5.8 GHz Staggered Pattern Charge Collector

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***Abstract*—A charge collector with two pairs of patch antennas is demonstrated. The charge collector is capable of harvesting energy from a 5.750 – 5.850 GHz band to power a 2 V LED. The charge collector is fabricated on a 31 mils FR4 substrate, with 1.4 mils copper conductor. The charge collector is designed based on a five stages Dickson charge pump. Demonstration showed that it was capable of supplying more than 1.5 V of DC supply to the LED test load at 50 cm away from the energy source.**

***Index Terms*—Charge collector, Dickson charge pump, patch antenna.**

I. INTRODUCTION

ENERGY HARVESTER is a device that derives and stores energy from available external source, such as solar power, thermal power, electromagnetic energy, kinetic energy. The above external source is usually available naturally and can be used without extra cost. However, the harvested energy is usually low in power, and is only suitable for powering low energy electronics.

A staggered pattern charge collector is represented in this article to be used as an energy harvester to power up low energy electronics. The energy source to be harvested is a 5.8 GHz of microwave signal broadcasted by horn antenna with output power of 1 Watt. The harvested energy is then converted to DC signal, and the voltage is raised by a charge pump, before being used to power up an LED.

The charge collector was demonstrated to be able to provide more than 1.5 V of DC supply to power up the LED up to 0.5 meters away from the horn antenna.

II. DESIGN PROCEDURE

The design calculation was optimized for fabrication on a standard 31 mils FR4 board, with 1.4 mils copper conductor. A microstrip transmission line technology was adopted to simplify integration with patch antenna. The components that were used to built the device were listed as follow:

- HSMS 2862 RF Schottky Diode
- SMT 06-03 Capacitor
- CMD 28-21 Low Power LED

A. Antenna Design

The charge collector was designed to have a +/- 45 degrees field of view with two arrayed pairs of patch antenna, as shown in Figure 1. Assuming a 5.8 GHz microwave source was placed at a 45 degrees angle from the normal vector of the charge pump board, as shown in Figure 2, there would be a phase difference between the two microwaves incidental onto the two antennas. The phase difference needed to be corrected to allow constructive wave interference at the input of the charge pump. The phase correction could be realized by implementing a longer microstrip line on one side of the antenna pair.

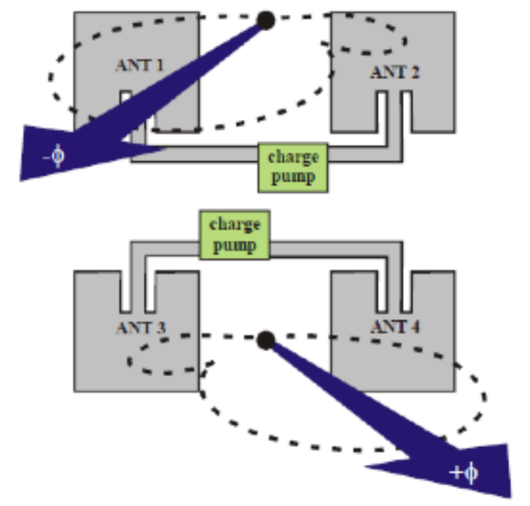

Fig. 1. Wide angle staggered patter charge collector.

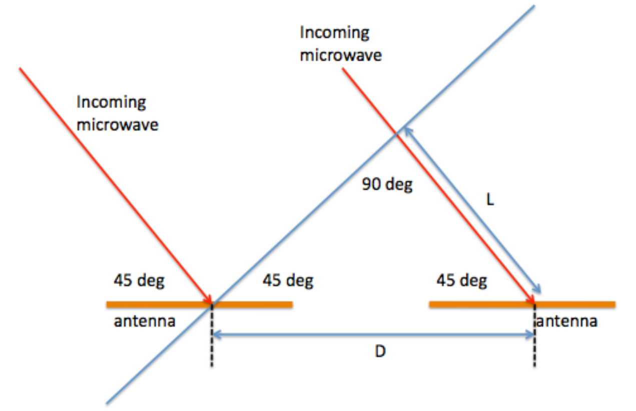

Fig. 2. Phase difference between the two microwaves hitting the two antennas.

