Knowledge Integration Module 1
Fall 2016
**Basic Objective of KI-1:** The knowledge integration module 1 or KI-1 is a vehicle to help you better grasp the commonality and correlations between concepts covered in ECE 311, 331 and 341 during LSM 1 and 2. All activities relevant to the KI-1 should be performed as a group (you should have received an email telling you who your group members are).

**Prework:** To be completed prior to ECE 341 lecture on Tuesday 20th September, 2016

As a group, study the basic functional building blocks of your cellphone (any smartphone). You should be able to identify what these functional blocks are and their connections to each other. At this point, a detailed knowledge of the operation of each block is not necessary. You are encouraged to access any information source such as the internet, textbooks, periodicals and magazines, youtube videos etc.

As a part of the prework, you will have come across the power supply or power management system (PMS) as one of the functional blocks. For your reference, a schematic of a generic PMS is provided below. Identify all possible concepts, from LSMs 1 and 2 of ECE 311, 331, and 341, that are relevant to understanding how the PMS operates. Make a list of these concepts (concept names only) and bring this list to the first KI-1 class (Tuesday 20th, 12:30-1:45 PM, Weber (Bane, Room # pls)).

![Fig. 1: Basic Schematic of Power Management System](image)

**Laboratory Assignment/Component of the KI:** To be completed prior to ECE 331 lecture on Monday 26th September, 2016

This KI involves four parts (A-D) consisting of laboratory or lab-like activities. These activities are to be done by students working as groups. For those activities which require lab facilities, students will are encouraged to use the labs C 105/107 during the evening hours. If students have any questions/ doubts they can ask the TA Lang Yang during their normal ECE 331 Lab hours.

The circuits of this KI need to be built and tested on the Digilent discovery boards available in C 105/107. The link ([https://learn.digilentinc.com/list](https://learn.digilentinc.com/list)) has all the relevant videos required for students to train themselves on how to use the discovery boards. The important videos for this KI are:

- Project 1: Waveform Generator (Basic Periodic Signals)
- Project 1: Oscilloscope (Basic Waveform Measurement)
- Project 6: Oscilloscope (Exporting Data)
A. Standard Design Problem: In this activity, you will need to design a bridge rectifier circuit as shown in Fig. 1. This bridge rectifier will play the part of the PMS. The rectifier should output $V_{out} = 3\text{V DC}$ with a ripple voltage of less than 10% (~300mV ripple voltage). The components you have at hands are limited in couple of wires, 4 1N914 diodes, a 10 kΩ resistor, a capacitor of arbitrary value and a 60 Hz AC source. In order to satisfy this design specification, what is the value of the capacitor you will need?

Prior to building the circuit, what kind of waveform do you expect to see at $V_{out}$ for a correct design? Sketch this waveform. Also answer the following theoretical questions regarding the rectifier circuit.

- Is this rectifier circuit, in practice, a linear or nonlinear circuit? Is there any way to validate your answer? (Hint: Can you combine different source waveforms from the function generator to demonstrate the principle of superposition?)
- Describe the charging and discharging action of the capacitor in the positive and negative half cycles from the concepts of E-field within a capacitor or charge stored by the capacitor.
- How would your $V_{out}$ change if the capacitor prior to use in the rectifier held some nonzero charge?

Now, take a capacitor of value closest to what you need and build the rectifier circuit of Fig. 1 on the Digilent discovery boards. Measure $V_{out}$ using the oscilloscope. Sketch the output waveform and compare it with what you expected. Does your result match? If not, come up with possible reasons that can explain the discrepancy between expected and measured results.

B. Design Variations: Every group will next to tackle a specific design scenario. Each group needs to take their group number (say x) and $y = (x \text{ mod } 8)+1$ will be the number of the design scenario (1 to 8) you have to consider from the list below. Note that all design scenarios are related to the standard design problem A.

1. Assume that out of the four diodes only one works. Can you implement a rectifier using one diode? To what value does C need to be changed to achieve the same ripple voltage? Build your circuit and measure your output. Compare the measured output with the result from Problem A. Does your circuit match? If not, come up with possible reasons that explain the discrepancy between the results.

2. You are informed that the R and C in Fig. 1 have a +/- 10% tolerance. What will you change in terms of C to guarantee the circuit’s functionality? (You need to think about worst case scenario). Show your reasoning and all mathematical steps.

3. If your capacitor has a parasitic resistance as high as 1 kΩ (modeled as a resistor in series with capacitor in Fig. 2), how will that affect your $V_{out}$? What can you change to maintain the same ripple and peak voltage at 3V if that’s the case? Build your circuit and measure your output. Compare the measured output with the result from Problem A. Does your result match? If not, come up with possible reasons that explain the discrepancy between the results.

