**University of Michigan**
**EECS 311: Electronic Circuits**
**Fall 2008**

# LAB 3 – PERPETUAL LED (PART 1)

Issued 10/6/2008
Part 1 due in Lecture 10/13/2008

## Introduction

In this lab you will design a stand-alone circuit that is capable of harvesting RF energy from a cell phone and using it to blink an LED. The lab will be designed in two parts: 1) design and build a rectifier stage, and 2) design and build an LED switching stage. These parts are illustrated in Figure 1. All of part 1 should be completed the first week (pre-lab, in-lab, and post-lab) and handed turned in 10/13 in lecture. Part 2 will be assigned the second week.

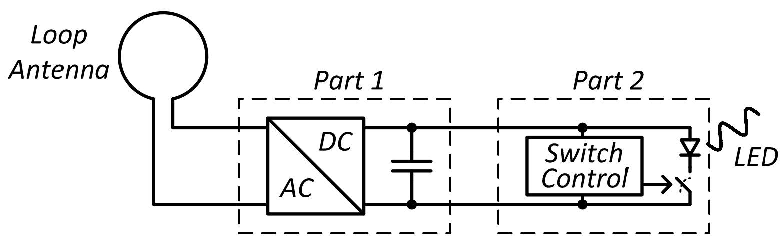


**Figure 1. Overview of lab 3 components.**

During a call, your cell phone is sending and receiving voice information to and from a base station, usually located less than a mile away. A GSM phone (i.e. specifically GPRS/EDGE - most AT&T phones) transmits your voice on a signal with the following characteristics. The signal from the phone will be centered at a frequency around $850MHz$, and will transmit in short bursts of signal that are $570\mu s$ long that repeat every $4.6ms$. This is shown in Figure 2.

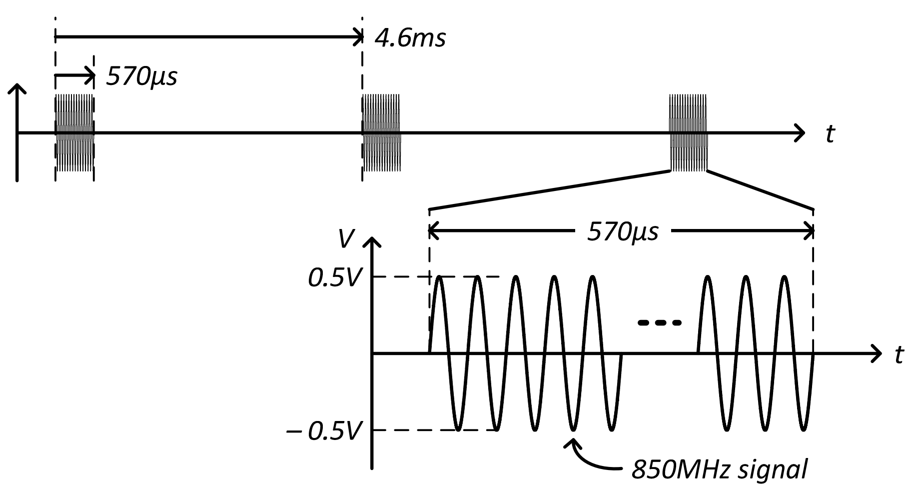


**Figure 2. Signal transmitted from a GSM phone.**

**Part 1 – Rectifier Stage**

This week you will design and build the radio frequency (RF) rectifier stage. This stage will convert a sine wave into a DC signal, boosting the voltage using switched capacitors. The specifications of the rectifier are given in Table 1.

| Specification | Value |
|---|---|
| RF Center Frequency | 850MHz |
| RF Signal Duration | 570µs |
| RF Signal Repetition Rate | 4.6ms |
| RF Source Impedance | 300Ω |
| DC Storage Capacitor | 33µF |
| Rectified DC Voltage | 1.7V |

**Table 1. Rectifier specifications.**

The signal from the cell phone will be captured using a loop antenna tuned to $850MHz$. This antenna can be modeled by a voltage source with a source impedance of $300\Omega$ as shown in Figure 3.

