5.8 GHz Staggered Pattern Charge Collector

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I. INTRODUCTION

Charge collectors are becoming increasingly popular for use in RF energy harvesting circuitry. The goal of this project was to design and implement a circuit that converts RF energy into a DC voltage that can power digital components. In order to achieve this, a charge pump circuit was designed and built. Capacitors and diodes were the only circuit elements used to assemble the charge pump. Passive components were used instead of active components because passive components minimize the amount of RF energy that is dissipated.

The charge pump converts a 5.8 GHz continuous wave signal to a DC voltage in order to drive a low-powered LED. A 4-element staggered pattern charge collector that is capable of operating in the unlicensed ISM band with a target range of 50 cm was built. It was designed to work in several directions depending on the position of the antennas in relation to the RF source.

II. CHARGE PUMP DESIGN

A. Theory and Initial Calculations

A three-stage Dickson charge pump was designed. Figure 1 illustrates a simple schematic of the circuit. The charge pump chains voltages together in order to increase the voltage at the output. Signal current will flow through the grounded diodes on the negative cycle, and charge will be stored in the specific stage series capacitor.
The capacitor discharges during the positive cycle, which increases the voltage in the next capacitor. With each change in polarity, the capacitor will discharge. This leads to a peak voltage over the stage that should theoretically be slightly less than twice the original input voltage [1]. The calculation of the DC output voltage was calculated with the following formula:

$$V_{DC} = N(V_A - V_t) \quad (1)$$

In equation 1, V_{DC} is the output voltage, N is the number of stages, V_A is the peak voltage at the antenna, and V_t is the threshold voltage of each diode. Increasing the number of stages, increasing the peak voltage at the antenna, and decreasing the diode threshold voltage all theoretically increase the charge pump output voltage.

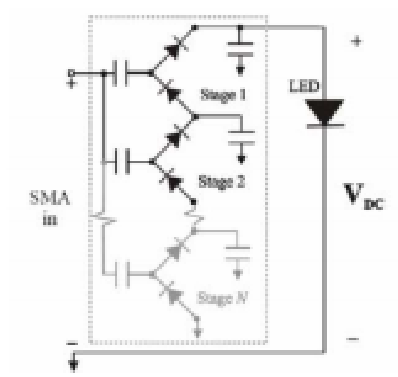

Fig. 1. Circuit diagram of a generic charge pump.

To achieve a large output voltage, a HSM-2862 Schottky diode was used which has a forward voltage of about 300mV. A CMD28-21 LED[2] was placed at the output of the charge pump to indicate when significant power was being collected.

Agilent ADS was used to simulate the charge pump. Models for the HSM-2862 and generic LEDs were used to improve the simulation accuracy. All capacitors and diodes were assumed to be ideal. More accurate results could be obtained by accounting for parasitics. The purpose of the simulation was to provide a basis for how the design of the circuit should function.

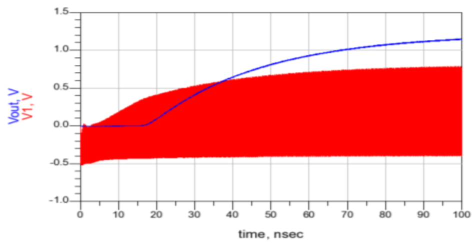

Fig. 2. Simulated charge pump output voltage.

The transient simulation of the output voltage is shown in Fig. 2. Values were tuned during the simulations to see if a more desirable output could be achieved by decreasing or increasing the capacitances. After continued simulation, it was found that 20 pF for the capacitance and 120 pF for the output capacitance were appropriate numbers to achieve a high output voltage. The output capacitor was slightly higher to reduce the ripple voltage. This design aimed for a 10-15% ripple voltage.

B. PCB Board Layout

The circuit was laid out using EAGLE, as shown in Fig. 3.

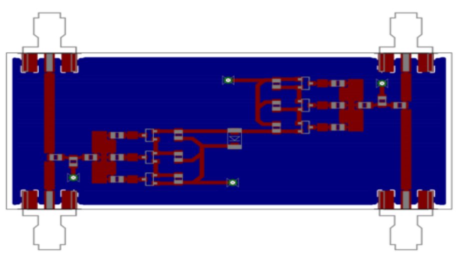

Fig 3. PCB Layout.

Four SMA connectors were soldered on to connect the charge pumps to antennas. Two charge pumps were connect in parallel, each collecting energy from two antennas. The antenna junctions were staggered so the signal phase going into each charge pump was different. The authors later realized that the antennas could have been laid out on the same board, but due to time constraints, this alternative was not pursued. The option to include a matching network was included at each of the antenna inputs. The matching network could be adjusted if the LED did not light up. However, it was discovered the LED would light up when the matching network was populated with shorts and opens. Unfortunately, it was difficult to determine the impedance looking into the charge pump and the impedance looking into the two RF inputs. This prevented the design of an optimized matching network. The layout was implemented on 31 mil FR-4 with 1 oz copper traces. The populated board is displayed in Figure 4.

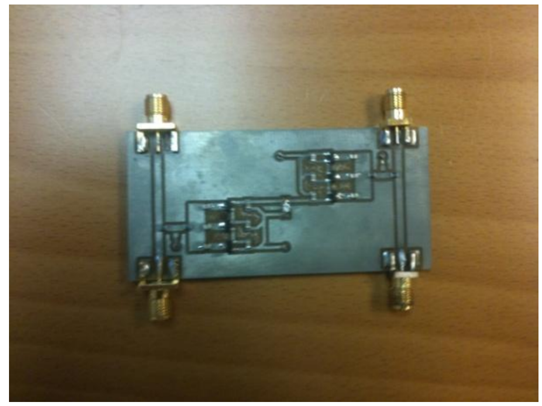

Fig. 4. Populated board

III. Results

Several different antennas (with different frequencies) were connected and the LED was able to light up intermittently. This proved that the charge pump could receive enough power to power the LED, even if the lighting of the LED was not consistent. This erratic behavior was attributed to the poor antenna choices, the different frequencies of the input signal from the network analyzer, and the design of the matching network. The voltage across the antenna fluctuated depending on the positioning of the charge pump antennas and the distance away from the broadcast antenna. This low voltage was likely due to having no matching network.

