Knowledge Integration Pre-work 1

<u>Basic Objective of KI-1:</u> The knowledge integration module 1 or KI-1 is a vehicle to help you better grasp the commonality and connections between concepts covered in ECE 311, 331 and 341 during LSM 1 and 2. In the KI, we will consider the illustrative example of a general radio system e.g., a cellphone to see how the materials covered in the courses ECE 311, 331, and 341 inform engineering and design.

<u>Pre-work:</u> To be completed and turned into the BC Infill on Monday, September 23rd by 8 am.

Consider the system in Figure 1 and its two (sub)-systems: the rectifier in green and the RC circuit in blue. Assume that all components are ideal (unless otherwise stated) and the characteristics of the components do not change over time.

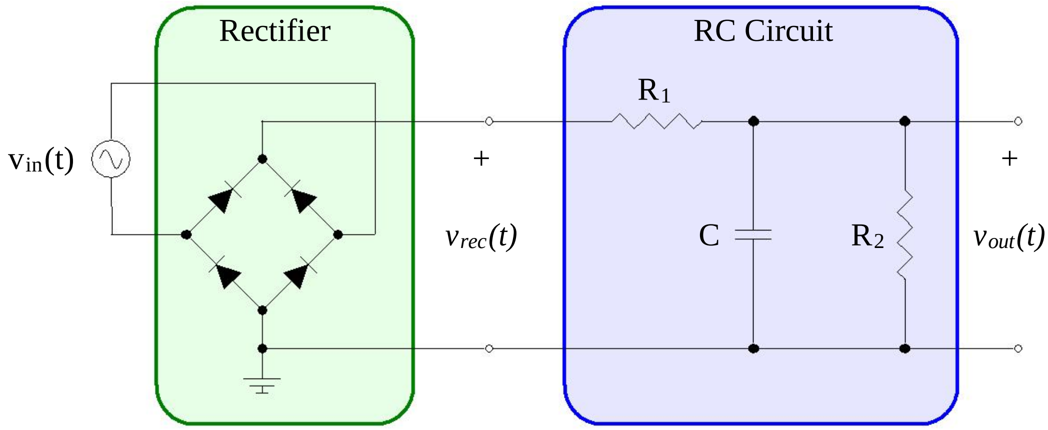

Figure 1: Power Supply Circuit

1) Linearity and time-invariance:
   a. Is the rectifier a linear system? Is it time-invariant? Justify your answers.
   b. Is the RC circuit a linear system? Is it time-invariant? Justify your answers.
   c. If the rectifier is removed from Figure 1, can a DC output voltage be generated from an AC source with the RC circuit alone? Justify your answer.
   d. Find a mathematical expression for the impulse response h(t) of the RC circuit.

2) In diodes, the drift current signifies that the velocity of charge carriers is proportional to the applied electric field E. This is only true for moderate magnitudes of the field E. The velocity is no longer proportional for very high magnitudes of the field E. Why? Feel free to use Google and/or any other electronic resource to explain why this is a problem in MOS transistors.

3) Let us revisit the depletion region in a diode as shown in Figure 2. If the electric field in this region is in the longitudinal (→) direction as shown, we all know this field retards diffusion current but aids drift current. Now, if we add a new electric field in the transverse (↑) direction as well, what will happen to the magnitude of the drift and diffusion current? Can you name a

device where such a transverse electric field occurs (hint: you will definitely cover this device in ECE 331 in LSM 3)? Feel free to use Google and/or any other electronic tools information sources for your answer.

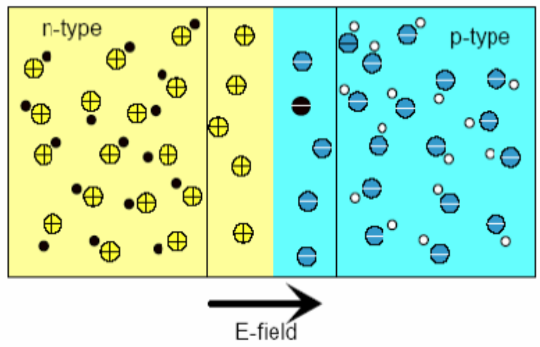

Figure 2: Depletion Region

4) *Convolution*: Consider the entire system in Figure 1. Suppose $vin(t) = Asin(\omega_0 t)$.

a. Using linearity and time-invariance, explain whether or not you expect the output $v_{out}(t)$ of the system to be periodic.
b. Using the convolution integral, find a mathematical expression for $v_{out}(t)$.
Hint:

$$\int \sin(\omega_0\tau)\, e^{a\tau} d\tau = \frac{1}{\omega_0^2+a^2} e^{a\tau}\,(a\sin(\omega_0\tau) - \omega_0\cos(\omega_0\tau))$$

5) Sketched in Figure 3 is a *pn* junction between two semiconducting half-spaces, doped *p* type and *n* type, respectively. The volume charge distribution in the semiconductor can be approximated by the following function: $\rho(x) = \rho_0\,(x/a)\,\exp(-|x|/a)$, where ρ_0 and *a* are positive constants. The permittivity of the semiconductor is ε. Find: (a) the electric field intensity vector in the semiconductor, (b) the electric scalar potential in the semiconductor, and (c) the built-in voltage of the *pn* junction (diode), namely, the voltage between the ends of the semiconductor, from the end on the *n*-type side to the end on the *p*-type side of the junction.

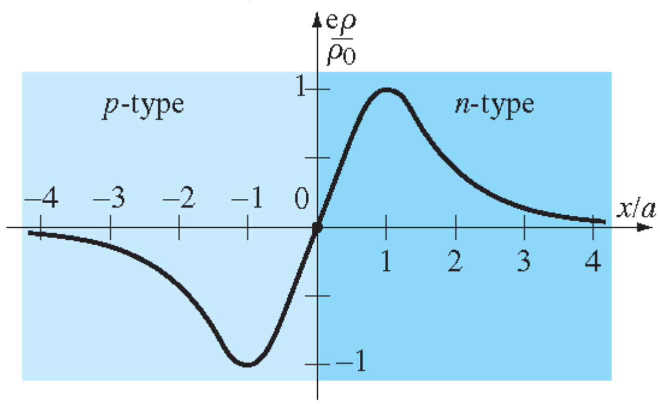

Figure 3: Model of a pn junction with a linear-exponential charge distribution