Effect of Infill Density on the Performance of Recycled PET-Based 3D Printed Microstrip Antenna

Rupinder Singh, Bhanu Pratap Singh, Amrinder Pal Singh, Sanjeev Kumar, Yang Wei

Abstract Polyethylene terephthalate (PET) is commercially being used for making food containers, soft drink bot- tles, etc., and is one of the large contributors to municipal solid waste. One of the solutions to address this issue is the use of recycled PET in some high-end products which may add value to this waste. This study focuses on using primarily recycled PET which has been used to 3D print substrates with fused deposition modeling set up for fabrication of sensors. In this study, after ascertaining the rheological, mechanical, and morphological properties of selected PET waste, a ring resonator was fabricated followed by the fabrication of 3D printed substrates of various infill densities (33%, 50%, 100%). Further vector network analyzer was used to explore sensing capabilities of prepared microchip antenna. The results obtained for recycled PET were com- pared (at 100% infill density) based upon dielectric constant (εr) as 2.34, with commercial thermoplastics (such as acrylonitrile butadiene styrene (ABS) (εr 2.59), ninja flex (εr 2.90), and nylon (εr 1.02). The result of the study outlined that recycled PET-based sensors are one of the suitable alter- natives for better sensing applications.

Keywords PET · 3D printing · Microstrip antenna · VNA

The waste in the form of plastic has been increasing day by day and the prediction is that it will be in abundance in near future. The growing awareness of the environmental impact of plastics has therefore inspired the search for new technologies and other solutions not only to deal with the increasing amount of plastic waste in the environment [1]. The idea is to convert the disposed of material into some usable sensor that may be used in various high-end applications [2]. A sensor can be put into multiple uses as they are small in size, and easily manufactured. This saves the material cost, helps in waste recycling, and in return provides a useful product [3]. The ability of a material to act as a sensor/transmitter may be verified by fabricating a patch antenna and observing its transmitting ability. 3D printing is a growing market for small-scale manufacturing same may be adopted for sensor fabrication mainly due to its near-accurate finishing and ease of forming complex shapes [3, 4]. Studies show that due to thermoplastic use in commercial manufacturing, gases are emitted at high temperatures [4]. For example, while melt processing ABS, outputs such as hydrogen cyanide, carbon monoxide, and other unstable organics are observed. Also while melt processing of ABS, as compared to PET, a large number of ultrafine particles are noticed (which are harmful to the environment), which makes PET a suitable material to be worked upon.

In this study, melt flow index (MFI) testing was performed on available PET waste as per ASTM D1238. The MFI of the selected PET sample came out to be 5.7 g/10 min. MFI is one of the basis rheological properties of a material and a deciding parameter for its use on FDM [5]. In this study, MFI testing was performed on pre-heated material at 60 °C, below its glass transition temperature to facilitate moisture removal. The substrates were printed using an open-source FDM commercial printer, (make Ender 3 pro), for three infill densities of 33%, 50%, and 100% with a rectilinear infill pattern, 03 number of perimeters, and 02 top and bottom layers. A ring resonator was fabricated to quantify the loss tangent (tanδ), and εr of the material for sensor application. The dielectric constant of the material has been calculated by using the equations from the previous literature on ring resonators [6–8]. After ascertaining tanδ, and εr, VNA results were used to design a patch antenna using equations from the literature [7, 8]. The results of VNA and antenna dimensions are shown in Table 1.

Patch Antenna was designed and simulated on Ansys HFSS software and the results are as shown in Fig. 1. As observed in Table 1 and Fig. 1 it is evident that the maximum S11 parameter for recycled PET, − 23.184 dB is better than ABS (− 18.90 dB) [9], nylon (− 18.85 dB) [10], ninja flex (− 15.78 dB) [11] which implies that recycled PET antenna has higher radiating power for a given power input contrasting to the rest and hence can act as a sensor with appreciable qualities.

Figure 2 shows that εr derived from recycled PET follows a similar linear pattern to that of ABS [9], nylon [10], and ninja flex [11]. This allows it to easily interpolate εr and, as a result, anticipate patch antenna size. Recycled PET has a near similar εr at 100% infill density (1.71 at 33% infill density, 1.83 at 50% infill density, 2.34 at 100% infill density) as that of ninja flex (2.23 at 33% infill density, 2.40 at 50% infill density, 2.90 at 100% infill density) and ABS (2.66 at 33% infill density, 2.52 at 50% infill density, 2.59 at 100% infill density) while more than nylon (0.35 at 33% infill density, 0.52 at 50% infill density, 1.02 at 100% infill density). Over- all recycled PET has a better S11 parameter than ABS, ninja flex as well as nylon and hence can be successfully applied as a flexible wearable antenna.