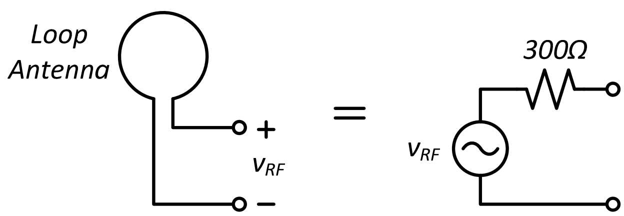


**Figure 3. Thevenin equivalent circuit for the loop antenna.**

**Part 1 Pre-Lab Exercises**

**P3.1** The schematic for the voltage-boosting rectifier discussed in lecture is shown in Figure 4. The final stage DC output voltage can be approximated by $V_{DD} \approx N(V_{amp} - V_{ON})$ where $V_{amp}$ is the amplitude of the input sine wave, and $V_{ON}$ is the diode on voltage. Given the Schottky diodes have a turn-on voltage $150mV$, calculate the minimum number of stages required to meet the specified value for $V_{DD}$.

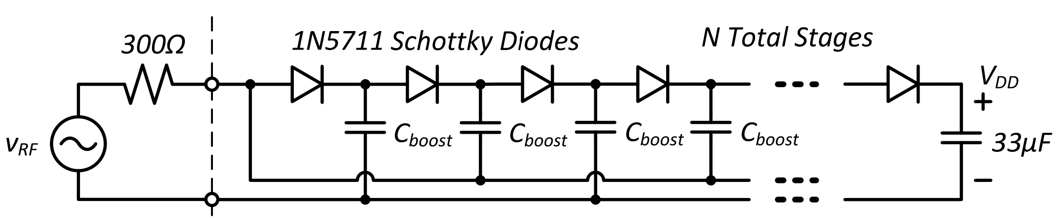


**Figure 4. Voltage-boosting rectifier circuit schematic.**

**P3.2** Build the rectifier in Cadence and simulate to choose a value for $C_{boost}$.

a) From the *Library Manager*, create a new library named *lab3* (do not attach a techfile). Create a new schematic cell view named *rectifier*.

b) Built the circuit shown in Figure 4 using the number of stages chosen in P3.1. For the input, use the *vsin* component from the *AnalogLib* library. Give it an amplitude of 0.5V and frequency of 850MHz. For the diodes, use the *diode* component from the *AnalogLib* library. In the model name field, enter *1n5711*. The final stage capacitor should have a value of $33\mu F$, also **give this capacitor an initial condition of $\mathbf{0.5V}$**. For each boost capacitor, for the value of capacitance, give it the variable name *cboost*.

c) Open Analog Environment and add the design variable *cboost*. Give *cboost* an initial value of $100pF$. Perform a transient simulation (check *conservative* accuracy) for $10\mu s$. Note that this is not long enough to observe the final value of $V_{DD}$, however the initial change in $V_{DD}$ should be observed. The simulation to find the final value of $V_{DD}$ takes a very long time, therefore you'll only look at the initial change. Experiment with different values of *cboost*. Find a near optimal value for *cboost* that results in the fastest charging rate of the $33\mu F$ capacitor over the $10\mu s$. Measure the charging rate. Use only capacitor values that are available in the lab, which can be found at the following site, and do not use a value larger than $10nF$.

http://www.eecs.umich.edu/courses/eecs311/f08/labs.html

Print the result of a transient simulation using your final value of *cboost* and turn this in.

**Hint:** Try out the *Parametric Analysis* tool in *Analog Environment* (*Tools > Parametric Analysis* …). Use this to simulate multiple transient analyses at once while sweeping the value of *cboost*.