The phase difference of the two microwaves was calculated using Equation 1, where D is the distance between the two

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antennas, and lambda is the wavelength of the microwave in free space. Choosing D = lambda = 0.0517 m, the phase difference was calculated to be 254.6 degrees. Then using the LineCalc tools in ADS, the difference in length of the microstrip line is 781.1 mils.

$$phase\_diff = \frac{D \cdot \cos(45°)}{lambda} \cdot 360° \tag{1}$$

The dimension of the patch antenna was calculated using EM Talk online calculator to be L = 458 mils, W = 598 mils, R = 261 Ohms. The antenna was, then, matched to a 50 Ohms load with a 114 Ohms quarter wave transformer. The dimension of the quarter wave transformer is W = 10 mils, L = 298 mils.

B. Charge Pump Design

The purpose of a charge pump is to convert an input voltage and raise it by charging several stacks of capacitors. Normally, a charge pump is a DC-to-DC voltage converter. In this paper an AC-to-DC variant of Dickson charge pump is represented.

The operation of the charge pump represented in this paper is similar to a Cockroft-Walton voltage multiplier. Figure 3 shows the schematic of the charge pump. When voltage of the input is lower than the ground voltage, the lower level capacitor on the left column is getting charged up. When the input voltage is higher than the ground voltage, the left capacitor is then charging the higher-level capacitor on the right column. This process continues on until the charge pump reaches its steady state.

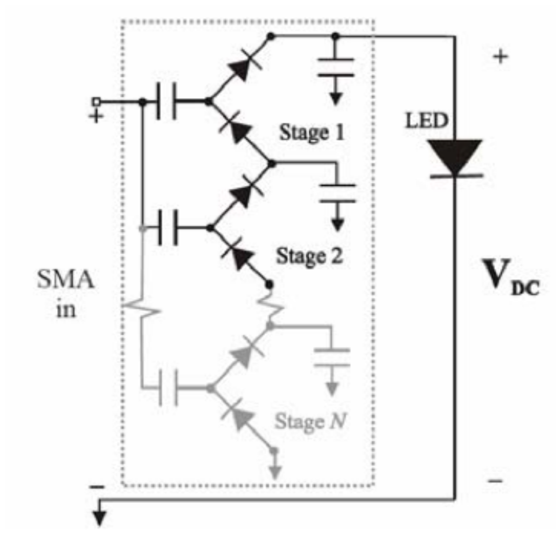

Fig. 3. Dickson charge pump.

Equation 2 and 3 were used to approximate the input voltage of the charge pump, assuming the input impedance of the whole system, and the charge pump itself, was 50 Ohms and there was no energy loss between the charge pump and the antenna (no mismatch in impedance). The gain of the transmitter horn antenna and receiver wide view patch antenna was approximated to be 10 and 6.3 respectively, based on the characteristic of the antenna design. The results are shown in Table 1. Equation 4 was, then, used to estimate the value for the capacitors needed in the charge pump. The charge pump was picked to have 5 stages for maximum output voltage. The diode was identified to have a threshold voltage of 0.3 V. The LED was identified to have an operating voltage of 2.1 V on a 20 mA current. The resistance of the LED was approximated to be 105 Ohms. In reality, the above approximation was inaccurate due to the non-linearity of the LED. The estimate values of the capacitor are shown in Table 1.

$$P_R = P_T \frac{G_T G_R \lambda^2}{4\pi r^2} \tag{2}$$

$$P_R = \frac{1}{2}\frac{Vin^2}{Rin} \tag{3}$$

$$Vout = \frac{(N+1)(Vin - Vt)}{1 + \dfrac{N}{f \cdot C \cdot R_L}} \tag{4}$$

Table 1

Input Voltage Variation by Distance from Source

Distance from source (m)	Input Voltage (V)	Capacitor Value (pF)
0.5	2.32	1.73
1.0	1.16	5.66
1.5	0.77	23.61
2.0	0.58	N/A

Next, the charge pump was simulated using LTSpice. The diode was modeled based on the Spice variables available in the datasheet. The LED was modeled as a 105 Ohms resistor. As mentioned in the above discussion, the LED estimation was inaccurate because of the non-linearity of the LED. At this stage, several values of capacitors were simulated to obtained the highest output voltage possible. After simulation, the output capacitor was chosen to be 180pF. A relatively large value was desired at the output in order to supply enough current to the LED while maintaining the required output voltage. Figure 4 shows the charge pump simulations when Vin = 1V, C = 2pF and 22pF. According to simulation, C = 2pF led to only 600 mV of output voltage, while C = 22 pF led to almost 1.6 V to output voltage.

