Patch Antenna Array for a Microwave Charge Pump at 5.8 GHz (December 2012)

Matthew Campbell, Mark Ficker, Stefan Lepkowski, and Max Liao

***Abstract*—The goal for this design is to create an antenna that can receive RF energy at 5.8 GHz and convert it through an energy harvester to provide power to a low-power LED. The antenna designed for this purpose is an array of 4 patch antennas. The antennas are designed to radiate at the operating frequency and they are matched and phased in order to provide maximum gain. The impedance matching network for this antenna array consists of microstrip lines. These lines also provide proper feeding from the feed, a 50 Ohm SMA connection. The energy harvester is designed with the same SMA connection and uses multiple capacitor/diode stages to light the LED.**

***Index Terms*—Charge Pump, Energy Harvesting, Patch Antennas, Antenna Arrays**

I. Introduction

RF energy is constantly being transmitted in modern environments. This energy typically goes to waste when no receivers are present to pick up the signal. A microwave charge pump can be used to gather this energy and convert it into a low-leveled power supply. An array of antennas provides a continuous 5.8 GHz signal to the energy harvesting circuit. The circuit will convert this signal into a DC power source to light a low power LED. The energy harvester and patch antennas will be constructed separately and the two devices will be interfaced with a 50 Ω SMA transmission line. In this design, 4 patch antennas will be used as the receiver and a 4-stage charge pump will provide power to the LED.

II. Antenna Array

A. Patch antennas

The antennas to be used in this design are four identical patch antennas. Patch antennas have advantages as they are not only cheap and easy to fabricate but also versatile in terms of resonant frequency, polarization, pattern, impedance, and conformability to planar and non-planar surfaces. They can also easily be placed in an array as long as their feeds are matched and phased correctly.

In this design, the patch antennas to be used have dimensions of: 460 mils in length and 630 mils wide. These dimensions were picked using the following equations.

Max Liao is a senior with the Georgia Institute of Technology, Atlanta, GA 30318 USA (phone: 404-314-7825; e-mail: yliao7@gatech.edu).

Stefan Lepkowski is a senior at the Georgia Institute of Technology pursuing Bachelors in Electrical Engineering and is schedule to graduate in fall of 2012.

The width of each patch antenna was calculated using Eq. (1). The resonant frequency was chosen to be 5.8 GHz and the relative dielectric constant was selected to be 4.1. This equation takes into account the permittivity of the substrate that the patch antenna will be attached to.

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

After the width was selected, we calculated the length of each patch using Eq. 2. The resonant frequency was chosen to be 5.8 GHz. The relative effective dielectric constant was found using Eq. 3. The value for ΔL was found using Eq. 4 with the height chosen to be 1.5mm.

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \quad (2)$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (3)$$

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \quad (4)$$

An effective dielectric constant is used to account for fringing effects that occur with patch antennas. The patch antennas have finite dimensions; so the electric field tends to fringe at the edges of the patch. The effective dielectric constant accounts for the electric field lines that will be travelling in through the air above the patch to reach the ground plane. Also because of fringing effects, the patch antenna will look longer electrically than it will be physically. The ΔL term addresses this issue by reducing the physical length of the patch by a certain amount.

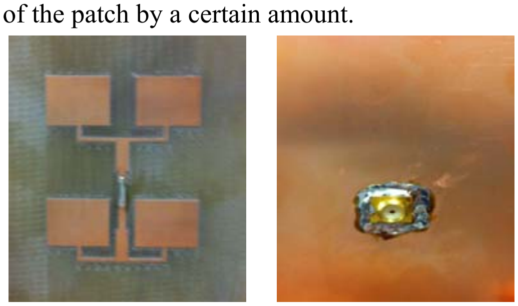

Fig. 1 Array of patch antennas fed with SMA connection

An SMA connection was soldered at the halfway point along the central microstrip line. This can be used to interface the antenna array and the energy harvester. The SMA used is a standard 50 Ω connection and both devices must be matched to provide adequate transmission.

B. Microstrip Line

The matching network for the antenna was design to eliminate deconstructive reflections in the lines. In the feed networks to the antenna the line the length was tuned to account for the reflection coefficient encountered at the antenna. The reasoning was that a 360 phase change to the feed point for a set of two antenna would provide constructive interference to the feed point and therefore to the other antenna.

The line width and length was calculated in ADS's LineCalc tool. This tool takes into accounts the physical parameters and dimensions when calculating the length and width of the trace. It allowed for rapid synthesis of the trace dimensions for a given effective electrical length.

