ECE 6361 Project 3: 5.8 GHz Energy Harvester

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Abstract— **This paper presents a high performance AC-DC charge pump that converts 5.8 GHz RF continuous wave signal to a DC voltage to power an LED. The required voltage to drive the LED is 2.1 V with 1 mA current. The charge pump design presented uses conventional techniques, i.e using only diodes and capacitors. The fabrication of the design board was completed in-house. Measurement results show the charge pump provides good performance, as it drives the LED with as low as 3.9dBm input power at 5.8GHz**

I. Introduction

The area of power scavenging has attracted much attention in recent times. Various methods (piezo-electric, electronic, and polymers) are currently being researched and employed for this purpose. For this project, we will consider an electronic method (charge pump) to scavenge RF power. Charge pumps generate a higher output voltage than the input supplied voltage from which they operate. High efficiency rectifiers are used to convert AC voltage into DC output; However, the output of the conventional rectifiers have reduced output voltage with high input signal, hence charge pumps are used to raise the output voltage [1]. A charge pump consists of only diodes and capacitors. A basic AC-DC charge pump with diodes generating positive voltage is shown in Fig. 1. By cascading more than one stage, the charge pump can be made to produce higher output voltages (but lower current). To avoid high threshold voltage drop commonly associated with MOSFET devices (the threshold voltage drop directly affects the output voltage), Schottky diodes were used in this project. In addition to the threshold voltage drop, Schottky diodes are also preferred due to their better rectifying efficiency [2], [3].

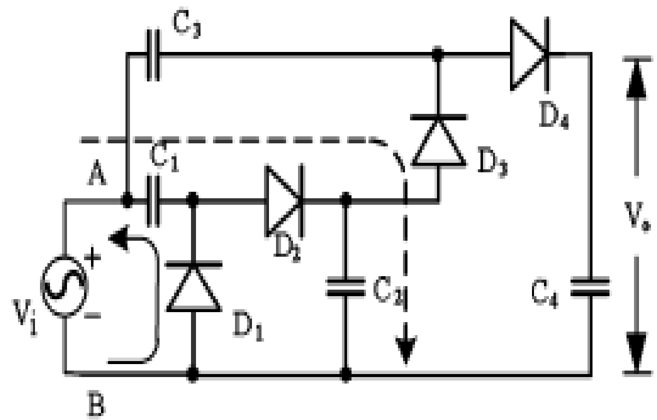

Fig. 1. Conventional charge pump design.

In this project, the design of a microwave charge pump, which converts 5.8GHz continuous wave RF input signal into a DC power supply, is considered. The DC supply is used to power a light emitting diode (LED). The design uses a Schottky diode by Avago, the HSMS2862 series, an 850 pF DC blocking capacitor, and a green CMD28-21 LED. In addition, a matching network was considered prevent any losses due to mismatch between charge pump and 50Ω SMA. Note that the matching network itself was not simulated due to the difficulty of determining the load impedance (the charge pump circuitry). A lumped element matching network was included in the board layout for future use once the load impedance was measured. However, it was found that the charge pump worked without the matching network with input power of only 4dBm.

Section II describes the design process and the selection of the number of stages. The simulation results are given in Section III. The layout and measured results are shown in Section IV and V, respectively. Finally, the paper concludes with a brief summary.

II. Charge Pump Design

Utilizing Agilent ADS simulation software, three, four, and five stage charge pumps were investigated. In order to simulate effects of the LED, a 1mA current source in series with a 2 kΩ resistor was used (for 2 V output voltage).

From the ADS built-in model libraries, HSMS8262 Schottky diodes were chosen to account for the parasitic effects of the package in simulations. Figures 2, 3, and 4, show the designed charge pump schematics with an input DC blocking cap of 10 pF and equivalent LED model.

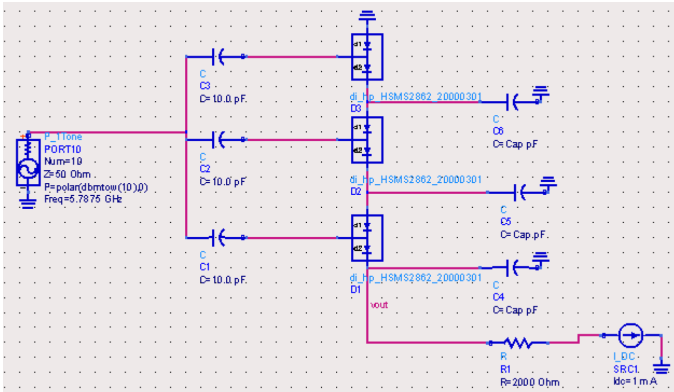

Fig. 2. 3-stage charge pump schematic.

