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Accessing High Temperature Stereolithography Photopolymers Compatibilities for Antennas

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Abstract—This paper presents a 2D-rectenna fabricated using a Plastronic approach for ambient Radio Frequency energy harvesting from Wi-Fi band 2.45 GHz. The first experimental vehicle is a patch antenna with a transmission line feeding method connected to a rectifier with a series topology. Measurements show a rectified voltage of 72 mV and a RF-DC efficiency of 13% with a load of 10 kΩ when operating at RF input power of -24 dBm. The device is made with a combination of Additive Manufacturing and Plastronics, which will allow in the future fabricating antennas on 3D substrates.

Keywords – Additive Manufacturing, Plastronics, Rectenna, Energy Harvesting.

I. INTRODUCTION

Before 2025, 25 billion Internet of Thing (IoT) devices are expected in the world. Their shape and volume will be very disparate as well as their applications. Therefore, it would be convenient to implement in the same device, antennas and Radio Frequency (RF) components on the 3D polymer housing of the many familiar objects around us.

In this case of mass-produced objects, this is possible with a technology called Molded Interconnected Device (3D-MID) [1] also named Plastronics [2]. However, there is still a lack for relevant technology for prototyping.

Therefore, we report here on the combination of 3D printing by Additive Manufacturing (AM) and electroless metallization of copper for prototyping an antenna associated to a rectifier circuit to realize a rectenna for energy harvesting. As proof of concept, a planar device is developed but the technology allows prototyping antennas on a 3D shape or even network of antennas.

Among many different AM technologies, we decided to use Stereolithography (SLA) in order to take advantage of photopolymers compatible with conventional soldering technologies. SLA allows also manufacturing accurate parts with good surface roughness at moderate cost [1]. The challenge here was to evaluate if the electromagnetic properties of the photopolymers were sufficient to design an antenna with acceptable performance.

II. MATERIAL CHARACTERIZATION

A. Fabrication

1.5 mm thick sheets were 3D printed with a Formlabs printer with the photopolymer High Temperature (HT) Resin V1 from Formlabs, selected for its capability to withstand high temperature. The polymer was metallized with a 7 µm layer of electroless copper (measured by X-ray fluorescence) with 2.2 µΩ/cm resistivity (4 points probe) as described in [2].

B. Material Characterization

First step of designing printed RF circuits is to extract key parameters: the relative permittivity (ε_r) and the loss tangent (tanδ) of substrates. Nowadays, many methods are developed for characterizing insulating materials. Two Transmission Lines method is selected here for its accuracy and its simplicity of implementation over a wide band of frequency (from 1 MHz to 100 GHz) [3].

After validating the method by characterizing commercial Rogers 4003C (ε_r = 3.55 and tanδ = 0.0021), the relative permittivity and loss tangent of HT Resin V1 are measured in the 0.5-2.5 GHz range. The results are presented in Table 1.

According to Table 1, Rogers 4003C has a higher relative permittivity, which allows us to have a smaller patch antenna. Moreover, the lower loss tangent of Rogers 4003C gives us a higher gain but a narrower band patch antenna. A comparison of the gain and the band of frequency of antennas will be presented in the next section.

TABLE 1. MEASURED RELATIVE PERMITTIVITY AND LOSS TANGENT OF MATERIALS (0.5 GHz – 2.5 GHz)

<table>
<thead>
<tr>
<th>Material</th>
<th>ε_r</th>
<th>tanδ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rogers 4003C</td>
<td>3.52 – 3.57</td>
<td>0.002 – 0.004</td>
</tr>
<tr>
<td>HT Resin V1</td>
<td>2.90 – 3.10</td>
<td>0.025 – 0.028</td>
</tr>
</tbody>
</table>

III. RECTENNA

Rectennas play an important role in harvesting ambient RF energy and conversion into DC energy. A vehicle test 2D rectenna at 2.45 GHz is studied in this section.

A. Patch Antenna

The patch antenna is selected for the sake of simplicity and low-sensitivity to small variations on geometry. The patch antenna printed on HT Resin V1 is shown in Figure 1.

With the measured ε_r and tanδ, the antenna is optimized at the frequency of 2.45 GHz. The simulations are deployed in CST Studio Suite 2019. The radiating parameters of these antennas are shown in Table 2. Note that the dimensions of Rogers’ substrate are identical to the HT Resin V1’s one and the patch printed on Rogers are slightly smaller.
Comparing to the patch printed on Rogers, the bandwidth of HT Resin V1’s patch is broader. Its gain is 2.8 dB lower than Roger’s patch but still acceptable for energy harvesting.

### TABLE 2. RADIATING PARAMETERS OF THE PATCH ANTENNAS

<table>
<thead>
<tr>
<th>Band of freq. (GHz)</th>
<th>Sim. (Rog)</th>
<th>Mea. (Rog)</th>
<th>Sim. (HT V1)</th>
<th>Mea. (HT V1)</th>
</tr>
</thead>
</table>

### TABLE 3. S-PARAMETERS OF THE RECTIFIER

<table>
<thead>
<tr>
<th>Band of freq. (GHz)</th>
<th>Sim. @ -20 dBm</th>
<th>Mea. @ -20 dBm</th>
<th>Sim. @ -25 dBm</th>
<th>Mea. @ -25 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.405 – 2.49</td>
<td>2.443 – 2.53</td>
<td>2.37 – 2.458</td>
<td>2.41 – 2.495</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 4. COMPARISON TO STATE-OF-ART

<table>
<thead>
<tr>
<th>Ref</th>
<th>Freq.</th>
<th>Rect. type/diode</th>
<th>In pow. / Pow. dens.</th>
<th>Rect. volt/pow.</th>
<th>RF-DC eff</th>
<th>Size of rect. in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>[5]</td>
<td>2.45 GHz</td>
<td>4 quasi-Yagi with series rect. /SM57630</td>
<td>-34 dBm</td>
<td>--/124 nW</td>
<td>6.1%</td>
<td>65 x 65 x 65</td>
</tr>
<tr>
<td>[6]</td>
<td>GSM-900 GSM-1800 UMTS-2100</td>
<td>Dual-port microstrip patch with 1 series rect. /SM57630</td>
<td>-25 dBm</td>
<td>--</td>
<td>6.2% @ 2.17 GHz</td>
<td>175 x 200</td>
</tr>
<tr>
<td>[7]</td>
<td>2.45 GHz</td>
<td>/SM57630</td>
<td>-24 dBm</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

### IV. CONCLUSION

This work presents an experimental study about the performance of a 2D-rectenna fabricated by a Plastronic approach. The characterized electrical parameters of the substrate illustrate the possibility of using this material to create the RF circuits. Additionally, the electrical performances are compared to the state-of-art and thus confirm the possibility of implementing a harvesting function on top of a polymer object.

ACKNOWLEDGMENT

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REFERENCES