![Fig. 2: Considering Capacitor Parasitics](image-url)
4. Assume your source has a source resistance $R_s=500$ Ohms (modeled as a resistor in series with the AC source in Fig. 3). What would you expect as the new output voltage waveform? Build your circuit and measure the output. Compare the measured output with your expected output. Does your result match? If not, come up with possible reasons that explain the discrepancy between the results.

Fig. 3: Considering Non Zero Source Resistance

5. If the R load has a $1 \mu F$ input parasitic capacitance, this capacitor can be modeled in series with load resistor as shown in Fig. 4. What is the expected new output voltage waveform? Why? Build your circuit and measure the output. Compare the measured output with your expected output. Does your result match? If not, come up with possible reasons that explain the discrepancy between the results. Does that disable your design for power supply purpose? Explain.

Fig. 4: Considering Resistance Parasitics

6. Due to faulty manufacturing, the diode D1 is shorted. Will you get a rectifier output? Is there any way to change C and input source amplitude to meet same ripple and peak voltage? Explain. If possible, build your new circuit and measure the output. Show that this output satisfies the specifications.

7. Due to some broken routing, you end up with a big parasitic resistance ($500 \Omega$) at the output of D1/D3 as shown in Fig. 5 (next page). What does that do to your $V_{out}$? What do you need to change to have same peak voltage and ripple voltage at output? Build that circuit and measure the output. Show that this output satisfies the specifications.
8. With your designed AC amplitude, you are only allowed to use up to 60% of the original amplitude but still outputs 3V peak. You are allowed to use one extra capacitor to modify your circuit. (Hint: the extra capacitor can be placed in series with the original cap as shown in Fig. 6. Search the internet for full wave voltage doubler if having issue)

Fig. 6: Considering Voltage Doublers in Design
C: Comparing Numerical Results with Observations.

- Step 1: Build the schematic in Fig. 7. Apply a 5 V amplitude sinusoidal signal from the function generator at 60 Hz. Acquire the output waveform from this schematic and save as .CSV file. (You may name it as RecRC.csv)

- Step 2: Remove R₁, R₂, and C. Use the same function generator setup as in Step 1. Then measure the full wave rectifier output V_{out} without R and C as shown in Fig. 8. Export the acquired data in a .CSV file, such as RecNoRC.csv.
• Step 3: Construct the RC circuit shown in Fig. 9 separately. Set the function generator to create a periodic step function (square wave) of frequency 2 Hz (period 0.5 sec), 50% duty cycle and 5 V amplitude. Next, capture the output data $V_{\text{out}}$ from oscilloscope. Make sure that when you capture the output data all transients have died down (i.e., the output has ‘settled’ down). Export and save the measured data as a .CSV file (e.g. Pulse.csv). The measured data over a positive half cycle (0.25 sec) approximates the step response of the RC circuit. Why is this the case?

![Fig. 9: Schematic for Step 3](image)

• Step 4: Import the CSV file from step 3 (Pulse.csv) into Matlab. Take the 0.25 sec of the data, and differentiate it using the `diff()` command in Matlab. Normalize the resulting signal by the dynamic range of the step function you generated in Step 3. The result of is the impulse response of the R-C circuit in Fig. 9. Why is this the case?

• Step 5. Convolve the impulse response with the signal you recorded in Step 2 (i.e., with RecNoRC) using `conv(.)` command in Matlab. What would this produce?

• Step 6: Compare the result of the convolution with the measured signal in Step 1 (i.e., the signal recorded in RecRC.csv). Comment on the similarities between the two waveforms.
D: Design and build a variable capacitor for the rectifier

Review this, think about it, and discuss in your team. Further instructions on the actual design and building of your capacitor will be sent later.

Design a variable capacitor in pF range with variability of at least 20 pF for the rectifier circuit of Fig. 1. Provide explanation of the working of the capacitor with an estimation of its range. Measure the actual range of capacitance. Use this variable capacitor in parallel with the capacitor in the diode bridge rectifier. Select three values of this variable capacitance – the maximum, minimum, and any intermediate value of your choice. For each value check the output measured in Part A by the oscilloscope. Does this match your expectations? Explain in details.

Capacitance of a capacitor can be varied by varying one of the following three quantities:
(A) Surface area of the overlapping parallel plates/electrodes,
(B) Distance between the electrodes, and
(C) Dielectric of the capacitor.

Some of the ways this can be achieved are:

1) **Match-box area type:** Take a sliding match-box. Inset and fix copper plates through the outer sheath at regular intervals. Connect a lead from the top plate. Insert and fix copper plates in the sliding part in such a way that these plates slide in between the plates on the sheath. Connect a lead connecting all the sliding plates. Sliding the sliding bit in and out will change the surface area and will result in change of capacitance.