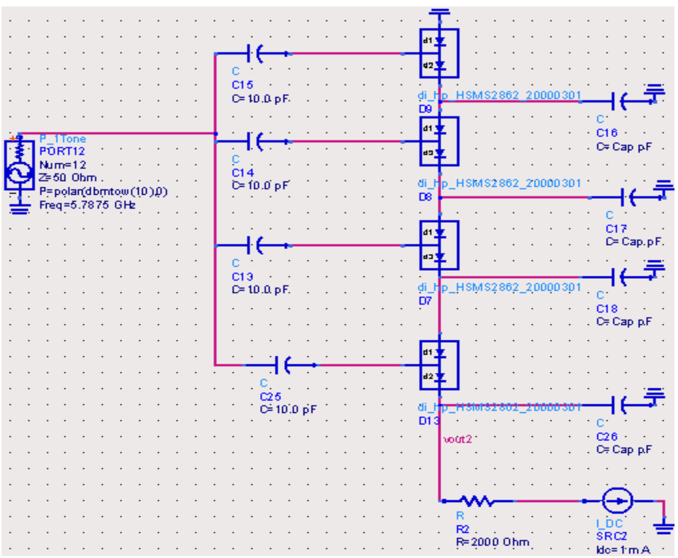

Fig. 3. 4-stage charge pump schematic.

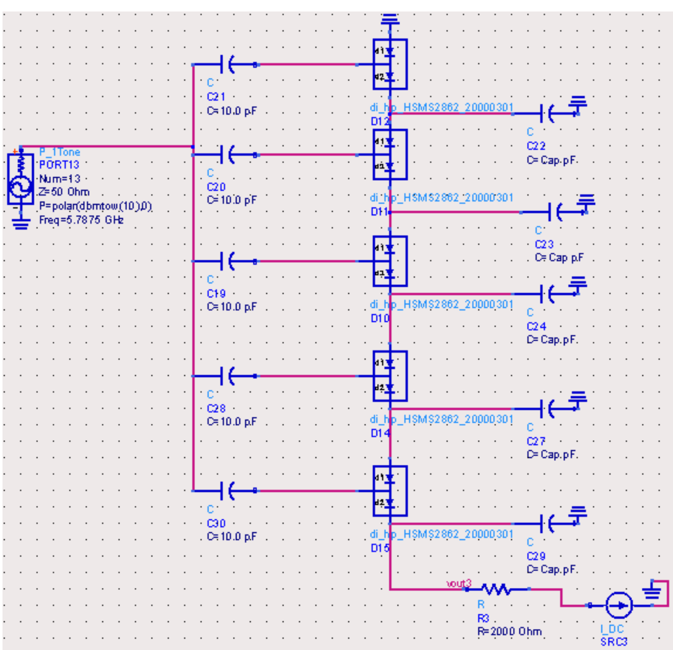

Fig. 4. 5-stage charge pump schematic.

As an alternative, a 3-stage charge pump using quad-bridge diodes (HSMS826F) was designed, and the schematic is shown in Fig. 5.

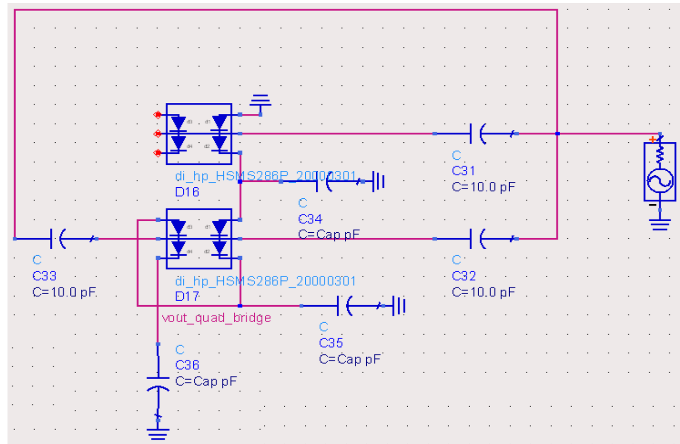

Fig. 5. Quad-bridge diode 3-stage charge pump design.

III. Simulation

Harmonic Balance simulation was performed using a single tone input with 10 dBm input power at 5.8 GHz. Output was plotted in the time domain to measure the DC output voltage and peak-peak ripple. Simulation results for three, four, and five stage charge pump are shown in Fig. 6, and results from the 3-stage charge pump using quad-bridge diodes are shown in Fig. 8.