**P3.3** The loop antenna you will use to capture the signal from you phone can be made out of hookup wire in the lab. The antenna is simple a circular loop of wire, where the circumference of the loop should equal one wavelength. Calculate the wavelength of an $850MHz$ wave travelling in freespace at the speed of light.

**In-Lab Exercises**

You will now build your rectifier stage. In your labkit, you are given several 1n5711 diodes – they are banded together with paper strapping. The pinout of diode is shown in Figure 5. Which side of the diode symbol is the **A**node?

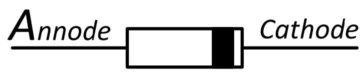


**Figure 5. 1N5711 Schottky diode pinout.**

**L3.1** Before connecting the rectifier to an antenna, you will verify its operation using the function generator as the source. The source resistance of the antenna should be correctly modeled, as shown in Figure 3. Therefore, wire the function generator to a $240\Omega$ resistor on your breadboard, and use the opposite end of this resistor as your test input source. Configure the function generator as a sine wave, high-Z mode, frequency of $20MHz$, peak-peak voltage of $1V_{ppk}$, and $0V$ offset voltage.

**L3.2** Begin building your rectifier circuit using the schematic in Figure 4 as a guide, with the number of stages and value of $C_{boost}$ found in your prelab. It is recommended you use the small breadboard found in your labkit. Build your circuit one stage at a time and measure the output voltage after adding each stage to verify the circuit is working properly.

**Hint:** Trim the leads on your components to keep them short (minimizes parasitic inductance), and try to minimize the number of rows used on your breadboard to build your circuit (minimizes parasitic capacitance).

**L3.3** Once the complete circuit has been built, have your GSI come by and show you how to capture the startup transient on the scope. Record the final value of the DC voltage at the output stage. Record the peak-peak ripple voltage on the DC output. Record the time it takes to reach the specified value of $V_{DD}$ of $1.7V$. Sketch the transient response. Have the GSI check you off on this part.

**L3.4** Now build a loop antenna tuned to $850MHz$. Cut a piece of hookup wire to the length found in P3.3. Form the wire into a circle, and connect both ends of the loop to the positive and negative inputs of your rectifier (**remove the $240\Omega$ resistor**). Find someone with a GSM cell phone (AT&T uses GSM, T-Mobile and Verizon do not). Ask them to place a call (e.g. to voicemail). Put the phone near the loop antenna while measuring the DC voltage on a scope or multimeter. Record the highest DC voltage you are able to “harvest” from a cell phone.

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LAB 3 (PART 1) – PRE-LAB REPORT TEMPLATE

NAME: ________________________________________ LAB SECTION: ____________

**Pre-Lab Exercises**

**P3.1** Minimum number of stages: $N =$ ______________

**P3.2** **Use only component values available in the 311 lab, listed at** **http://www.eecs.umich.edu/courses/eecs311/f08/labs.html**

Optimal value of $C_{boost}$: $C_{boost} =$ ______________

Attach a Cadence plot of the transient response of $V_{DD}$ over $10\mu s$.

Charging rate of $V_{DD}$: $m_{rate}$ = ______________ [V/s]

Assuming the $33\mu F$ capacitor charges with an exponential response, the time constant can be calculated from the initial slope of the response ($dV/dt|_{t=0} = (V_{final} - V_{initial})/\tau$). Calculate the charging time constant using the rate found above:

$\tau = (V_{final} - 0.5V)/m_{rate}$ = ______________

**P2.3** Wavelength: $\lambda =$ ______________

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LAB 3 (PART 1) – CHECK-OFF SHEET

Have the GSI check you off on the following exercises after you have completed them. Be prepared to answer questions about your circuit or the results.

**Exercise ........................................................................................ Date Completed**

P3.x Prelab Report Template.................................................................._______________

L3.3 Complete rectifier stage ................................................................_______________

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LAB 3 (PART 1) – REPORT TEMPLATE

NAME: ________________________________________ LAB SECTION: ____________

Use the following lab report template to record your measurements. Use the space provided to answer questions.

