University of Michigan
EECS 311: Electronic Circuits
Fall 2008

LAB 3 – PERPETUAL LED (PART 2)

Issued 10/13/2008
Part 2 due in Lecture 10/27/2008

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.

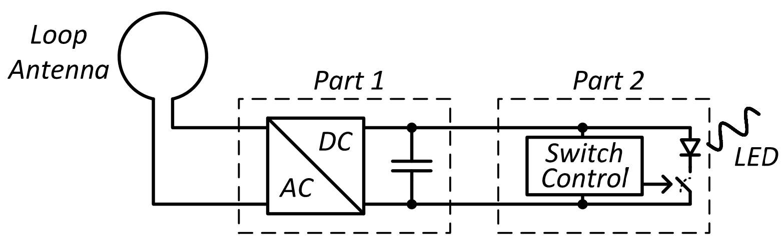

Figure 1. Overview of lab 3 components.

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 that are $570\mu s$ long and repeat every $4.6ms$. This is illustrated in Figure 2.

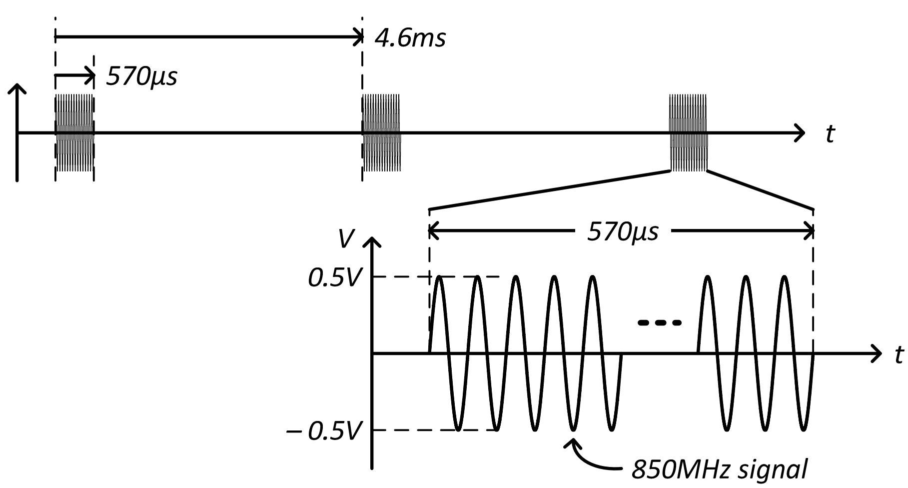

Figure 2. Signal transmitted from a GSM phone.

Part 2 – Hysteretic LED Switching Circuit

This week you will design and build the stage that controls the turn-on/turn-off of the LED, powered by the rectifier stage. This stage will detect when the rectified DC voltage reaches an upper threshold and then turn on the LED. This begins rapidly discharging the storage capacitor. When the DC voltage reaches a lower threshold voltage, the LED is turned off. This operation of switching with two thresholds is called hysteresis. The design specifications are given in Table 1.

Specification	Value
LED Turn-on Voltage	1.7 V
LED Turn-off Voltage	1.5 V
Power at 1.7 V (without LED)	100 μW

Table 1. Hysteretic LED controller specifications.

Part 2 Pre-Lab Exercises

In some pre-lab exercises, you are asked to choose values of resistors. Use only values available in the lab, which can be found at the following website.

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

P3.1 The circuit used to power the LED is shown in Figure 3. Show that this circuit has two stable modes of operation: 1) NPN and PNP in cutoff, 2) NPN and PNP on. Solve for the base and collector currents in the PNP transistor in both modes of operation. Also, identify the regions of operation of the NPN and PNP in both modes.

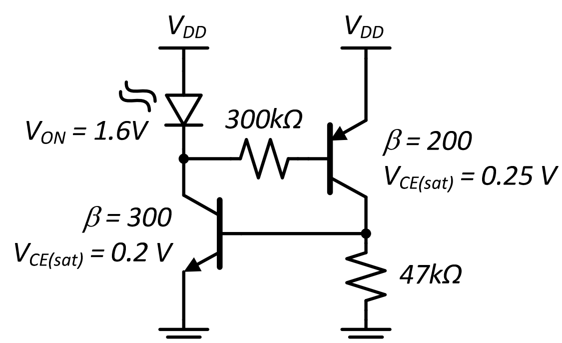

Figure 3. Bi-stable LED circuit.