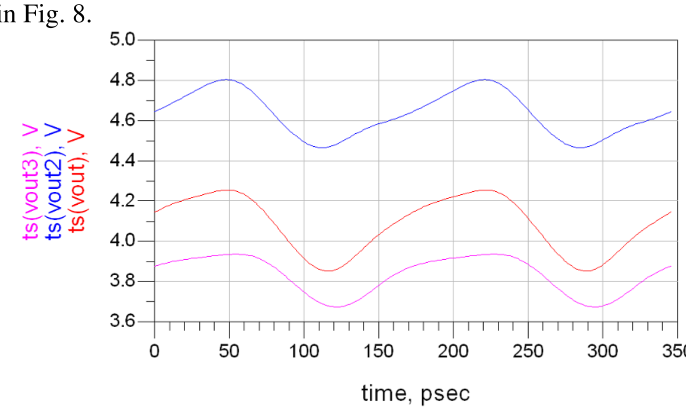

Fig. 6. V_{out}:for 3-stage, 4-stage, and 5-stage systems.

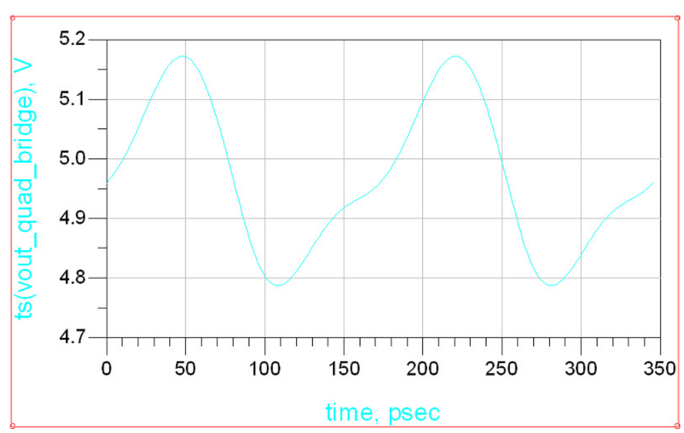

Fig. 7. Quad-bridge design simulation.

From the simulation results, it was observed that the quad-bridge diode design provided a much better DC offset with less voltage ripple, so the HSMS826F was considered an ideal choice. However, due the orientation of the package pins, the layout would require overlapping the RF input to the DC output as well as the ground signal. To avoid any problems in layout as well as signal degradation due to the overlap of traces, the HSMS8262 package was used for the charge pump design. From the simulation, it was noted that the higher number of stages resulted in higher output voltage; however, the output current is of note. A trade off between the output performance and number of stages was made, and two designs were fabricated: four-stage and five-stage as the primary and secondary designs respectively.

Due to difficulty of modeling the diodes for S-parameter measurement and determining the load impedance, a lumped element 'T' matching network was placed at the input to be completed once physical measurements of the load impedance were performed.

IV. Layout

The charge pump layout was designed to be as compact as possible. Coupling between signal lines was not a consideration. The final layout of the 4th and 5th order boards can be seen below in Fig. 8 and 9 respectively.

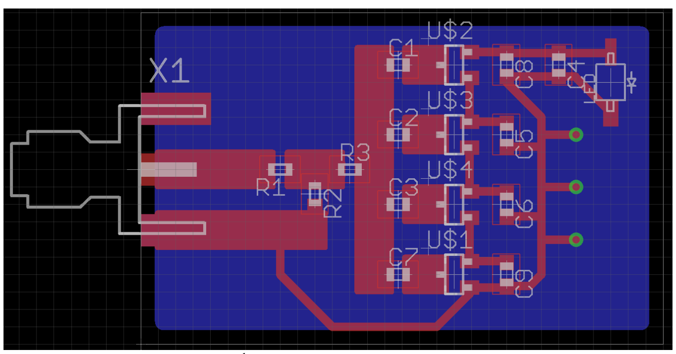

Fig. 8. PCB layout of the 4th order charge pump.