**Lab Report Template**

**L3.2** Value of $C_{boost}$ used in lab: $C_{boost}$ = _____________

**L3.3** Rectifier circuit

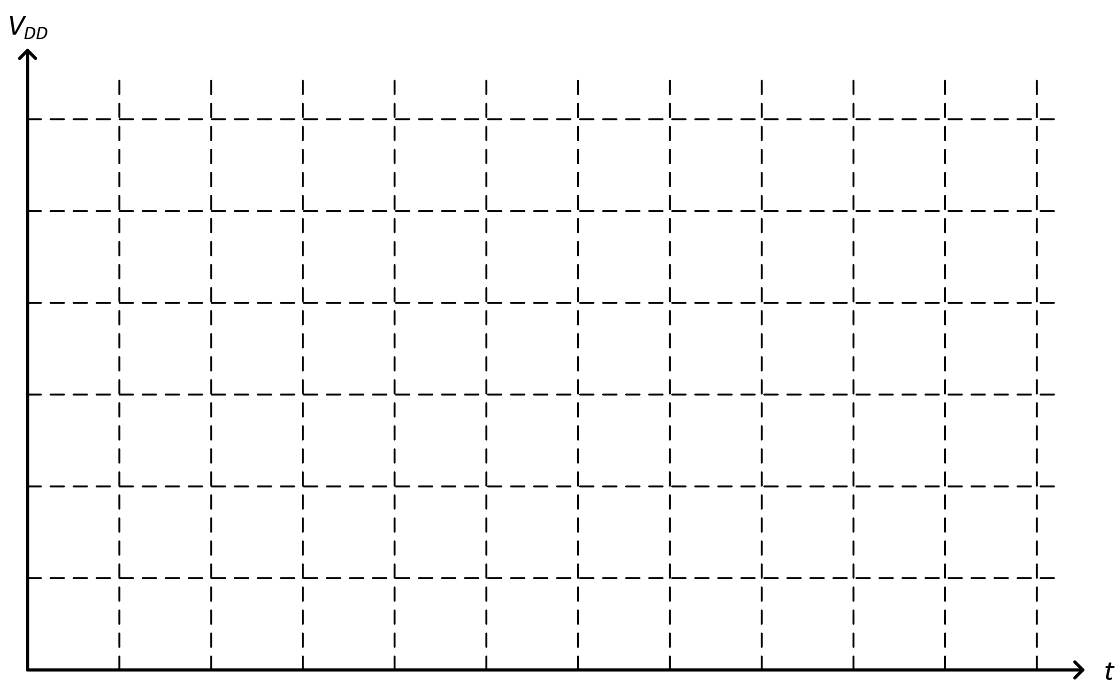
Response of $V_{DD}$ to a $1V_{ppk}$, $20MHz$ input sine wave:

Final value of $V_{DD}$ = _____________

Peak-Peak ripple voltage on $V_{DD}$ = _____________

Time from $0V$ to $1.7V$ = _____________

Sketch the transient response of $V_{DD}$:



Is the response of $V_{DD}$ (roughly) exponential? _______________

Approximate the time constant of the response: $\tau$ = _______________

Is this greater or less than the time constant found in the prelab? What is a possible reason for any change?

**L3.4** Highest $V_{DD}$ harvested from a phone: $V_{DD,max}$ = _______________

Service provider and manufacturer of the phone used.

Service provider (e.g. AT&T) = ______________________________

Manufacturer (e.g. Samsung) = ______________________________

In the space below, approximate the amplitude of the received RF signal and briefly explain how you arrived at this number. Base your approximation on your measurement of $V_{DD}$ with the function generator source at $1V_{ppk}$, and your measurement of $V_{DD}$ from the cell phone and antenna.