Wireless Energy Harvester from 700-900 MHz

Brock J. DeLong, Cedric W.L. Lee, Asimina Kiourti
Department of Electrical and Computer Engineering
The Ohio State University, ElectroScience Laboratory
Columbus, OH, USA

Satheesh Bojja Venkatakrishnan, John L. Volakis
Florida International University
Miami, FL, USA

***Abstract*—A broadband rectenna with a fractional bandwidth of over 25% was herein designed and validated. The operational frequencies span from 700 MHz to 900 MHz using an offset tapered dipole and wideband rectenna. This compact design can provide up to 64.3% RF-to-DC conversion efficiency, and can rectify efficiently with power densities as low as 1 μW/cm^2.**

I. Introduction

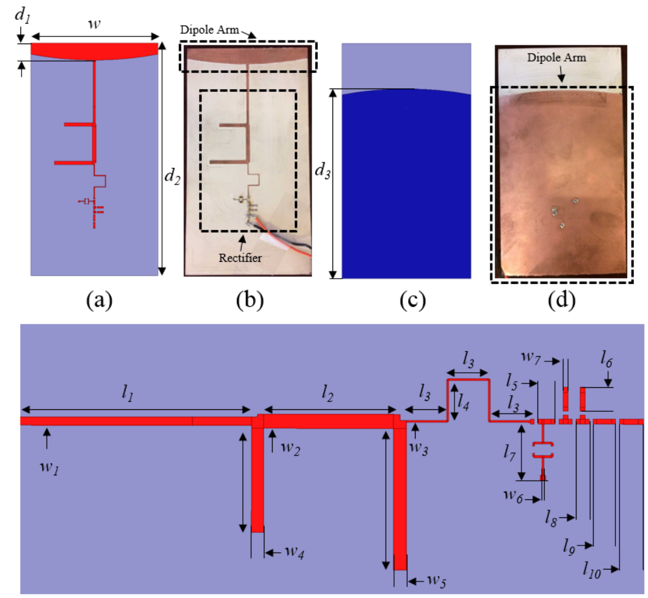
Signals in the 700-900 MHz range (also known as the UHF band) are various, and have been heavily used for mobile communication, broadcast, and navigation applications [1]. As such, these signals are nearly ubiquitous in application for daily life. Given their availability and their ability to penetrate walls, trees, building, etc. [2], these frequencies are attractive for more continuous wireless energy harvesting. The ability to penetrate walls, for example, could be used for wireless recharging of various sensors around home, such as smoke alarms, Internet of Things (IoT) sensors, and small medical devices.

Typical wireless power harvesting devices focused on the 2.4 GHz range, given the wide availability of WiFi [3]. However, many of the applications for 2.4 GHz have been limited to close range, or even near-field power transmission [4]. With this in mind, herein we propose and demonstrate a low frequency rectenna that covers the 700-900 MHz bands.

II. Antenna Design

To achieve a fractional bandwidth of 25%, we propose a planar tapered offset dipole antenna, shown in Fig. 1. The associated dimensions of the antenna and rectifier circuit are given in Table I. It is noted that a slight taper near the edges of the dipole leads to improved wideband performance. An important feature of the offset dipole is the large metallic ground plane, shown in Fig. 1(c) and Fig. 1(d). This ground plane was designed to be electrically large and serve as a sufficiently large ground for the rectifier circuit.

The offset tapered dipole was simulated and optimized in Ansys HFSS. The substrate was chosen to be Rogers TMM 10, with a relative permittivity of ε_r=9.2, a dielectric loss tangent of tanδ=0.0022, and a thickness of 60 mils with 1 oz. cladding.



(e)

Fig. 1. (a) Front face of the rectenna with dimensions, (b) fabricated frontside, (c) back face of the rectifier with dimensions, (d) fabricated backside, (e) rectifier with dimensions.

The antenna was fabricated without the rectifier circuit, and a UFL connector was placed at the feed point of the rectifier. Vias were drilled to connect the back-facing dipole arm to the UFL connector. The simulated and measured VSWR is shown in Fig. 2. VSWR less than 2 is shown between 700 MHz and 900 MHz. Also, the simulated gain pattern of the dipole showed a gain of above 2.2 dBi from 700-900 MHz.

TABLE I. Rectenna Dimensions

Rectenna Widths And Lengths			
Dimension	***Length (mm)***	***Dimension***	***Length (mm)***
w	81.3	l_8	2.2
d_1	10.7	l_9	3.9
d_2	148.4	l_{10}	4.1
d_3	119.8	w_1	1.4
l_1	40.1	w_2	2.4
l_2	22.4	w_3	0.3
l_3	6.9	w_4	2.1
l_4	6.9	w_5	2.2
l_5	2.9	w_6	0.3
l_6	4.1	w_7	0.9
l_7	9.7		

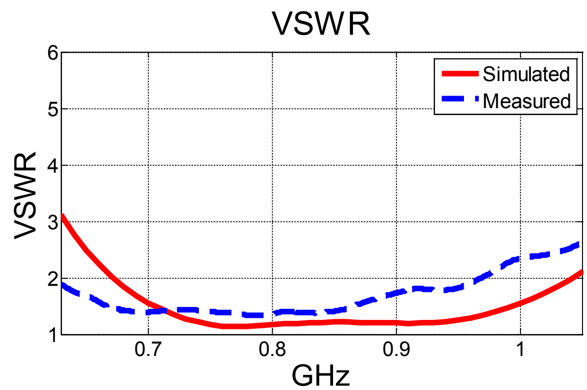


Fig. 2. Simulated and measured VSWR for the tapered offset dipole antenna.