The input impedance of the antenna array network was fixed to 50 ohms. This was matched with two quarter wave stubs at 70.7 ohms in parallel and each fed to 50ohm lines. In turn these lines are divided into two 100 ohm lines that feed the antenna.

To verify the model and reduce destructive we used ADS's model of currents and phase plots to tweak trace lengths.

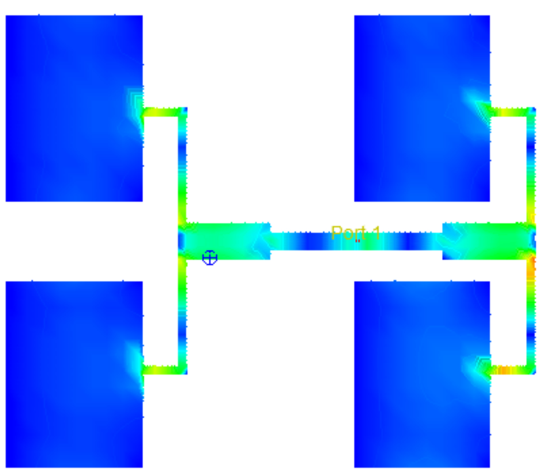

Fig. 2 Simulated ADS current plots helped to determine constructive and destructive points in the design.

C. Simulations

Prior to milling, the design was created in Agilent ADS and Ansoft HFSS to simulate performance. The ADS simulation graphically displays the S11 of the antenna array in dB as seen in Fig. 2. At the resonant frequency of 5.8 GHz, the maximum power is being delivered to the load. The simulation in the figure above shows a minimum of -20.7 dB at the operating frequency.

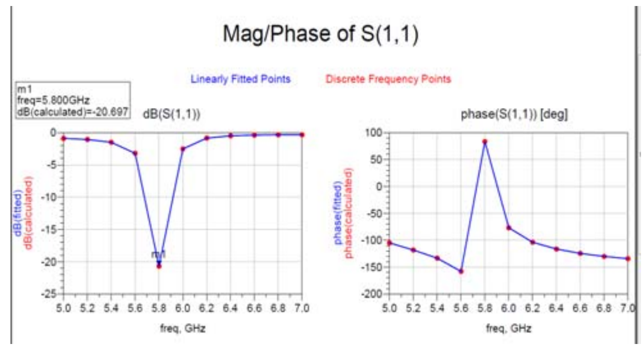

Fig. 3 Simulated S11 Magnitudes and Phase

The gain for our antenna array is simulated in ADS and ploted in a polar graph displayed. This simulation shows that the array radiates with a peak gain of 8.777 dB in the +z direction.

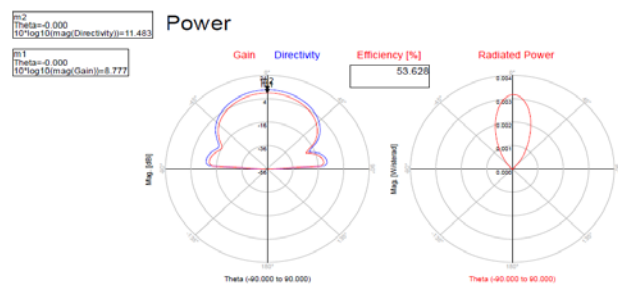

Fig. 4 Simulated Gain and Directivity

A 3D polar plot was constructed for the directivity of a single patch antenna in HFSS. In this simulation, an infinite ground plane was placed 1.5 mm underneath the antenna in order to increase our peak gains. There are nulls at the origin because of this ground plane and a maximum peak of in the z+ direction.

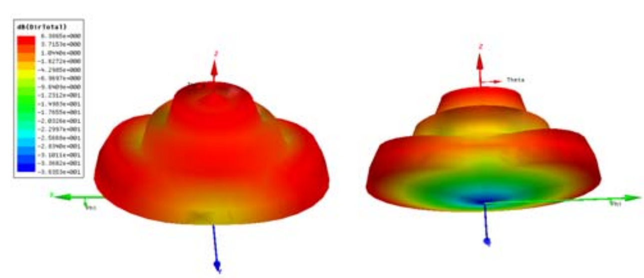

Fig. 5 Simulated 3D Polar plot for Directivity of one patch antenna

D. Measurements

After milling, the antenna is connected to a network analyzer to measure the S11 and compare that with our simulated results. The results show a minimum s11 of -31dB at a frequency of 5.8 GHz.

