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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 ($\tan\delta$) 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 ($\epsilon_r = 3.55$ and $\tan\delta = 0.0021$), 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)

Material	ϵ_r	$\tan\delta$
Rogers 4003C	3.52 – 3.57	0.002 – 0.004
HT Resin V1	2.90 – 3.10	0.025 – 0.028

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 $\tan\delta$, 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.

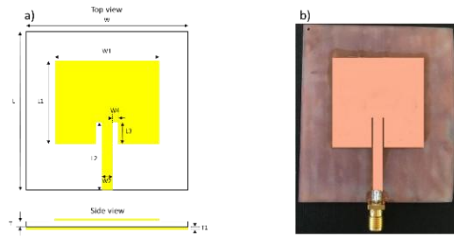


FIGURE 1. ANTENNA PRINTED ON HT RESIN V1 (A – GEO. ; B – PHOTO.)
 ($W = 60\text{mm}$, $W1 = 36.1\text{mm}$, $W2 = \text{mm}$, $W3 = 0.7\text{mm}$, $L = 70\text{mm}$, $L1 = 35.15\text{mm}$, $L2 = 33\text{mm}$, $L3 = 11.05\text{mm}$, $T = 1.5\text{mm}$, $T1 = 0.007\text{mm}$)

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

	Sim. (Rog)	Mea. (Rog)	Sim. (HT V1)	Mea. (HT V1)
Band of freq. (GHz)	2.438 – 2.464	2.436 – 2.459	2.42 – 2.486	2.41 – 2.495
Bandwidth (GHz)	0.026	0.023	0.066	0.085
Res. freq. (GHz)	2.45	2.449	2.453	2.452
Gain (dBi)	5.5	5.3	2.4	2.5

B. Rectifier

The rectifier is designed and optimized using Advanced Design System 2019 (ADS) and then validated by Co-Simulation of ADS Momentum at an input power of -20 dBm and the frequency of 2.45 GHz. The SPICE model with parasitic elements of the diode SMS7630 presented in [4] are used. The ADS models of the inductor of 9.1nH and the capacitor of 12pF provided by Murata are used in the simulation. The load is a 10kΩ SMD resistance from Yageo Corp. The circuit is printed on a 30mm x 40mm x 1.5mm HT Resin V1 board. The design of the circuit is illustrated in Figure 3 and S-parameters results are in Table 3.

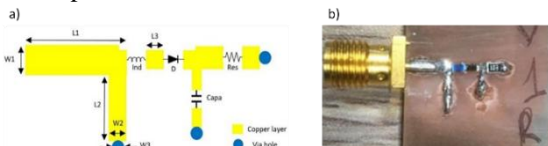


FIGURE 3. RECTIFIER CIRCUIT (A – GEO. ; B – PHOTO)
 ($W1 = 2\text{mm}$, $W2 = 1\text{mm}$, $W3 = 0.7\text{mm}$, $L1 = 4\text{mm}$, $L2 = 3.1\text{mm}$, $L3 = 1\text{mm}$)

TABLE 3. S-PARAMETERS OF THE RECTIFIER

	Sim. @ -20 dBm	Mea. @ -20 dBm	Sim. @ -25 dBm	Mea. @ -25 dBm
Band of freq. (GHz)	2.405 – 2.49	2.443 – 2.53	2.37 – 2.458	2.41 – 2.495
Res. freq. (GHz)	2.450	2.485	2.420	2.455

C. Measurement results

This rectenna is tested in an anechoic chamber where a horn antenna is placed in opposite of the patch antenna with a distance of 2.9m transmitting a power of 15 dBm. Hence, the receiving power at the patch is around -24 dBm. The measured rectified voltage, the RF-DC efficiency and a comparison of the experimental results against the state-of-art are provided in Table 4. We can find that our rectenna has a high efficiency

for a low input power with a small size and it has the same properties compare to the other works.

TABLE 4. COMPARISON TO STATE-OF-ART

Ref	Freq.	Rect. type/diode	In pow. / Pow. dens.	Rect. volt./pow.	RF-DC eff	Size of rect. in mm
[5]	2.45 GHz	4 quasi-Yagi with series rect. /SMS7630	-34 dBm	--/124 nW	6.1%	65 x 65 x 65
[6]	GSM-900 GSM-1800 UMTS-2100	Dual-port microstrip patch with 1 series rect. /SMS7630	-25 dBm	--/--	6.2% @ 2.17 GHz	175 x 200
[7]	2.45 GHz	-- /SMS7630	-24 dBm	--/--	~ 16%	--
This work	2.45 GHz	1 patch with 1 series rect. /SMS7630	-24 dBm	72 mV/--	13%	60 x 83

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.

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