C. Board Layout

Board layout was completed using the free version of Eagle software. The board was a standard 31 mils FR4 with two layers of 1.4 mils copper conductor. Microstrip line was preferred over coplanar waveguide to simplify integration with patch antenna. SMT 06-03 capacitor was chosen over the standard RF SMT 04-02 capacitor for easier soldering. The schematic and layout of the circuit is shown in Figure 5.

III. FABRICATION AND MEASUREMENT

The charge pump board was fabricated at in-house Georgia Tech facility. Via connections were manually filled by hand

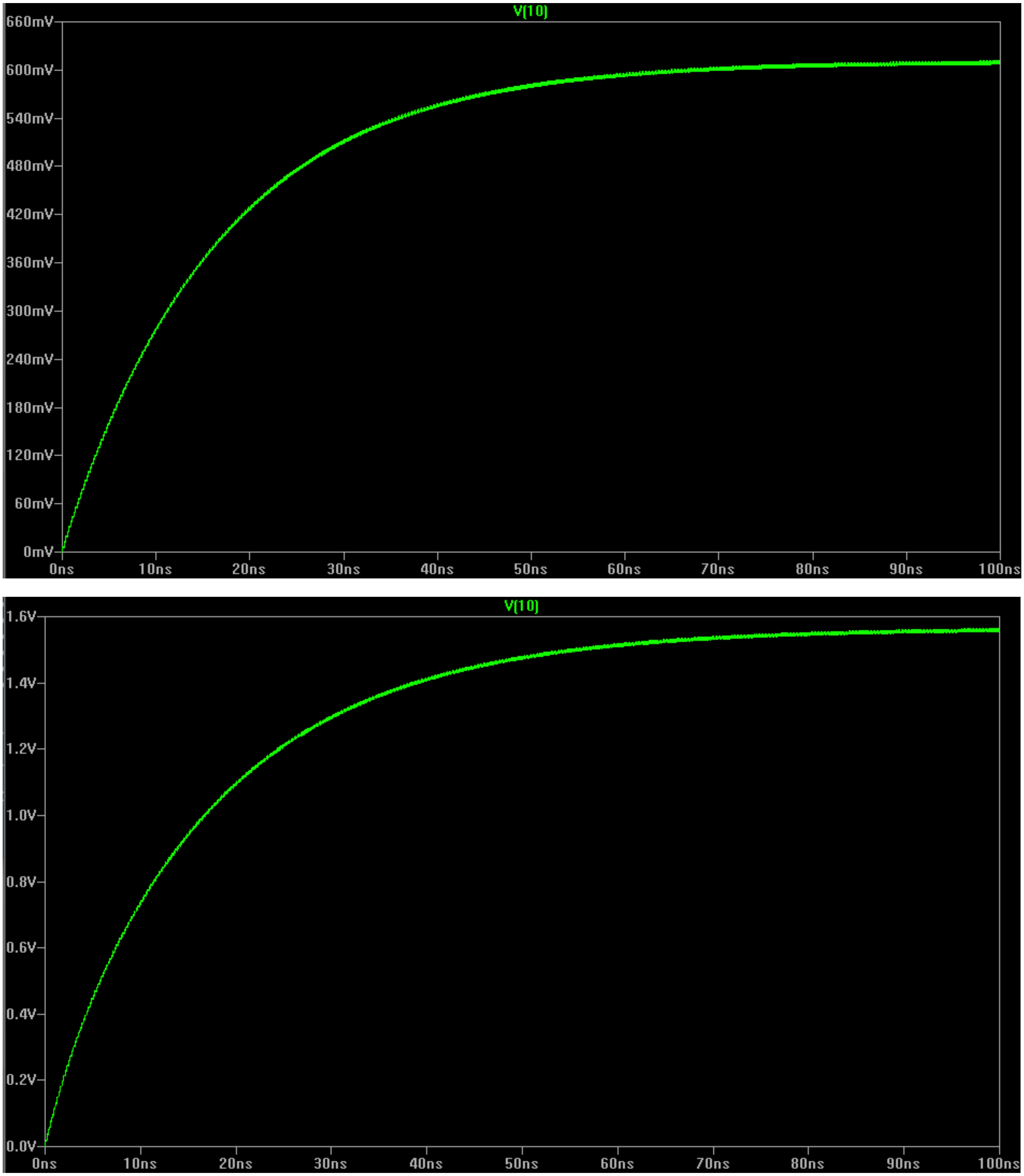

Fig. 4. Charge pump LTSpice simulation with Vin = 1V, C = 2pF (top) and 22pF (bottom).

and soldered to both top and bottom planes to provide ground connections. The completed board is shown in Figure 6.