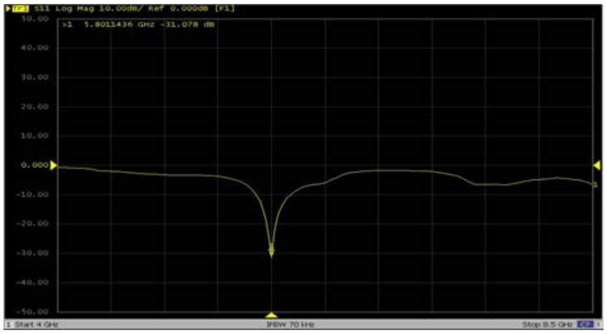

Fig. 6 Measured Magnitude of S11 for Antenna Array

III. Energy Harvester

A. Dickson Charge Pump

The energy harvesting circuit used to convert the signal from our antenna into a steady supply for the LED is a Dickson charge pump. Charge pumps operate by allowing current through the grounded diodes while there is negative voltage. With this current, the series capacitors charge over time. When the voltage becomes positive, the diodes allow the series capacitors to discharge, providing current to the parallel (grounded) capacitors. The parallel capacitors will discharge while there is negative voltage. The circuit is design using material provided during an in-class lecture given by Matthew Trotter. The charge pump utilizes DLI’s C06 series capacitors, Avago’s HSMS-268 series diodes, and CML’s CMD28-21 series green LED.

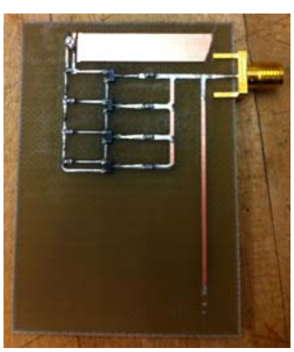

Fig. 7 Dickson Charge Pump

B. Stages and Matching

The charge pump was designed with four stages to provide sufficient power to the LED and includes an amount of overdesign to compensate for a poorly received input signal. With more than four stages, there is a significant risk of not providing enough current to the LED. During the SPICE simulations, a 33pF valued capacitor was found to provide sufficient current and was selected for use in this design. To create a design to be milled, the appropriate device packages were found within the EAGLE CAD software for a PCB layout design. To aid in matching with the 5.8GHz input signal, the circuit also features a matching stub line. After milling and assembling the PCB, this line was configured to an appropriate length to allow the maximum amount of power through. During testing of the circuit it was found that the LED emitted light at as low as 2.2dBm.

C. Measurements

The S11 of the energy harvester can be measured through a network analyzer and can be seen on a Smith chart in the following Fig. 7. The energy harvester was tuned based off the length of the matching stub based off of the S11 measurements.

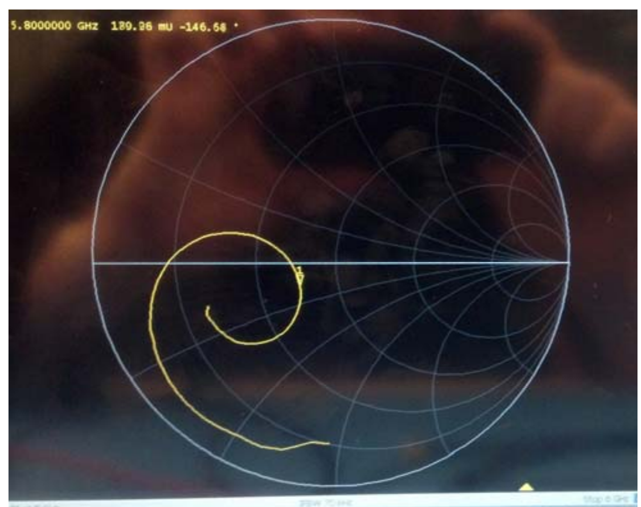

Fig. 7 Measured S11 on Smith Chart for Energy Harvester

IV. Conclusion

This design has been simulated, built, and tested using various software and PCB milling tools. We expect this design to operate well in the 5.725 – 5.85 GHz ISM band. Further optimizations will focus on matching the impedances of the antenna and charge pump.

References

[1] Constatine Balanis, “Microstrip Antennas,” in Antenna Theory, 3rd ed. John Wiley & Sons, Inc. Hoboken, New Jersey: 2005, pp. 811–843.

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