EE330 Mini-Project: Microwave Leakage Detector

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1 Introduction

The harvesting, or ”capturing” of RF energy, is one of many harvesting processes, similar to solar, thermometric, and wind, defining the process by which energy is sourced from external sources. The device above demonstrates the capturing of transmitted RF signals as a method to directly power a low power circuit, in this case an LED. The circuit designed above explores a rudimentary form of conversion, and is in no way efficient, as impedance matching and many other nuisances was was not explored.

2 Circuit-Theory

The design of this circuit revolves around a voltage multiplier, commonly called a voltage doubler. There are various ”versions” of voltage multipliers, however; for implementation, the Greinacher circuit was imposed as the voltage doubler layout. The Greinacher circuit, was chosen over a more simpler circuit, such as the Villard Circuit, due to its improvements from the latter, such as reduced ripple. This was an unnecessary upgrade, as either circuitry would have sufficed for its application, powering an LED.

2.1 The Diode

The implemented circuit, utilizes a BAT15-03W diode, a single silicon RF Schottky diode from Infineon. Infineon markets these diodes specifically for their RF applications, and includes various application notes and implementations notably for RF power detection circuits. More specifically, these diodes were used for their low barrier height and small forward voltage, which would become increasingly more important were there to be more stages, of the ”voltage doubler” implemented for greater voltage output. In general, the circuitry involved to ”capture” RF energy, even if the Greinacher circuit was not implemented, would need to consist of a diode, preferably a schottky diode, as this is the component that convert’s the RF’s AC signal, to a DC signal. A DC signal is preferred for this application, as without it, the LED would conduct for only the positive half cycle, essentially forming a half wave rectifier.

2.2 Voltage Doubler

The circuit designed for this device, closely follows the Greinacher circuit depicted in **Figure 2**. This circuit operates under the principle that the voltage arriving at the output of the circuit, should ideally be twice the peak voltage of the input waveform. The circuit consists of two main components, two diodes and two capacitors. In general, the circuit operation can be explained as rectifying the input signal for both the negative half of the input cycle, and the positive half of the input cycle. When the input voltage is negative, shown in **Figure 2**, C_1 will charge up as diode D_1 is in forward bias. Since this occurs during the negative half cycle of the input, C_2 will be unaffected, as D_2, is reversed biased. During the positive half cycle of the input, D_1 will now be in reverse bias, and D_2 will now be in forward biased. It is seen then, that the voltage applied to D_2 and C_2 will be the sum of the voltage on C_1 and the input voltage. Capacitor 2, will then be charged to twice the input.

Figure 2, can be called a single stage doubler, which can be further developed by connecting stages in series. Of course this has its limitations, and eventually after a set number of stages, the voltage will reach its maximum output. This circuit design, provided the necessary means to not only convert the RF signal to a DC output, but also enables the LED to respond to such input signals without the needs for additional amplifies, as the typical input signal would be significantly small.

Parameter	Symbol	Values			Unit	Note or test condition
		Min.	Typ.	Max.		
Breakdown voltage	V_{BR}	4	–	–	V	I_R = 100 µA
Reverse current	I_R	–	–	5	µA	V_R = 1 V
Forward voltage	V_F	0.16	0.25	0.32	V	I_F = 1 mA
		0.25	0.35	0.41		I_F = 10 mA
Differential forward resistance	R_F	–	5.8	–	Ω	I_F = 10 mA / 50 mA [1)]
Capacitance	C	–	0.28	0.35	pF	V_R = 0 V, f = 1 MHz
Inductance	L_S	–	1.8	–	nH	

Figure 1: Electrical Characteristics for Infineon BAT15-03W Diode

2.3 The Antenna

With the goal of detecting microwave leakage, which emits a frequency of $2.4GHz$, an antenna suitable for such ranges was sourced. Taoglas Limited, produces one of the smallest coaxial cable 2.4Ghz antenna, which suits the circuits purpose of detecting microwave leakage. The antenna has an incredibly small profile, $5.9 \times 4.1 \times 0.24mm$, and has a frequency range of $2.4 - 2.5GHz$ with a Center/Band frequency of $2.4GHz$. Instead of making a simple dipole antenna from a wire, this antenna made for a simpler implementation with a printed circuit board.

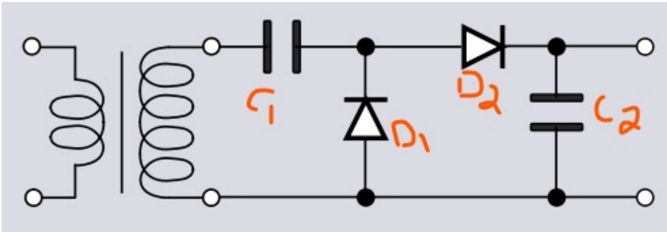

Figure 2: Voltage Doubling circuit, producing a DC output double the input

3 PCB Design Process

The following PCB was designed in the program KiCad, a free software suite that allows for electronic design, for both schematic layout and PCB layout. Thre process began by creating a component list for the desired circuit, from which symbols and footprints would be designed accordingly in KiCad. The following table displays all the components utilized in the circuit design.