Demonstration showed that the charge collector was capable of lighting up the LED only up to 0.5 m away from the transmitter. Measurement showed that the LED required at least 1.5 V of voltage supply in order to light up. Nevertheless, the performance of the charge pump was lower than its theoretical calculation, which should be able to light up the LED up to 1 m away from the transmitter with Vin = 1.16 V.

During design, testing, and evaluation process of the charge pump, the following design errors were identified:

- Transmission line was not properly matched across the board.
- Patch antennas were placed too close to the edges of the board.
- Inaccurate Spice simulation.

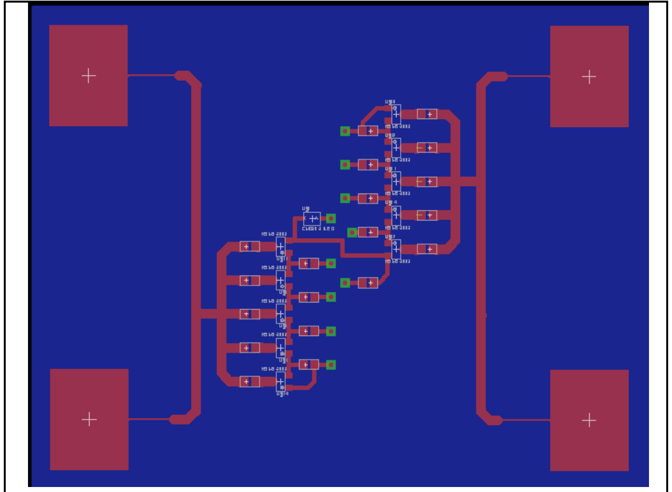

Fig. 5. Charge collector layout in Eagle software.

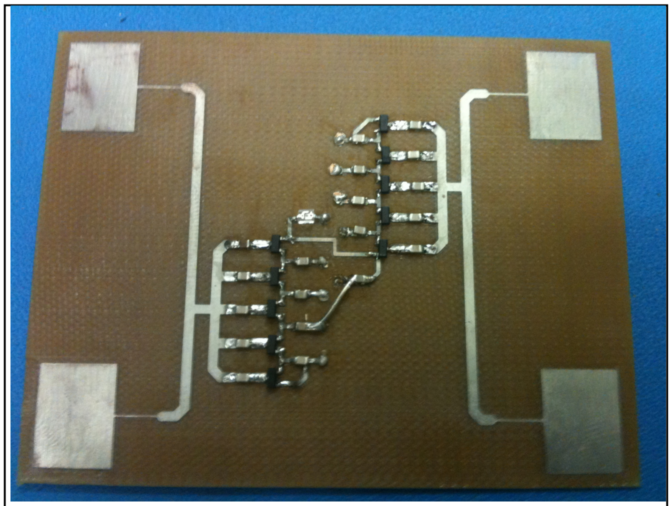

Fig. 6. Charge collector.

