Electrical Engineering Workshop (ইলেকিট্রকাল ইঞ্জিনিয়ারিং) 3 hours/day

Week 1: From Electrons to Circuits (ইলেক্ট্রন থেকে সার্কিট)

Lesson 1.2: Fundamentals of Electricity: Capacitors, Inductors, and Motors (ইলেক্ট্রিসিটির মূলসূত্র)

• RECAP: Okay, yesterday we learned about resistors. If we have one resistor, we can tell what value it is right? And if we connect one resistor right after another resistor like this (show series), we know that we can add the two resistor values to get the total resistance between these two points.	• 2 m
• ASK STUDENTS: Now what if we connect two 2K resistors together, like this? (show parallel). What do you guys think will happen? Write down your hypothesis. o SURVEY: Pick on students to say what they think the total resistance is o GUIDE THEM THROUGH THINKING: Okay let's say that these one resistor is connected to a voltage source. How much current is going through? Calculate. o ASK THE STUDENTS: Now let's have the parallel resistors connected to voltage source. How much current is going through this resistor? How much current is going through the other resistor? o ASK: what's the total current going through both resistors? o GUIDE THEM: let's use Ohm's law to determine what R is, since we know V, and we know total I. Okay, see that total R is half of R. o PERSONAL VERIFICATION: Verify that this is true using your LCR meters and two resistors in parallel. o ASK THE STUDENTS: What if we have a 2K and a 4K together? Let's calculate the total R this way. o ASK: How can we generalize this method to get a formula to describe the total resistance of two resistors in parallel? o GUIDE: them through calculating algebraic formula for R || R o WORKSHEET: 5 min worksheet problems on R series and parallel	• 15 m
• NEW CONCEPT: We know about a voltage source and how it can keep a steady voltage right? But we can also have a voltage that changes over time. Usually, we call this type of voltage an AC voltage. And we call the steady, non-changing voltage a DC voltage, okay? o DRAW: graph on the board: voltage versus time o DRAW: 6 examples of voltage signals and ask students if AC or DC o NEW VOCABULARY: We call a voltage an electrical signal. Why? What is a signal? Think about a traffic signal. That is a signal right? It gives you information. In the same way, a voltage can convey information. When we are looking at a voltage to hold some sort of information, we call it an electrical signal, okay? This is important because when you build your heartbeat monitor you will be converting your pulse to an electrical signal using light sensors – we will learn about that soon! o WORKSHEET: 5 min worksheet problems on drawing AC and DC signals	• 10 m
• NEW CONCEPT: Now let's learn about some new components. This is another type of component that you can easily blow up! It's called a capacitor!	
• EXAMPLE: First let's think about static shock. Have any of you ever felt a shock when you touched a doorknob? (probably not though because Bangladesh is super humid) If you have, then you have experienced proof that your body is a capacitor! o EXPLANATION: You build up charge from touching certain types of objects, usually dry and cold weather, and so on. And then when you touch something metal or something with less charge than you, like another person, you both feel a little shock! o DO IT: Let's try it! Everyone get in teams of two. One person blow up your balloon and then rub your hand and hair on the balloon. Now the second person, touch a finger on the first person's hand or hair. Did you feel a shock! Yes! That's because the first person built up charge and then the transferred it to the second person with an electric shock! o WORKSHEET: Explain what happened in your experiments.	• 10 m

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EAT + ANALOGY: A capacitor is like an ice cream sandwich! (Have ice cream sandwiches for the students). The outer metal plates are like the cookies on the outside, and on the inside is something called a dielectric material – this is the ice cream in your case.