Table 1 Results of recycled PET at different infill density

Infill density	Resonating frequency (GHz)	s parameter (dB)	ε	tan$o$	Length of a patch (mm)	Width of a patch (mm)
33%	3.11	− 14.898	1.71	0.0041	46.31	52.57
50%	3.02	− 18.526	1.87	0.0043	44.71	51.38
100%	2.73	− 23.183	2.34	0.0046	39.73	47.38

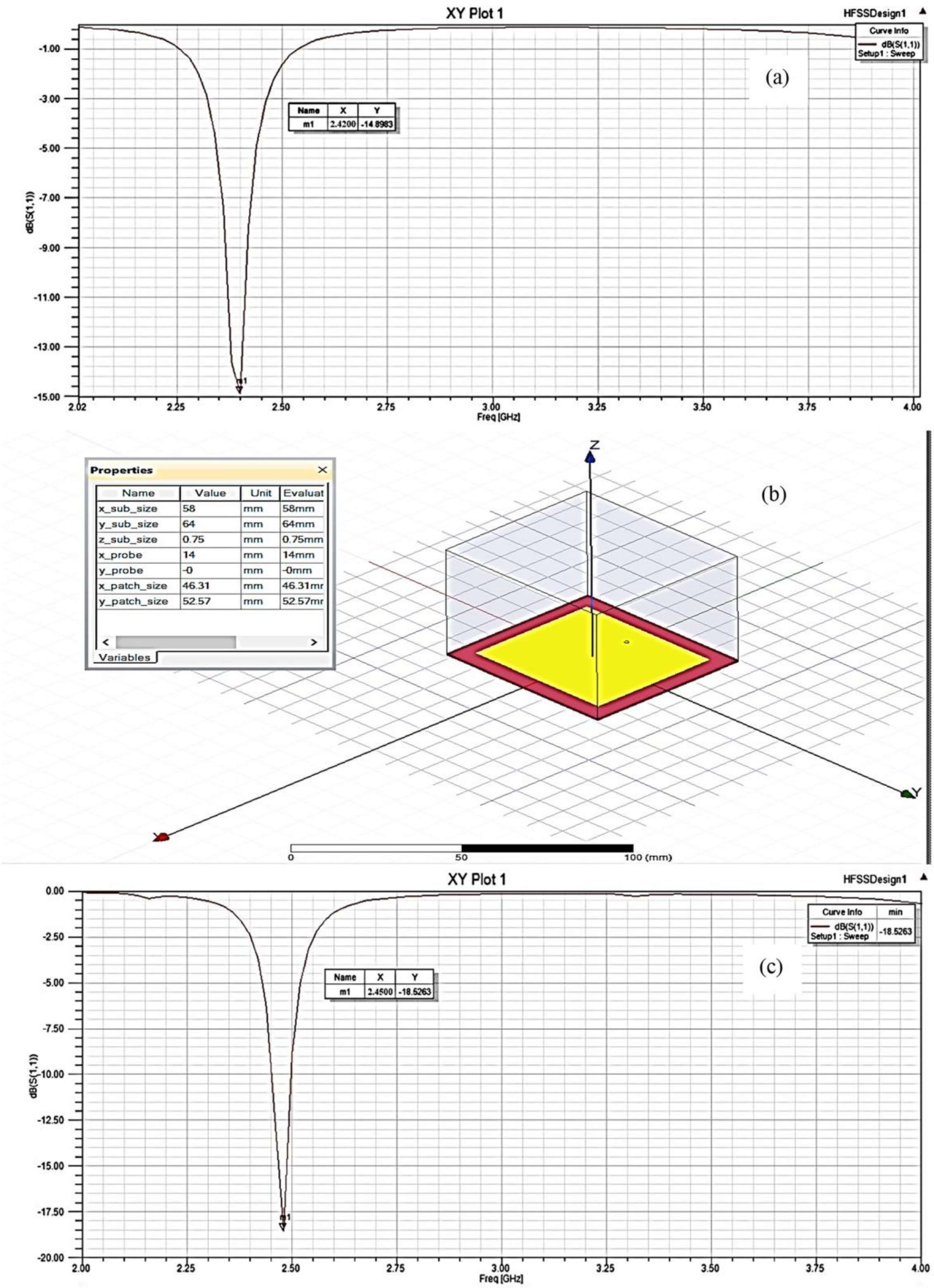

Fig. 1 S_{11} parameter for recycled PET (**a**), Ansys HFSS model for recycled PET (**b**), S_{11} parameter for ABS (**c**), Ansys HFSS model for ABS (**d**), S_{11} parameter for nylon (**e**), Ansys HFSS model for nylon (**f**)