While the LED was able to light up, it was not able to do so at the required compliance distance. The LED, oriented vertically and with only two antennas attached, was only able to light up at a distance of roughly 30 cm.

During compliance testing, the performance improved when two identical antennas made by another group of designers were used instead of the ones found in lab. These antennas were designed at a frequency of 5.8 GHz, but transmitted at 6.2 GHz.

The LED lit up more brightly and at a farther distance from the broadcast antenna. Only two antennas were used, so the charge pump was not receiving the maximum possible voltage. While the output voltage would not necessarily be cut in half by such a change, it would significantly decrease the amount of power received.

IV. CONCLUSION

In the future, many changes could be made to improve the performance of the charge pump. Adding more stages to the charge pump would have most likely increased the output voltage. The designers were restricted to a three-stage pump because not enough diodes were available to implement more stages. If more diodes were available, a four or five-stage charge pump would have been fabricated. Also, antennas could have been laid out directly on the board as opposed to connecting external antennas. While this may not produce superior results to having four separate antennas, it would decrease the amount of loss due to the SMA connectors with the antenna.

If a proper matching network was implemented, the results would likely have improved. To improve the matching, the design could have used an inductive stub. After fabricating the board, this stub could have been shortened down using an Exacto knife until the desired match was found. This imprecise method would still leave some control to the designers. In addition, test structures could have been designed to measure the impedances of the antenna and the charge pump. Once these numbers were measured, the matching network could have been created to maximize the output voltage.

The bill of materials of the charge pump is in Appendix B.

REFERENCES

[1] D. M. Pozar, *Microwave Engineering*, 3rd ed. Wiley, 2005.

[2] HSMS-286x Series Surface Mount Microwave Schottky Detector Diodes
Data Sheet, Avago Technologies, http://www.propagation.gatech.edu/ ECE6361/resources/Schottky Diodes AV02-1388EN.pdf.

[3] M. Trotter, "Effects of DC to DC Converters on Organic Solar Cell Arrays for Powering DC Loads," (unpublished work).

Appendix A: Charge Pump Schematic

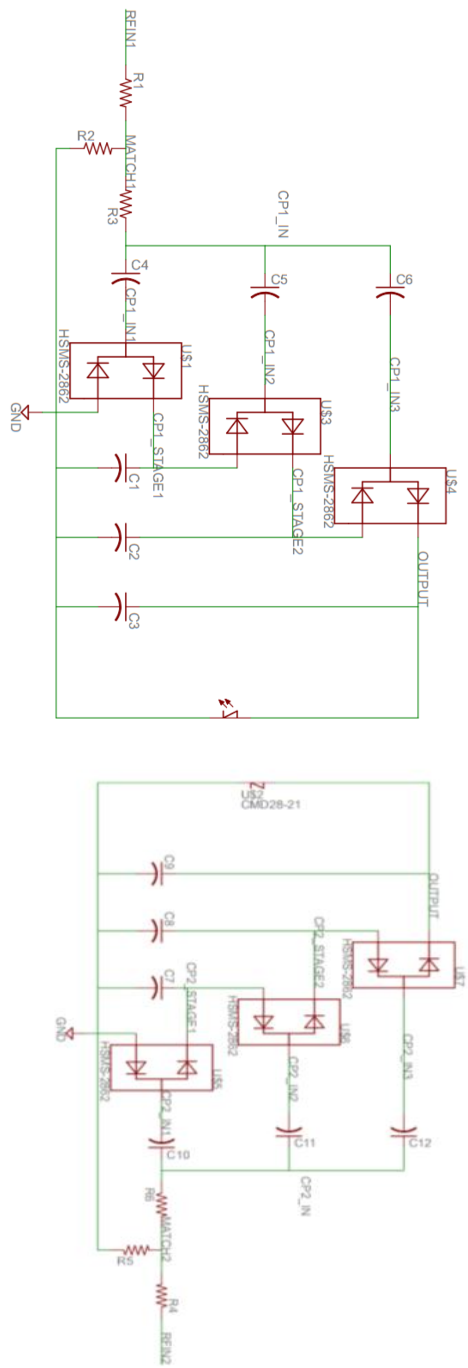

Fig A.1. Schematic of the charge pump with matching network.

Appendix B: Bill of Materials

Item	Reference	Part	Part #	Manuf	Supplier	footprint	cost	qty	total cost
1	U1, U3, U4, U5, U6, U7	RF Diodes	HSMS-2862	Avago	Avago	SOT-23	$1.31	6	$7.86
2	U2	LED	CMD28-21	LLC	Digikey	gull wing	$0.31	1	$0.31
3	C1, C2, C4, C5, C6, C7, C8, C10, C11, C12	Cap - 18pF	VJ0805A180JXACW1BC	Mouser	Vishay	0805	$0.10	10	$1.00
4	U8, U9, U10, U11	SMA Conn	J502-ND	Digikey	Emerson	end launch	$5.10	2	$10.20
5	C3, C9	Cap-120pF	VJ0805A121JXBAT	Mouser	Vishay	0805	$0.07	2	$0.14
6	R1, R3, R4, R6	Res - 0 Ohm	CRL0805-FW-R050ELF	Mouser	Bourns	805	$0.07	4	$0.28
7	R2, R5	Open	-	-	-	-	-	-	-
									$19.79