DRAW: diagram of the ice cream sandwich, connected to battery terminals.
ASK: So what happens when two metal plates are connected to a battery? Well, current will try to flow right? So what will happen?
EXPLAIN: When current tries to flow, will it be able to flow then there is a dielectric material that doesn't conduct electricity in the middle? No!
ASK & EXPLAIN: So what happens instead? The electrons/holes rush really quickly because here there is no resistance right. They rush really quickly through the wires and get to the metal plates. And then what happens?
EXPLAIN: Electrons and holes build up on the two plates. These are called charges. One plate is positive and the other is negative. And since we can't lose the energy, the energy from the battery is stored in something called an electric field that exists between the two plates.
(How to explain electric field???)
ASK THE STUDENTS: What is the voltage across the capacitor in this circuit?
RECAP: So we know what happens when we put a steady DC voltage across a capacitor. The capacitor builds up charge until it reaches that voltage. And it maintains a static electric field.
WORKSHEET: Draw diagram of capacitor and built up charges

ASK THE STUDENTS: What do you think happens when you have a really fast changing voltage across the terminals of the capacitor? In other words, what do you think will happen when current is trying to flow back and forth across the capacitor?

GUIDE THEM: Remember how we talked about electric fields? So when you have a DC current, you have a static electric field. The current cannot jump to the other plate. But when you have an AC current, the electrons are moving back and forth (show with arrows on drawn diagram) on one plate, then the electric field inside the capacitor is also changing direction, and this causes the same back and forth movement of electrons on the other plate (draw). So that back and forth movement of electrons, or current, can go through a capacitor.
(What's a good way to demonstrate this concept by getting the students on their feet and moving around?)
WORKSHEET: Explain what happens to DC and AC signals in capacitor.

DEMO: Let's open up a capacitor and look at it!! → Do the demo!
Okay, now remember how we talked about series and parallel?

ASK: Can someone draw what capacitors in series would look like?
NEW CONCEPT: so what will be the values of capacitance? What equation can we use to determine capacitance? Well, there are two. One is that $C = eA/d$ (and explain this meaning with diagrams, more C means more energy storage so more area of plates means more energy storage in the form of charges gathering up. And less distance means more energy storage because that makes a stronger electric field!)
ASK STUDENTS: So now let's think about what it means to put two capacitors together. Let's see what the charges look like when we have four plates back to back like this (draw – make sure to color in where the dielectrics are, and label A, and d). So how can we draw this capacitor as one capacitor? Any ideas?
GUIDE THEM: So we know these two metal plates are connected by a wire right, so they basically cancel each other out. But how?
I'm going to tell you something new, so bear with me. What happens when these capacitors build up charge is that one plate builds up a lot of positive charge and the other plate builds up a lot of negative charge. So here's what that looks like. Any plate that has a positive charge, on the plate next to it will be negative charge, and vice versa.
ASK: So can someone come up and draw in what charges the rest of the plates will have if this first one (+ side of batt) has positive charges?

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- Right, so now let's look at these two metal plates in the middle that are connected together. They are positive and negative, so they cancel each other out! Now we can model these two capacitors in series like this:
  - DRAW: diagram of one capacitor with A and 2d.
  - ASK THE STUDENTS! So what is our total capacitance? (1/2 of what it was before!) Verify that this is true using your LCR meters and two capacitors in series.
  - ASK THE STUDENTS: What does this look like? Does this remind you of anything we did with two or more resistors? (Yeah! Resistors in parallel right? Does anyone remember the equation for resistors in parallel? + write it up on the board) Now, what's the capacitor equation for capacitors in series? Same thing right, except C1 and C2 instead of R1 and R2!
  - WORKSHEET: Capacitors in series design examples
- NEW CONCEPT: Let's look at two capacitors in parallel. Can anyone tell me what two capacitors in parallel would look like on a schematic?
  - ASK: let's think about what the total value of capacitance will be. This time how can we think of these two capacitors as one capacitor? Does the distance change like last time?
  - ASK THE STUDENTS: What does change? Anyone have any ideas? (If not or wrong, say: it's the area of the plates that change this time right?) So cool, if we have two capacitors, that means our area is what?
  - DRAW: diagram of one capacitor with area 2A on the plates instead of A
  - ASK: Can someone come up and write the new equation for the value of this capacitor? (they should write: C = e*2A/d, and what does this mean? The capacitor value is double now!)
  - ASK: So what happens with capacitors in parallel? Does this remind you of anything we did with resistors? (Yeah! Resistors in series). So can someone write to me what the equation for two parallel capacitors will be (They should write: C = C1 + C2)
  - PERSONAL VERIFICATION: Verify that this is true using your LCR meters and two capacitors in parallel.
  - WORKSHEET: Capacitors in parallel design examples