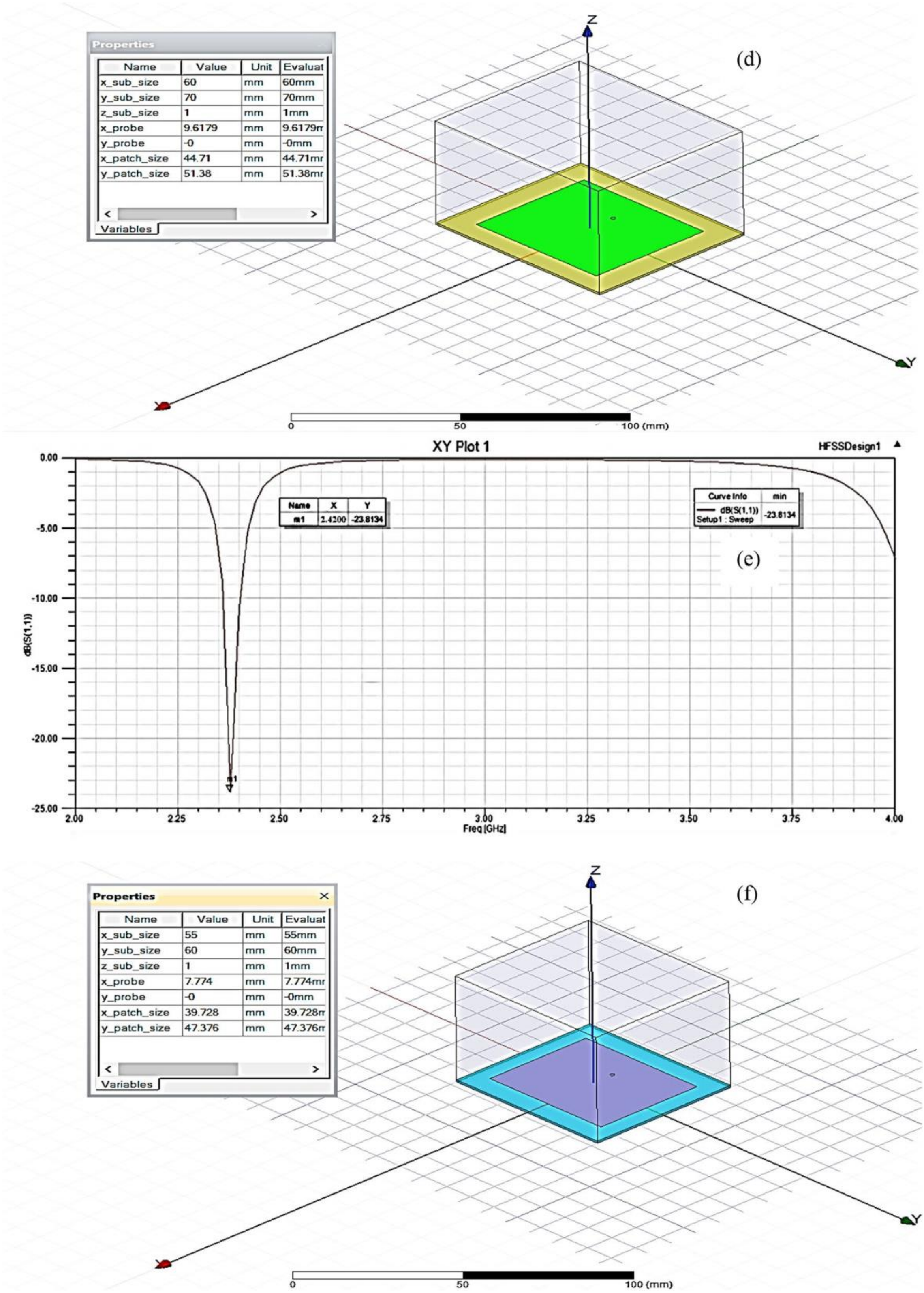

Fig. 1 (continued)

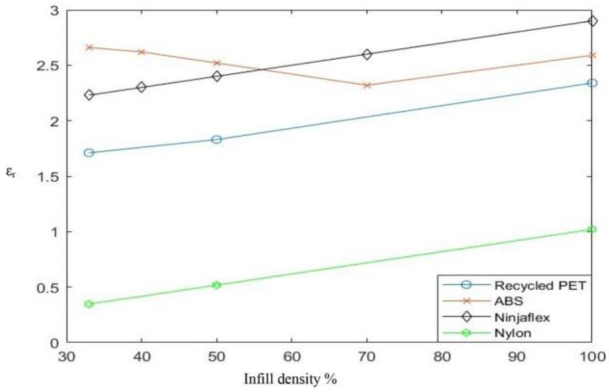

Fig. 2 Infill density versus εr.

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Declarations N/A

Conflicts of interest

The authors don’t have any conflict of interests/ competing interests.

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