IV. DESIGN ERRORS

During input voltage calculation, the input impedance of the entire system was assumed to be 50 Ohms. Due to the complicated structure of the charge pump, accurate input impedance could only be obtained via measurement. Mean while each transmission line that connected the charge pump to the antennas was designed to have 50 Ohms characteristic impedance. Reflection coefficient calculation at transmission line intersections was also omitted. The above errors led to significant power loss at the transmission lines.

In addition, patch antennas were placed too close to the edges of the board. There wasn't enough ground coverage around each patch antenna, thus shifting the resonant frequency of the antenna. Because of the above, the gain of the receiver antenna at 5.8 GHz was less than the theoretical value of 6.3.

During evaluation process, a second Spice simulation was performed using Agilent ADS software. In the simulation, a built in HSMS-2862 diode model was used for the diode, and a 105 Ohms resistor was used to model the LED. However, Figure 7 shows the opposite result compare to the LTSpice simulation. ADS Simulation shows that C = 2pF yielded to a higher output voltage of 1.5 V, compared to C = 22pF which yielded an output voltage of 0.5 V. Further experiment is needed to investigate the issues.

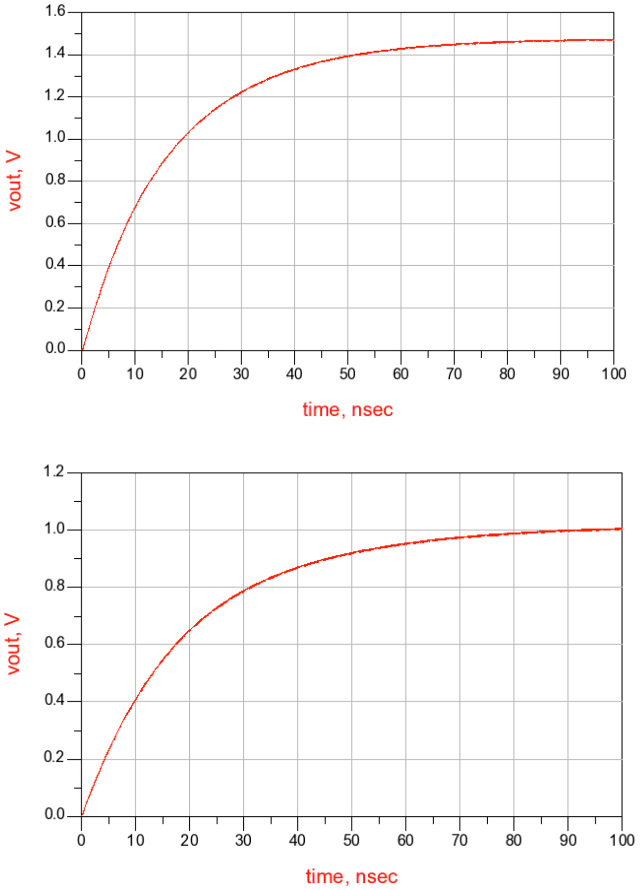

Fig. 7. Charge pump ADS simulation with Vin = 1V, C = 2pF (top) and 22pF (bottom).

V. CONCLUSION

It was shown that a staggered pattern charge collector could be used to harvest a 5.8 GHz electromagnetic wave to power up a low energy electronic. The device successfully powered an LED up to 0.5 m away from the transmitter, effectively meeting product specification. However, the performance of the charge pump was still significantly below theoretical expectation, and addressing the above design errors would lead to significant improvement in performance.

APPENDIX

LT-Spice code

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V1 vin 0 AC SIN (0 1 5.8G)
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D1a 0 1 HSMS286x
D1b 1 2 HSMS286x
C1a vin 1 22p
C1b 2 0 22p
D2a 2 3 HSMS286x
D2b 3 4 HSMS286x
C2a vin 3 22p
C2b 4 0 22p
D3a 4 5 HSMS286x
D3b 5 6 HSMS286x
C3a vin 5 22p
C3b 6 0 22p
D4a 6 7 HSMS286x
D4b 7 8 HSMS286x
C4a vin 7 22p
C4b 8 0 22p
D5a 8 9 HSMS286x
D5b 9 10 HSMS286x
C5a vin 9 22p
C5b 10 0 22p
RL 10 11 105
V2 11 0 0
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