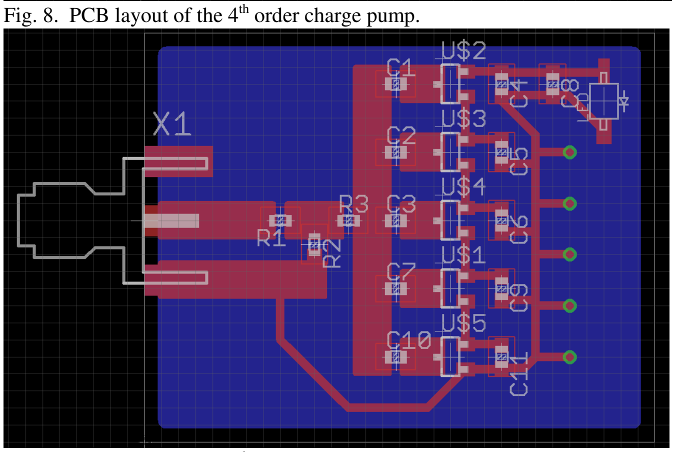

Fig. 9. PCB layout of the 5th order charge pump.

50 Ω transmission lines were kept as short as possible in order to reduce the effects of phase. They were made only long enough to give sufficient space for each component. Multiple vias were placed in parallel to reduce any parasitic inductance.

The Bill of Materials for this design is given in Appendix A.

V. Actual Measurement

Bob House fabricated the charge pump boards in-house. Overall, the fabrication results were excellent, with one error. The layout was designed for a substrate with 60 mil thickness; however, the fabricated boards were 30 mils thick. In any case, good performance was observed, even without the addition of a matching network. Both the 5th order and 4th order boards were populated two 0 Ω resistors in place of the matching network.

Initial testing with the 5-stage charge pump was unable to light up the LED. It was determined that although the voltage was more than sufficient, the current was less than that required to power the LED (1 mA). Next, the 4-stage charge pump was tested; unfortunately, the 4-stage design did not work either, so the debugging of the circuit was done using the signal generator and oscilloscope. A 10dBm signal at 20MHz was place at the input, and each output node was probed using the oscilloscope. It was noted that the 3-stage design fulfilled the voltage requirement; hence one of the stages of 4-stage charge put was opened to make it 3-stage design. While measuring the modified deign, the LED worked up to 20 MHz, but did not have enough voltage to light up at 1 GHz with the same input power. As an alternative, two different matching networks were tested. They actually made the output voltage worse. Finally, 0 Ω resistors were placed back, removing the input matching, and output capacitors were removed. After removing the load capacitors, unexpectedly, the LED operated at 1 GHz as well as at 5.8 GHz with 10 dBm input power.

Another test was done to find the minimum input power required at 5.8 GHz to light up the LED. It was determined that 3.9 dBm would be enough to light up the LED.

VI. Summary & Conclusion

The overall design process and measurement was relatively easy for charge pump. Schottky diodes provided better performance in providing the required output voltage to light up LED. Finally, the charge pump was built and fully functional at 5.8GHz to drive a LED with as low as 3.9dBm of input power.

VII. References

[1] Xiao Wang, and Bowei Jiang, "A High Efficiency AC-DC Charge Pump Using Feedback Compendation Technique", IEEE SSC conference 2007, Nov. 2007, pp. 252-255

[2] U. Karthaus and M. Fisher, "Fully integrated passive UHF RFID Transponder IC with 16.7-μW Minimum RF input power," IEEE Trans. Solid State Circuits, vol. 38, no. 108, October, 2003, pp. 1602-160

[3] W. Jeon, J. Melngailis, and R. W. Newcomb, "CMOS passive RFID

transponder with read-only memory for low cost fabrication", Proceedings, IEEE SOCC 2005, Washington DC, Sept. 2005, pp. 181-184.

[4] Surface Mount Microwave Schottky Dectector Diodes, HSMS-2862, Avago Technologies, 2005

[5] Broadband DC Blocks, 850pf, C06BLBB2X5_SX, Dielectric Laboratories, October 04, 2006.

[6] Surface Mount Technologoy Light Emitting Diode (LED), CMD28-21VGC/TR8/T1, CML Innovative technologies,

Appendix A: Bill of Materials

ECE 6361 Project 3 Bill of Materials						
Part Description	Manufacturer	Part Number	Cost (USD)	Quantity Needed	Line Total (USD)	Comment
Schottky diode	Avago	HSMS2862	0.62	3	1.86	
DC blocking caps - 10 pF	Murata Electronics North America	ERB1885C2E100JDX5D	0.306	10	3.06	Only need 3, but minimum quanity order applies
Green LED	CML Innovative Technologies Inc	CMD28-21	0.31	2	0.62	
0 Ω Resistor	Stackpole Electronics Inc	RMCF 1/16 0 R	0.14	2	0.28	
				Total Cost	5.82	