Long Range, Safe Power Transmission using Iteratively-Tuned Rectification

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***Abstract*— A long range wireless power system operating at 2.45 GHz is developed. The system is comprised of: 1) high gain horn antennas, 2) iteratively tuned matching/filtering network, 3) high efficiency rectifier, and 4) optimized load. An iterative technique is then used to match the antenna to the rectifier to greatly improve the efficiency. The rectifier is built around a single shunt diode rectifier topology. The output of the rectifier is fed to an optimized load, producing efficiency above 45% at 0 dBm. The overall system is able to operate across half a meter wirelessly.**

I. INTRODUCTION

Conventional RF energy harvesters suffer from short range operation, low efficiency, and low output power. For this reason, there is strong interest to develop a practical power delivery system suitable for long range wireless battery charging. In this paper, we present a new RF energy harvester topology and system. This can be used for remote recharging of cell phones, sensors, batteries, and many other small electronics in an office setting.

II. LONG RANGE WPT SYSTEM

The block diagram of the long range system is shown in **Fig. 1**. In this setup, the source of power is an Anritsu 68369 signal generator. In accordance with federal regulations, the maximum EIRP of a 2.4 GHz signal is 30 dBm. Therefore, an output power of 20 dBm with an antenna gain of 8.5 dBi will be used as the transmitted EIRP.

The signal is received over a distance by a horn antenna. Once the RF signal is received, it is rectified using a single shunt diode rectifier. The matching between the horn antenna and the rectifier was performed using an iteratively tuned matching/filtering network. The output of the rectifier is attached to a load. In this case, the load can be a power management chip and a supercapacitor. The power management chip is the Texas Instruments BQ25570, which is responsible for regulating the rectifier's output voltage to 3V [2]. This chip will require at least -7 dBm to operate. Finally, the BQ25570 chip is connected to a 3V supercapacitor to store charge. Thus, the main components of WPT receiver include: 1) antenna, 2) matching/filtering, 3) rectifier, and 4) load.

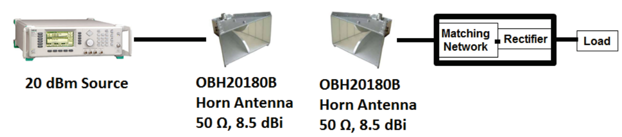

Fig. 1. Long Range WPT Setup

III. ANTENNA

The antennas used in this design were 8.5 dBi horn antennas that were mounted between 10 cm and 50 cm apart. At 10 cm, the received power was 8 dBm, and at 50 cm, the received power was -4 dBm. This power range will satisfy the minimum power for the power management chip (-7 dBm). The EIRP of the transmitted signal is 28.5 dBm, which falls beneath the maximum EIRP of 30 dBm according to the FCC. Thus, this system is safe for commercial use. In comparison, this is the same magnitude of signal power that a laptop or router might generate. In the future, we would like to expand this range to over 1 meter using a highly directive patch array.

IV. MATCHING AND FILTERING

The rectifier is highly non-linear, as its impedance changes mainly due to the load and input power. The load was determined as the BQ25570 power management circuit (which we simulated using a 2kOhm resistor), and the input power is given in the range of -4 dBm to 8 dBm.

To transfer the maximum amount of power between the antenna and rectifier, it is essential for a well-matched network. The matching circuitry is shown in **Fig. 2**. Now, in typical linear systems, it is a straightforward process to create a matching network because the S-parameters always remain the same. In this case, the S-parameters are constantly changing due to different input power levels. As described in [3], it is actually impossible to obtain a matching circuit for this type of system. Therefore, an iterated process of matching the rectifier is demonstrated here.

Beginning with an initial guess at the input impedance to the rectifier, we measured the efficiency of the overall system in simulation. Then, we adjust the output impedance. This change in output impedance would then require change in the input impedance. This process was iterated until an ideal input and output matching network was obtained, giving the highest efficiency possible.

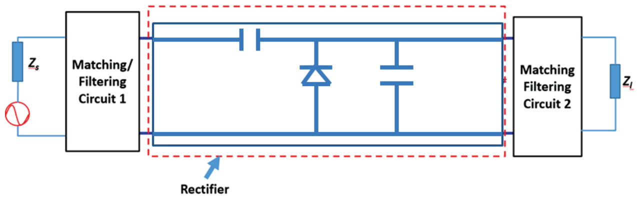

Fig. 2. Matching/filtering circuitry around the rectifier

As shown in **Fig. 3**, poor matching results in a strong presence of harmonics. A well-matched system reduces harmonics, thus maximizing the amount of delivered power to the rectifier.