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- BUILD: Let's prove that a capacitor stores energy. Every team of two has a 10V capacitor (value?). Everyone charge up your capacitor by hooking it up to a battery. After 30 (more?) seconds, disconnect the capacitor and connect it across a resistor and LED in series. The LED lights up! What does this mean? Can you convince yourself that the capacitor must be storing energy in order to light up the LED without a battery?
  - ASK: Why does the LED brightness fade with time?
  - EXPLAIN: Capacitors can also be discharged, so when their energy is going away into another component, that means a slow current is flowing out and so the number of charges on the plates decreases, meaning the voltage across the capacitor decreases until there's not enough current going through the resistor to power the LED
  - CALCULATION: Voltage needed to sustain LED light given the R and minimum current?
  - WORKSHEET: Draw the built circuit, show calculations for LED voltage

- 15 m

- NEW CONCEPT: It's time for another component!!! It's called an inductor. This is also a pretty simple type of component. It's basically a piece of wire that is wrapped around a core multiple times.
  - DRAW: diagram of what an inductor looks like + schematic element
- BUILD: So let's all build an inductor right now! Everyone take the magnet wire on your desk and wrap it around your finger until you run out of wire. Now connect both ends to your LCR meter and measure what the inductance is!
  - What did you guys get as your inductance values?
  - WORKSHEET: Draw inductor and log made inductor values.
- EXPLAIN: So what does an inductor do? Remember how a capacitor stored energy in an electric field? An inductor stores energy in a magnetic field! How can I prove this to you?

- 7 m

   - DEMO: We can take a magnet and move it in and out of a coil and show you that current is flowing through the wire, just by us changing the magnetic field in the core!!
- ASK THE STUDENTS: Now, how does an inductor react to DC voltage, DC current? Anyone have any ideas? I'll give you a hint: an inductor is basically just a wire right? So how does a wire react to DC? It just lets it pass. And the magnetic field doesn't mind because it's constant. This is the OPPOSITE of the capacitor right? The capacitor blocks DC current and voltage.
- ASK THE STUDENTS: How does an inductor react to AC voltage and current? Any guesses? Who thinks the inductor will allow the AC signal to pass through? Who thinks the inductor will try to block the AC signal? Anyone want to explain why they think that?
   - Okay, cool, so let's think about what happens when the inductor experiences very fast changes in current? Well, let's see. Draw diagram of inductor with current going through and a magnetic field. See how when the current is DC or stable, there is a constant magnetic field? That magnetic field is hard to change very fast – so what happens when the current tries to drop to 0 now?
   - Well, the magnetic field can't collapse immediately, so to make up for the drop in current, the voltage across the inductor will spike up super fast to thousands of volts and your inductor will probably burn up and die!
   - WORKSHEET: Explain what inductor does with DC and AC signals
- ASK STUDENTS: Can someone draw for me what inductors in series look like? And what do inductors in parallel look like on a schematic?
   - What do you think their behavior is like? Like a capacitor or a resistor? Any guesses?? Is an inductor more similar to two plates like a capacitor, or to a resistance? → Yes, it behaves more like a resistor in terms of series and parallel.
   - Can anyone come up and write the equations for two inductors in series?
   - And someone for two inductors in parallel?
   - WORKSHEET: Inductors in series and parallel examples
- If time, show students what a motor looks like and what it does.
   - DEMO: of 9V motor running from battery
   - EXPLAIN: model of motor as a resistor. But really the true model is the following: draw resistor, inductor in series with parallel (capacitor, current source)
   - WORKSHEET: Draw two models of a motor
- EXIT: Yay that's it! Everyone's exit ticket is a piece of paper with their (1) rating of the class, (2) list of up to three things they liked a lot, and (3) list of up to three things they didn't like and what they would like instead.

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