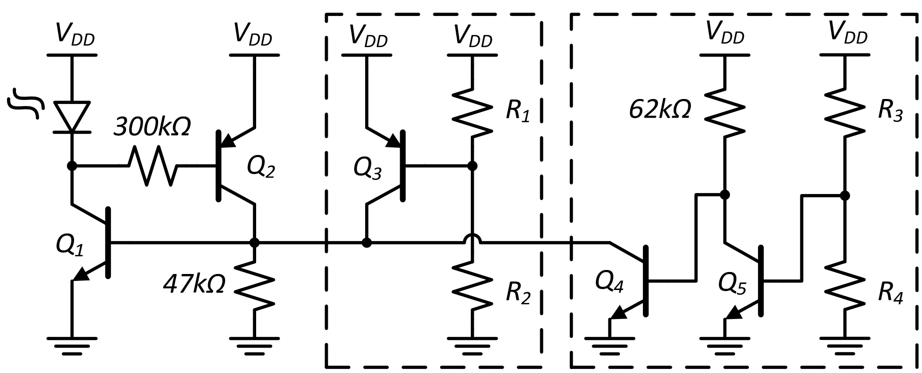

Figure 4. Complete switching circuit.

P3.2 The complete circuit is shown in Figure 4. The bi-stable LED circuit is forced into the "on" mode by driving current onto the $47k\Omega$ resistor with the PNP transistor Q_3. The circuit shown in Figure 5 will be used to detect the turn-on voltage threshold (Table 1). The PNP device is defined as on when the base-emitter voltage reaches -0.7V. Derive expressions for R_{TH} and V_{TH} in terms of V_{DD}, R_1, and R_2. Determine values for R_1 and R_2 that will turn on the PNP when V_{DD} reaches the turn-on voltage (ignoring base current). Take into account the specification on total power consumption when choosing resistor values.

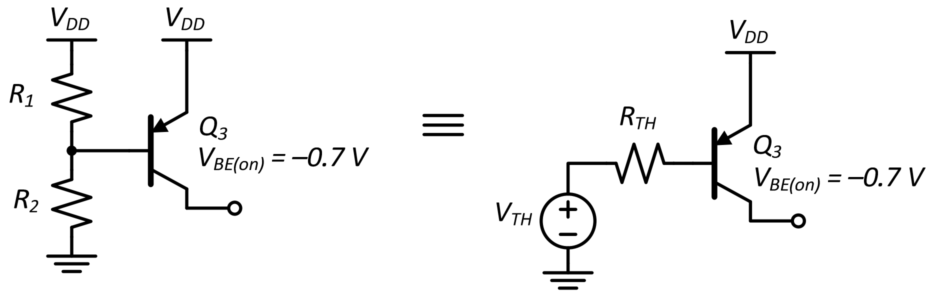

Figure 5. Turn-on threshold detection circuit.

P3.3 The bi-stable LED circuit is forced into the "off" mode by using Q_4 to pull down the base voltage of Q_1 in Figure 4. The circuit shown in Figure 6 will be used to detect the turn-off voltage threshold (Table 1). When V_{DD} drops below the turn-off threshold voltage, Q_5 turns off and Q_4 turns on, forcing the LED circuit to the off mode. The NPN is defined as on when the base-emitter voltage reaches 0.7V. Derive expressions for R_{TH} and V_{TH} in terms of V_{DD}, R_3, and R_4. Determine values for R_3 and R_4 that will turn on the Q_5 when V_{DD} equals the turn-<u>off</u> voltage (ignoring base current). Take into account the specification on total power consumption when choosing resistor values.

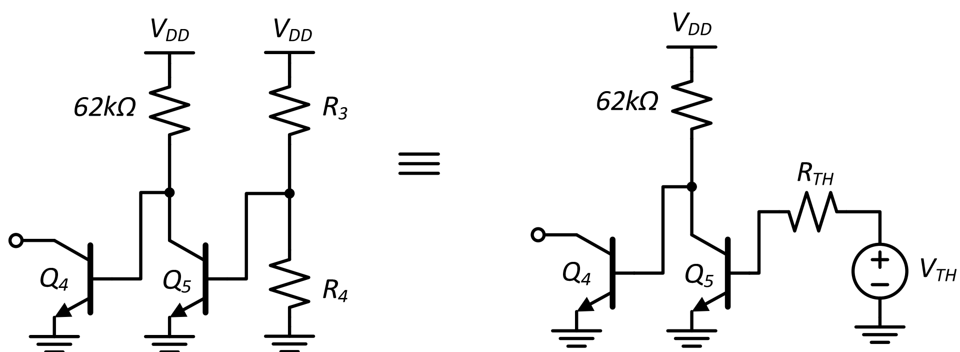

Figure 6. Turn-off threshold detection circuit.