2) **Match-box dielectric type:** In this design we replace the copper plates in the sliding bit with dielectric slabs. Sliding the sliding bit in and out will change the amount of dielectric and will result in change of capacitance.

3) **Screw:** Take a plastic screw. Partially screw it in a substrate. Stick a circular copper plate on the underside of the screw-head. Connect a lead from there. Stick a circular copper plate of the same dimensions on the substrate right underneath the first one. Connect a lead from there. Screwing the screw in and out will change the distance between the two plates and will result in change of capacitance. You can also have semi-circular copper plates in which case it will be a combination of A) and B).

4) **CD and cover:** Cover half of CD with aluminum foil and connect a lead. Cover half of one side of the inside of the CD cover with aluminum foil and connect a lead. Place the CD inside the CD cover. Rotate the CD in order to change the capacitance.

5) **Pipes:** Take two pipes of different radii. Cover the pipes with aluminum foil and connect leads. Place one inside the other and slide them in and out to change the capacitance.

6) **Soda can:** Take two soda cans. Cut out their bottoms. Stick paper or plastic sheet on one of the cans. Slide the other can over the first one. Connect leads to both the cans. Slide the cans over each other to change capacitance. For example: [https://www.youtube.com/watch?v=YWLVZ8dF5oo](https://www.youtube.com/watch?v=YWLVZ8dF5oo) – soda can capacitor (varies $S$)

Theoretical, conceptual, and computational questions

Eight sets of questions are provided below. As before, using the value $y = (x \mod 8)+1$ you will select the $y^{th}$ set to answer.
Answer the following questions. Provide detailed solutions and complete work, with sketches of structures, vectors, etc., and all equations, derivations, explanations, and computations.

**Set 1:**

**Capacitors/General**

1. Your variable capacitor should roughly (even if not truly a parallel plate) follow the following formula: 
   \[ C = \varepsilon S/d. \] Using this formula, what value of capacitance do you expect?

2. How much can you vary your capacitor? Which variable are you changing?

3. In what region of the capacitor is energy stored?

4. How much electric energy does your capacitor contain on average when running in the rectifier?

5. Suppose you have an air filled parallel plate capacitor whose plates are separated by 7 mm. The dielectric strength of air is 3 MV/m. What is the breakdown voltage of this capacitor?

6. The capacitor from the previous problem has Teflon inserted into it. Teflon’s breakdown field strength is 60 MV/m. What is the breakdown voltage now?

7. The energy supplied to this circuit is supplied by 60Hz source. Is all the energy getting to the load resistor and capacitor? If not, where is energy being lost?

**PN Junction**

A PN junction has a charge distribution as given below…

\[
\rho(x) = \begin{cases} 
-\rho_0 e^{x/a} & \text{for } x < 0 \\
0 & \text{for } x = 0 \\
\rho_0 e^{-x/a} & \text{for } x > 0 
\end{cases}
\]

1. What is the electric field x-component (Ex) for all x? Use Gauss’ Law in integral and differential form as well as Poisson’s Equation.

2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 2:

Capacitors/General
1. Your variable capacitor should roughly (even if not truly a parallel plate) follow the following formula: \( C = \varepsilon S/d \). Using this formula, what value of capacitance do you expect?

2. In your rectifier circuit, there are voltage drops, meaning that there are electric fields as well. Identify where electric fields in your circuit are located. Try to list as many places as possible.

3. Describe the electric field distribution in and around a parallel plate capacitor.

4. How would putting two capacitors next to each other in parallel affect the total capacitance?

5. How would putting two capacitors in series affect the total capacitance?

6. If you detached the load resistor and your capacitor from the rest of the rectifying circuit, how long would it take for 90% of the capacitor’s charge to dissipate?

7. For the previous problem, how much energy would be discharged over that interval of time? In what form is this energy converted to?

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2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 3:

Capacitors/General
1. The energy supplied to this circuit is supplied by 60Hz source. Is all the energy getting to the load resistor and capacitor? If not, where is energy being lost?

2. Your variable capacitor should roughly (even if not truly a parallel plate) follow the following formula:
   \[ C = \varepsilon S/d \]
   Using this formula, what value of capacitance do you expect?

3. How much can you vary your capacitor? Which variable are you changing?

4. Suppose you have an air filled parallel plate capacitor whose plates are separated by 7 mm. The dielectric strength of air is 3 MV/m. What is the breakdown voltage of this capacitor?