Name of Component	Label	Value
Diodes	$DSmall_1$-$DSmall_4$	BAT15-03W
Capacitors	C_1-C_2	$0.1\mu f$
Load Resistor	R_1	110Ω
MHF1 Connector	J1	N/A

3.1 KiCad PCB Schematic

All components had pre-established symbols and footprints, as most were fairly common. The only expectation as the MHF1 connector, used to connect the antenna to the PCB. Luckily enough, I-PEX the designer of the I-PEX MHF1, the connector used in the circuit, partnered with SnapEDA, a company that provides footprints for various components. The schematic for the RF detector, designed in KiCad can be seen in **Figure 3**. Originally, the design followed a Greinacher circuit quite accurately, however two storage capacitors were removed as a final revision. Being the case that the goal was to light an LED when in the proximity of an RF signal, it seemed optimal to remove those capacitors, as with them the LED would continue to stay on for a small time duration, even after exiting the area where RF signals should be detected.

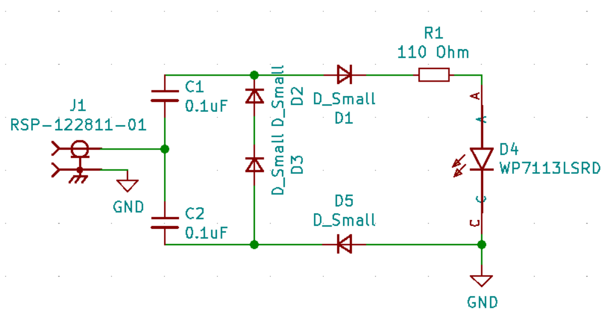

Figure 3: KiCad Schematic for RF Detector Circuit

3.2 KiCad PCB Tracing/Layout

With the symbols established and footprints assigned, the PCB could be laid out and traced. **Figure 4** displays the completed PCB with all components placed and traced accordingly. The image seen on the front of the silkscreen was sketched in AutoCAD, and displays an image of a microwave and what I like to imagine, is a good hot bowl of Pho...my favorite.**Figure 5** is the completed imagine in AutoCad, which was exported as a DXF, and placed on the front silkscreen layer. The edge components of the imported DXF, were then used to establish the edge cuts for the PCB. Regrettably, the text EE340, which should have read EE330 (this class), was not noticed until after the designs were sent to the manufacturer/fabricator.

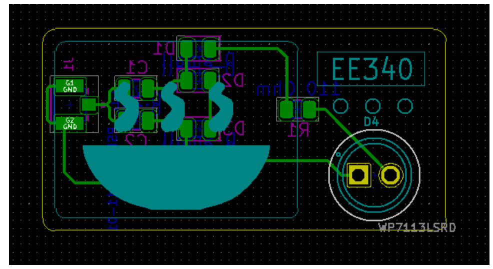

Figure 4: KiCad PCB Layout for RF Detector Circuit

3.3 Fabricating the PCB

Typically, the circuits I design get sent over seas and fabricated by a company called PCBway, however; time concerns were can issue and shipping could potentially take a few weeks. Luckily, there is an exceptional manufacturer based in Portland Oregon, that can produce rapid prototyping PCB's and will ship out the PCB in under two days. The printed circuit board was manufactured on the standard (FR4), with a thickness of $1.6mm$. The board's dimensions were kept minimal, and the overall board the dimensions of $32.0 \times 16.0mm$.

Precautions were taken when hand-soldering the PCB, especially in an attempt to avoid Electro Static Discharge while placing the Shottky Diodes. The finished product can be seen in **Figure 5**.

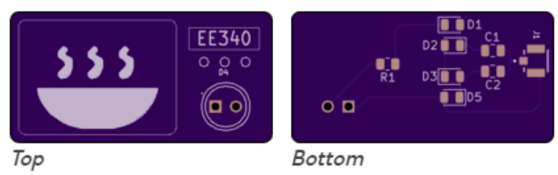

Figure 5: Finalized PCB Layout sent to OSHPARK for fabrication

4 Video Demonstration

The video demonstrations of the designed RF detector can be found through my github repository, along with all the files for the PCB.

5 Sources

- Circuit Design for Energy Harvesting From Digital TV Band
- Enhanced RF to DC converter with LC resonant circuit
- Joe TATE Ambient Power Module
- Greinacher Voltage Doubler