P3.4 Open Cadence and create a new cell in your *lab3* library called *ledcontrol*. Build the circuit shown in Figure 4, using resistor values found in the previous parts. Use the *lab3_led* component found in the *EECS311Lib* library for the LED. For the NPN devices, use the *AnalogLib > npn* component. Give each npn a model name of *2n3904_typical*. For the PNP devices, use the *AnalogLib > pnp* component. Give each pnp a model name of *2n3906_typical*. Do not add a voltage source for V_{DD} yet.

P3.5 In your *ledcontrol* schematic, add a piecewise-linear voltage source connected to the V_{DD} pins and ground. This source can be found in *AnalogLib > vpwl*. Within the *vpwl* properties, change the number of pair points to *4*, and enter the pairs given in Table 2.

Time	Voltage
0	0
10m	2
20m	2
30m	0

Table 2. Time-voltage pairs for piecewise linear voltage source.

Perform a transient simulation of your circuit and determine the values of V_{DD} that turn on and off your LED circuit. Attach a plot of your simulation.

P3.6 Remove the *vpwl* source and replace it with a $33\mu F$ capacitor. Give the capacitor an initial condition of *2V*. Perform a transient simulation of your circuit and determine the length of time the LED stays on. Attach a plot of your simulation.

Part 2 In-Lab Exercises

As with any large circuit, you will build and test each stage individually before assembling the entire circuit. You'll start by building the switching stage and testing it with a power supply as the DC voltage source. Then you will replace the source with your rectifier stage from Part 1 and try powering the LED with a signal generator and a cell phone.

L3.1 Build the circuit shown in Figure 4 using the component values found in the prelab. For now, wire all V_{DD} and ground pins together, but do not connect them to any supply or to your rectifier circuit from Part 1.

L3.2 Connect the DC power supply to your V_{DD} and ground pins. Begin with the power supply set to 0V and slowly increment the voltage until your turn-on circuit turns on the LED. Record the voltage at which the LED turns on. Once the LED is on, next slowly lower the DC supply voltage and record the value at which your turn-off circuit turns the LED off. Finally, vary the DC voltage from 0 to something over your turn-on voltage several times to make sure the turn-on/turn-off operation is repeatable. Show your circuit to the GSI.

L3.3 Remove the connection to the DC supply and connect the output of your rectifier from Part 1 to the V_{DD} and ground pins. Connect the input of the rectifier to the signal generator through a 240Ω resistor, the same as you did in Part 1. Configure the signal generator as a sine wave, frequency $20MHz$, and high-Z mode. Increase the amplitude of the function generator until the LED just begins to blink. Record the peak-peak voltage required to power your LED.

L3.4 Finally, replace the function generator with the antenna built in Part 1. Use your cell phone to power the rectifier by placing a call and holding your phone very close to the antenna. You may need to try out different positions of the phone to get any rectified voltage. Probe the DC voltage with an oscilloscope while powering the rectifier to verify it is charging and record the peak voltage seen on the rectified V_{DD}.

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LAB 3 (PART 2) – PRE-LAB REPORT TEMPLATE

NAME: ____ LAB SECTION: ____________

Pre-Lab Exercises

P3.1 PNP base and collector currents, and regions of operation in two modes:

Off Mode: NPN Region = ______________ PNP Region = ______________

PNP I_B = ______________ PNP I_C = ______________

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

R_{TH} = ______________ V_{TH} = ______________

R_1 = ______________ R_2 = ______________

Power in R_1 and R_2 branch at 1.7V = ______________

P3.3 **Use only component values available in the 311 lab, listed at** **http://www.eecs.umich.edu/courses/eecs311/f08/labs.html**

R_{TH} = ______________ V_{TH} = ______________

R_3 = ______________ R_4 = ______________

Power in R_3 and R_4 branch at 1.7V = ______________

P3.5 Piecewise linear simulation in Cadence.

Turn-on voltage = ______________

Turn-off voltage = ______________

Attach a plot of your simulation.

P3.6 Transient simulation of capacitor source with initial condition.

On-time of LED = ______________

Attach a plot of your simulation.

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LAB 3 (PART 2) – CHECK-OFF SHEET

NAME: ______________________________________ LAB SECTION: ____________

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 ....________________

L3.2 Switching stage with DC source ....________________

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LAB 3 (PART 2) – 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

L3.1 Values of resistors used in lab:

$R_1 =$ _____________ $R_2 =$ _____________

$R_3 =$ _____________ $R_4 =$ _____________

L3.2 Switching circuit powered by voltage source.

Turn-on DC voltage = _____________

Turn-off DC voltage = _____________

L3.3 Switching circuit powered by rectifier with signal generator source.

Peak-peak voltage required to blink LED = _____________

L3.4 Complete circuit powered by cell phone.

Peak rectified voltage seen from cell phone signal = _____________

Number of rectifier stages used = _____________