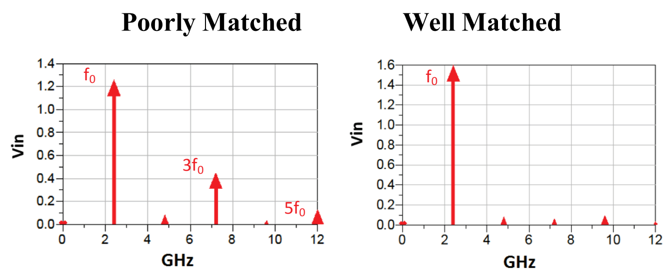

Fig. 3. Poorly matched (left) and well matched (right) circuit

V. Rectification

A single shunt diode was used with two capacitors for rectification. This simple design allowed for easy fabrication. With two 100 pF capacitors, an HSMS2860 diode, and a well-matched input and output filter, the design was fabricated at our laboratory. All circuitry was modeled in ADS. The circuit diagram and printed circuit are shown in **Fig. 4**.

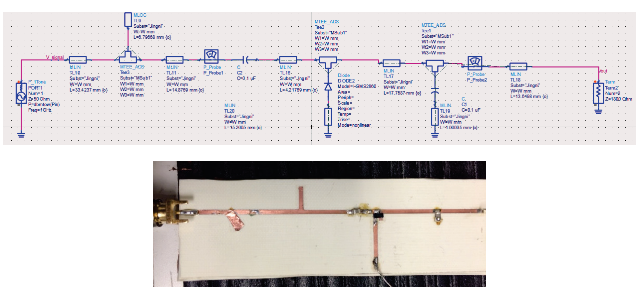

Fig. 4. Rectifier simulation in ADS and printed design

This design builds upon previous work which consisted of two diodes or more [4][5]. The single diode, capacitors, and transmission lines are optimized into a resonant structure so that the diode will rectifier over 50% of the power. Indeed, a typical diode can only rectifier 50% of the power, but at high frequencies, a diode can be resonated by creating a well matched input and output circuit. The rectifier circuitry will be optimized for power reception in range of -4 to 8 dBm, as this will be the practical range of operation for this scenario. Measured results show efficiencies nearly 30% efficiency at -4 dBm and 58% efficiency at 8 dBm as shown in **Fig. 5**. The efficiency at 0 dBm is 45%.

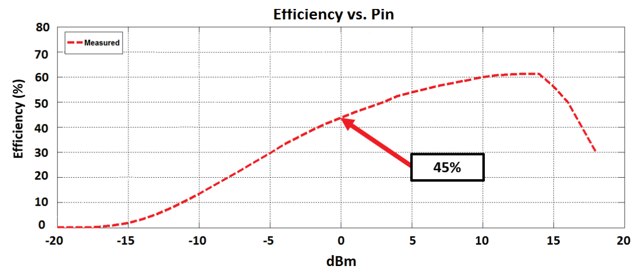

Fig. 5. Rectifier simulation in ADS and printed design

VI. Rectifier Load

A variety of electrical loads are possible with this WPT system. For example, a Texas Instruments MSP430 microcontroller may be operated continuously [6]. However, in order for efficient charging, a power management chip can be used. The TI BQ25570 regulates the output of the rectifier to a desired voltage level. The BQ25570 is set to transform the rectifier output to 3 Volts. After being started, the BQ25570 requires at least 100 mV (or -7 dBm) to provide the transformed voltage. In this setup, a supercapacitor is then used as a charge storage device. After being charged, it may then be used for any purpose. The overall system may now be used to charge a supercapacitor across a distance of 10cm to 50cm.

VII. Conclusion

A long range wireless power transmission system capable of recharging electronics such as cell phones, sensors, and batteries was developed. An iterative technique to develop matching circuits for the rectifier was used. A rectifier with 30% efficiency at -4 dBm and 58% efficiency at 8 dBm was developed. Using safe levels of transmitted power, initial designs showed the possibility to recharge a battery or supercapacitor over a distance of half a meter. In the future, optimized antenna designs will be made that will expand this range to several meters.

References

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