Electrical Engineering Workshop (ইলেকিট্রিকাল ইঞ্জিনিয়ারিং) 3 hours/day

Week 2: Designing Basic Circuits ()

Lesson 2.1: Transistors ()

• RECAP/WARM-UP: Build a breadboard layout for this circuit with a new three-terminal device (transistor)
• POSE QUESTION: So far, every circuit that we've made has been a closed circuit. What about an open circuit? What does an open circuit mean and when is it useful?
  o DRAW: Circuit: parallel (V + R1, C, R2)
  o EXPLAIN: (Draw analogies to for example closed animal pen – compare and contrast to closed circuit – derive ideas why you think this circuit is called a closed circuit?) This circuit is closed why? Can anyone give me some ideas?
  o CONFIRM: Yes, because there is a wire connecting all of the elements.
  o ASK: What if I suddenly take out the wire between R1 and C? Then do we have an open circuit or a closed circuit? → Both! Because on the left side, the V and R are not connected to anything anymore so they are not part of a circuit. That's open. But there is still a closed circuit. Can anyone tell me where the closed circuit is?
  o CONFIRM: Yes, exactly. C is still connected to R2 and that forms a full loop.
  o (ASK: REVIEW:) If C is charged, what will happen? → Current will flow and the capacitor will discharge.
  o ASK: Now what if I replace the first wire and take out the wire between C and R2? Where is the closed circuit and where is the open circuit?
  o CONFIRM: Yes, closed on the left, open on the right.
  o (ASK: REVIEW:) What happens to the charge on the capacitor now? → Current will flow from the battery through the resistor and charge up the capacitor.
  o WORKSHEET: Identify open/closed circuits
  o CHALLENGE ASK: Now, can anyone think of why it might be useful to be able to control in this circuit when we open and close each loop?
  o WORKSHEET: Write down thoughts for above question
  o SURVEY: What did you guys think? Pick 2-3 students to give thoughts
  o EXPLAIN: So let's think about it. If we have the left circuit closed and the right circuit open, we can charge the capacitor. Then if we change that to left circuit open and right circuit closed, the capacitor discharges and delivers current to the resistor, right? So that resistor gets some power. So maybe we would sometimes like to control when the resistor gets current? We can control when a part of a circuit is open or closed with a switch!
• NEW CONCEPT: A switch! This component controls when there is a connection between two nodes or not. Switches between open and closed.
  o EXAMPLES: There are certain types of switches that you have to physically flip or push to open and close. Here are some examples. We can think of these switches as having three nodes right? One is the connection to one node in the circuit. The second is the connection to another node in the circuit. The third is the flip or the push mechanism that you have to press to open or close it.
  o NEW CONCEPT: The most common type of switch that doesn't require you to physically push something is a voltage-controlled or current-controlled switch. So with this type of switch, you still have the first two nodes, but instead of the third node being a mechanical thing, you can use a current or a voltage to close the circuit.
• NEW CONCEPT: Another type of component: Voltage and current controlled switches are called transistors: Specifically MOSFET's and BJT's.
  o DRAW: Schematic symbols for MOSFETs and BJTs.
  o MOSFET's are mainly used for lower current applications focused mainly on voltage levels.
  o BJT's are mainly used when you need to produce large currents. Good for high power circuits.
• DEMO: Use large mechanical model for BJT to demonstrate how BJT works.
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○ EXPLAIN: Voltage waiting but no current flowing at the top terminal, called the collector (name makes sense right?). The funnel getting thinner represents resistance to control the current flow when that node gets connected to the bottom node, which is called the emitter. ○ GUIDE: How can we close the circuit to allow the current to flow? Well, we can apply a small amount of current at this third terminal over here, called the gate. ○ ASK FOR VOLUNTEER: Someone come up and insert this small ball into the gate. What happens? The collector node gets connected to the emitter node and the balls from the collector can flow into the emitter now! Now take the small ball out. What happens? The balls stop flowing! This means the connection is open now. (ALTERNATIVE: Make mini versions of this big demo for each group of two to play with.) • NEW PERSPECTIVE: There's another way we can think about this transistor: It take a small current and makes it a large current right? ○ ASK: Do you guys know what it means to amplify? ○ VOCABULARY: An amplifier takes something small and makes it big. So a BJT can act like an amplifier do you see that? In this case it amplifies current, but you can also think about it amplifying a voltage. ○ POSE QUESTION: What do you think will happen if we put a small AC signal at the gate of this transistor (draw graph), and then hook up the collector and the emitter to voltages larger than the signal at the gate? ○ GUIDE THEM THROUGH: If we have this type of transistor (called an NPN), it will amplify positive currents/voltages. So the output will look like what? ○ DRAW: Graph of output voltage ○ ASK: But what if we also want to amplify the negative side of the AC signal at the gate? This is a question that we will try to answer next time! And we're going to play loud music next time so get excited! ○ For now, let's focus on the properties of these transistors by making some circuits! • ASK: How can we use a BJT, resistors, and voltage source to light an LED? ○ GUIDE THEM: Through design of circuit ○ USE WEB APP: To make breadboard layout ○ BUILD: Build the circuit on a physical breadboard • NEW CONCEPT: A MOSFET is similar to a BJT but instead of needing a small current, it needs almost no current at all at the gate. Instead, all it needs is a voltage level greater than or equal to the threshold voltage. ○ DRAW: diagram of MOSFET. Show gate to source voltage (Vgs): this needs to be >= Vthresh. Then current can flow between the drain (top) and the source (bottom) pins. If the Vgs is less than the Vthresh, then current cannot flow between the drain and source pins. ○ ASK: Knowing all this, how can we make a simple switch with a MOSFET? ○ GUIDE THROUGH: Making super simple switch circuit. ○ CHALLENGE ASK: Give a changing analog input voltage and ask them what the output voltage will look like. ○ WORKSHEET: Similar problem to above, but work on it individually • CHALLENGE DESIGN: Battery bad indicator!! ○ POSE QUESTION: A battery is only good when it's in a certain voltage range. For a 9V battery, that's 8.5 V or higher. How can we use a Zener diode, resistors, and MOSFET's to light an LED when the voltage of a battery is too low to be good to use? ○ EXPLAIN: Why this is an important problem to solve. NASA needs to know when their electronic modules are going to die on a spaceship without consuming too much power! ○ GUIDE THEM: Through designing this battery bad indicator. ○ WORKSHEET: Draw out battery bad schematic ○ USE WEB APP: Make your breadboard layout for the battery bad circuit! ○ BUILD: Now build and test it to make sure it works. Pass around a bad and a good battery to everyone so they can make sure their circuit works in both cases! ☺	

• ASK: Based on what we talked about, when do you guys think is better to use a MOSFET over a BJT? When do you think it's better to use a BJT over a MOSFET?
  o SURVEY: See what the students think.
  o DISCUSS: As a class, what the scenarios are.
• ENRICHMENT/CHALLENGE CONCEPT: Let's try to understand the Voltage-Current relationship of a BJT:
  o DRAW: Plot with axes of voltage CE and current C
  o DRAW: One curve. If the gate current is some small value, then this is what the curve looks like.
  o DISCUSS: What does this curve mean?
  o ASK: What happens if we increase the gate current a little bit? Will we get a bigger or smaller collector current?
  o DRAW: The larger gate current curve.
  o EXPLAIN AND DRAW: More curves to represent increasing gate currents.
• 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.	