III. RECTIFIER DESIGN

The broadband rectifier shown in Fig. 3 was designed and fabricated to operate across the bands of interest. The two diodes used were Skyworks SMS7630. A source-pull simulation using Keysight ADS showed that an input impedance matching network can be employed at our desired frequencies and power levels. Harmonic Balance and Large Signal S-Parameter (LSSP) engines were also used for characterizing the diode's non-linear performance.

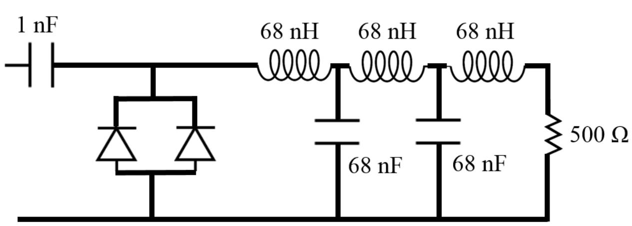


Fig. 3. Circuit schematic of wideband.

The fabricated rectifier performance is shown in Fig. 4. Similar to the antenna, the rectifier and matching network were designed on a Rogers TMM 10 substrate. Fig. 4 shows the approximate power delivered to the rectifier when the incident power density was 1 μW/cm^2. Also, Fig. 4 shows that a peak conversion efficiency of 64.3% is achieved at 700 MHz with an input power of 10 dBm.

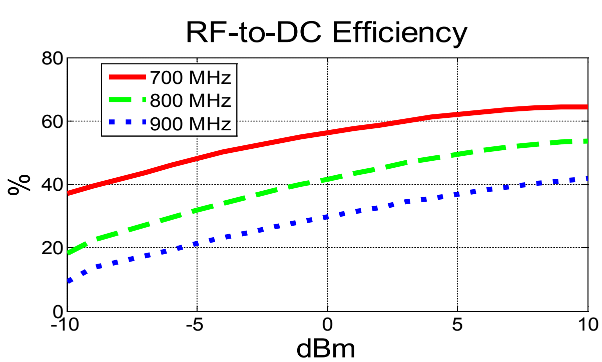


Fig. 4. RF-to-DC efficiency of wideband rectifier.

IV. SYSTEM MEASUREMENTS

Once the offset tapered dipole and wideband rectifier were independently validated, the two were combined to form the RF harvester. For testing, the 50 Ω antenna port was fed into the 50 Ω port of the rectifier and fabricated onto a single rectenna shown in Fig. 1.

The final rectenna was then characterized in an anechoic chamber. To do so, a signal generator was used to feed into a power amplifier, with the output signal feeding into the UHF horn antenna. The transmitting horn was placed a distance of 210 cm away in order to meet the far-field condition, viz. beyond $2D^2/\lambda$, and at sufficient distance so that the power density onto the rectenna was 1-10 μW/cm^2. The transmitted power density W_t was calculated at this distance using (1).

$$W_t = \frac{P_{in} \times G_a \times G_t}{4\pi r^2} \quad (1)$$

In (1), P_{in} is the input power from a signal generator, G_a is the gain of the amplifier, G_t is the gain of the transmit horn, and r is the distance the signal has radiated. The rectified power vs. power density for the fabricated rectenna is given in Fig. 5, showing a 10dB variation across the band.

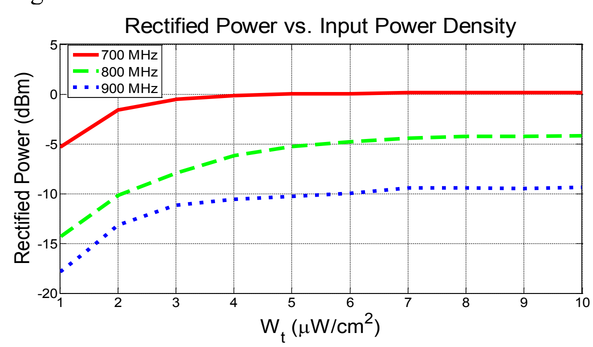


Fig. 5. Rectified power (dBm) vs.input power density.

V. CONCLUSION

A novel wideband rectenna was designed using a tapered offset dipole with greater than 25% fractional bandwidth and a wideband rectifier circuit. The conversion efficiency of the rectifier had a peak RF-to-DC conversion efficiency of 64.3%. The rectenna operates efficiently even with incident power densities down to 1 μW/cm^2. This wideband device can be used for sensor integration and in-home IoT applications.

REFERENCES

[1] National Telecommunications and Information Administration. (n.d.). United States Frequency Allocation Chart. [Online]. Available: https://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart

[2] A. Justice. (2010, July 15). 900 Mhz: The Wireless Workhorse. [Online]. Available: http://gridconnect.com/blog/general/900-mhz-the-wireless-workhorse/

[3] U. Olgun, C. C. Chen and J. L. Volakis, "Design of an efficient ambient WiFi energy harvesting system," in IET Microwaves, Antennas & Propagation, vol. 6, no. 11, pp. 1200-1206, August 21 2012.

[4] B. DeLong, C. C. Chen and J. L. Volakis, "Wireless energy harvesting for medical applications," 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, 2015, pp. 1213-1213.