tag{1}$$

meaning the current intensity (I) equals the quantity (Q) of charge that passes across a section through a conductor, divided by the amount of time (t) during which that amount of charge passes through. Equation (1) applies to a constant or average current; in terms of an instantaneous current, which may in general vary over time, we would more properly write:

$$i(t) = \mathrm{d}Q(t)/\mathrm{d}t, \tag{2}$$

i.e., the instantaneous current intensity i, which may in general be a function of the time t, is the the rate of change of $Q(t)$, the total quantity of charge that has crossed through the wire section up to time t. (Of course, the calculus expression here is only an approximation, since an electric current is not really continuous, but is composed of discrete particles; however, for macroscopic circuits, we can model it as if it were continuous.)

Of course, as with water flows in pipes, it does not matter where along the length of a wire we cut through it to define its cross-section; since electrons (like water) are conserved, if electrons are not to be accumulating somewhere in the wire, the flow out of any segment of wire must be equal to the flow into it, so the current intensity is the same everywhere along the length of the wire.

It's important to note that, since electrons are negatively charged, the direction of current flow is always the opposite of the direction in which the actual electrons are moving (assuming here that the electrons are the primary charge carriers for the current in question). When an electron crosses through a surface from left to right, we can say that (positive) charge has crossed the surface from right to left, since the total charge on the right side is now more negative than it was before.

The unit of current is called the ampere (A) or amp, and it is equal to 1 coulomb per second. (A=C/s.) In terms of electrons, one amp is thus about (−) 6.25 billion billion electrons per second.

So, why do we care about electric currents? We care because they have power – they can do work.

v.) Power of an electric current.

Let's quickly review how work is measured in physics. The SI unit of work (or energy) is the Joule. A Joule is the amount of work done when applying a force of 1 Newton over a distance of 1 meter. At standard gravity, a cell phone weighs on the order of 1 Newton (3.6 ounces), so, if you drop your cellphone from waist height (about 1 meter) onto your toe, the kinetic energy imparted upon that impact is about 1 Joule.

The amount of work that a unit of charge can do (or the power of a current) depends on its *voltage*, or electrostatic potential. You can think of voltage as being analogous to water pressure. Pressure tells you how much work a body of pressurized water (or other fluid) can do, per unit of volume (*i.e.*, per amount of fluid, in the case of an incompressible fluid). Pressure has the same physical dimensions as energy density (mass/(length×time)) and it is in fact equal to energy density, for that part of the energy within the fluid that is involved in imparting pressure on its container, and that can therefore do work on its surroundings. (Note that $p = f/a = e/v$ = energy density; *i.e.*, pressure p equals force f per unit area a equals work energy e that can be performed per unit volume v, since $v=al$ for a movable cylindrical piston of contact area a pushed, by fluid pressure, through a linear distance l by a volume v of fluid, and $e=fl$; the work e done is the amount of force applied, times the distance over which it is applied. Thus, $e/v = fl/al = f/a = p$.)

In the case of voltage, the underlying material that we care about is not volume of water, but quantity of charge. Voltage therefore measures the (electrostatic potential) energy *per unit of charge*. Thus, we write:

$$V = E/Q, \tag{3}$$

or, the voltage V equals the energy E divided by the quantity Q of charge. Keep in mind that since the electron charge is negative, electrons at a high voltage have *less* electrostatic potential energy than electrons at a low voltage; electrons therefore naturally tend to flow from regions of low voltage to regions of high voltage. But (positive) charge flows in the opposite direction, from high voltage to low.

The unit of voltage is the volt (V), defined as 1 joule per coulomb, V=J/C.

Equations (1) and (3) together allow us to immediately figure out the power (rate of energy flow) carried by an electric current.

$$I \cdot V = \frac{Q}{t} \cdot \frac{E}{Q} = \frac{E}{t} = P, \tag{4}$$

in other words, the intensity I of a current times the voltage V of that current turns out (after canceling the Qs in the numerator and denominator) to just be equal to the amount of electrostatic energy E conveyed per unit time (t) by that current, or in other words its power. More simply,

$$P = IV, \tag{5}$$

which is one of the classic formulas of electric circuits. Power is of course standardly measured in watts (1 W = 1 J/s), and so, in terms of units, it's also the case that 1 W = (1 V)×(1 A), since VA=(J/C)(C/s) = J/s.

As an example problem, suppose you have a 12 volt battery delivering 2 amps of current to a circuit. What then is the power output of that battery? We write:

$$(12\text{ V})(2\text{ A}) = 24\text{ VA} = 24\text{ W}. \tag{6}$$

So, the battery is delivering 24 watts of power to the circuit.

This material is also discussed in the textbook (§2.4).

3b) Basic circuit terms & notation.

Fill in more detailed notes here later. This material is also covered in the textbook (§2.1)

i. Icons for (DC) voltage sources.
ii. Icons for generic loads (rectangles) and resistors (zigzags).
iii. +/− annotations on sources and loads.
iv. Joins (solder dots) vs. nodes.
v. Branches.

3c) Basic circuit laws.

Fill in more detailed notes here later. This material is also covered in the textbook (§§2.2-2.3).

i. Kirchoff's current law.
ii. Kirchoff's voltage law.
iii. Ohm's law.