5. The capacitor from the previous problem has Teflon inserted into it. Teflon’s breakdown field strength is 60 MV/m. What is the breakdown voltage now?

6. Describe the electric field distribution in and around a parallel plate capacitor.

7. How would putting two capacitors in series affect the total capacitance?

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2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 4:

**Capacitors/General**

1. In what region of the capacitor is energy stored?

2. How much electric energy does your capacitor contain on average when running in the rectifier?

3. If you detached the load resistor and your capacitor from the rest of the rectifying circuit, how long would it take for 90% of the capacitor’s charge to dissipate?

4. For the previous problem, how much energy would be discharged over that interval of time? In what form is this energy converted to?

5. In your rectifier circuit, there are voltage drops, meaning that there are electric fields as well. Identify where electric fields in your circuit are located. Try to list as many places as possible.

6. Describe the electric field distribution in and around a parallel plate capacitor.

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2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 5:

Capacitors/General
1. How much can you vary your capacitor? Which variable are you changing?

2. How would putting two capacitors next to each other in parallel affect the total capacitance?

3. How would putting two capacitors in series affect the total capacitance?

4. If you detached the load resistor and your capacitor from the rest of the rectifying circuit, how long would it take for 90% of the capacitor’s charge to dissipate?

5. For the previous problem, how much energy would be discharged over that interval of time? In what form is this energy converted to?

6. Suppose you have an air filled parallel plate capacitor whose plates are separated by 7 mm. The dielectric strength of air is 3 MV/m. What is the breakdown voltage of this capacitor?

7. The capacitor from the previous problem has Teflon inserted into it. Teflon’s breakdown field strength is 60 MV/m. What is the breakdown voltage now?

PN Junction
A PN junction has a charge distribution as given below…

\[ \rho(x) = \begin{cases} \rho_0 e^{x/a} & \text{for } x > 0 \\ 0 & \text{for } x = 0 \\ -\rho_0 e^{x/a} & \text{for } x < 0 \end{cases} \]

1. What is the electric field x-component (Ex) for all x? Use Gauss’ Law in integral and differential form as well as Poisson’s Equation.

2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 6:

Capacitors/General
1. If you detached the load resistor and your capacitor from the rest of the rectifying circuit, how long would it take for 90% of the capacitor’s charge to dissipate?

2. For the previous problem, how much energy would be discharged over that interval of time? In what form is this energy converted to?

3. The energy supplied to this circuit is supplied by 60Hz source. Is all the energy getting to the load resistor and capacitor? If not, where is energy being lost?

4. Your variable capacitor should roughly (even if not truly a parallel plate) follow the following formula: \( C = \varepsilon S/d \). Using this formula, what value of capacitance do you expect?

5. In what region of the capacitor is energy stored?

6. Describe the electric field distribution in and around a parallel plate capacitor.

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1. What is the electric field x-component (Ex) for all x? Use Gauss’ Law in integral and differential form as well as Poisson’s Equation.

2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 7:

**Capacitors/General**
1. Your variable capacitor should roughly (even if not truly a parallel plate) follow the following formula: \( C = \varepsilon S / d \). Using this formula, what value of capacitance do you expect?

2. How much can you vary your capacitor? Which variable are you changing?

3. How much electric energy does your capacitor contain on average when running in the rectifier?

4. In your rectifier circuit, there are voltage drops, meaning that there are electric fields as well. Identify where electric fields in your circuit are located. Try to list as many places as possible.

5. How would putting two capacitors next to each other in parallel affect the total capacitance?

6. How would putting two capacitors in series affect the total capacitance?

7. The energy supplied to this circuit is supplied by 60Hz source. Is all the energy getting to the load resistor and capacitor? If not, where is energy being lost?

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\end{cases}
\]

1. What is the electric field x-component (Ex) for all x? Use Gauss’ Law in integral and differential form as well as Poisson’s Equation.

2. What is the charge source of this electric field?

3. Assuming the junction to be infinitely long, what is the voltage across the PN junction from the previous problem?
Set 8:  
**Capacitors/General**  
1. The energy supplied to this circuit is supplied by 60Hz source. Is all the energy getting to the load resistor and capacitor? If not, where is energy being lost?  
2. In what region of the capacitor is energy stored?  
3. How much electric energy does your capacitor contain on average when running in the rectifier?  
4. In your rectifier circuit, there are voltage drops, meaning that there are electric fields as well. Identify where electric fields in your circuit are located. Try to list as many places as possible.  
5. How would putting two capacitors next to each other in parallel affect the total capacitance?  
6. Suppose you have an air filled parallel plate capacitor whose plates are separated by 7 mm. The dielectric strength of air is 3 MV/m. What is the breakdown voltage of this capacitor?  
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