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Evaluation of Permittivity Values for Sargassum Seaweed Derived Bioplastic

Jeevan Persad, Kyle Seales, Sean Rocke, Akeem Mohammed, Megan Mahadeo and Aaron Roopnarine

Department of Electrical and Computer Engineering, The University of the West Indies, Jeevan.Persad@uwi.edu

GOAL OF THE STUDY

This study evaluated the relative permittivity (ϵ_r) of decomposable bioplastic produced from Sargassum natans seaweed. Testing was conducted across the 1-10 GHz range using a two-layer stripline measurement method. The bioplastic has potential applications, such as compostable RFID tags for fresh produce, health-monitoring sensors for direct application to plants, and livestock-tracking tags.

METHODOLOGY OF THE INVESTIGATION

Samples of bioplastic were prepared with a 0.10 mm thickness and cut into 30 mm x 40 mm pieces. A ground plane was attached to each sample using 3M 1125 copper foil. Fig. 1(a) shows a bioplastic sample, Fig. 1(b) a prepared testing sample, Fig. 1 (c) shows the COMSOL Multiphysics simulation model used to obtain the calibration curve for the testing rig, and Fig. 1(d) shows the testing rig. The rig features a 50 ohm microstrip line fabricated on a known dielectric (standard) material. The standard material was the Rogers Corporation 4350B laminate. The test sample is applied to the top of the microstrip line, thus sandwiching the transmission line and forming a pseudo stripline structure.

An Anritsu MS46122B VNA was used to measure the phase change ($\Delta\phi$) of the applied signal and the change in the electrical delay of the transmission line ($\Delta\tau_e$) before and after the application of the test sample. The $\Delta\tau_e$ can be used to obtain the effective relative permittivity of the stripline (ϵ_{effs}), where λ_0 is the wavelength of the applied signal in free space, l_p=40.00 mm is test sample length and, ϵ_{effm} is the effective relative permittivity of the microstrip line.

$$\epsilon_{effs} = \left(\sqrt{\epsilon_{effm}} + \frac{\Delta\tau_e.\lambda_0}{l_p}\right)^2, \epsilon_{effm} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\left(\frac{H}{w}\right)\right]^{-\frac{1}{2}} \quad (1)$$

$\epsilon_r = 3.48 \pm 0.05$ (Roger 4350B laminate), $H = 1.52 \pm 0.02$ mm, $w = 3.43 \pm 0.02$ mm and $\epsilon_{effm} = 2.73$. The value of ϵ_{effs} is used in conjunction with the calibration curve to obtain the ϵ_r of the test samples.

RESULTS AND ANALYSIS

The calibration curve obtained from the simulation model was given by:

$$\epsilon_{effs} = 0.302\epsilon_r + 2.428 \quad (2)$$

Table 1 shows the measured values of ϵ_{effs} for the test samples and the associated values of ϵ_r obtained using the calibration curve. Fig. 2 shows the plot of the measured values of ϵ_r vs frequency. The measured ϵ_r values mostly ranged from 2.68 to 12.99, with two notable resonance peaks at 2–3 GHz (9.99) and 6–7 GHz (89.06). The strong resonance near 6–7 GHz may result from molecular or lattice resonances linked to the material's additive composition. This property could be beneficial for frequency-selective or tunable RF applications, such as filters, absorbers, or dielectric resonator antennas. Expected dips in the value of ϵ_r owing to the presence of polar groups within the bioplastic molecular structure were not observed. This may be due to the degree of crosslinking achieved in the bioplastic. The study limits include the the sample size (n=6) and the single material composition of the samples.

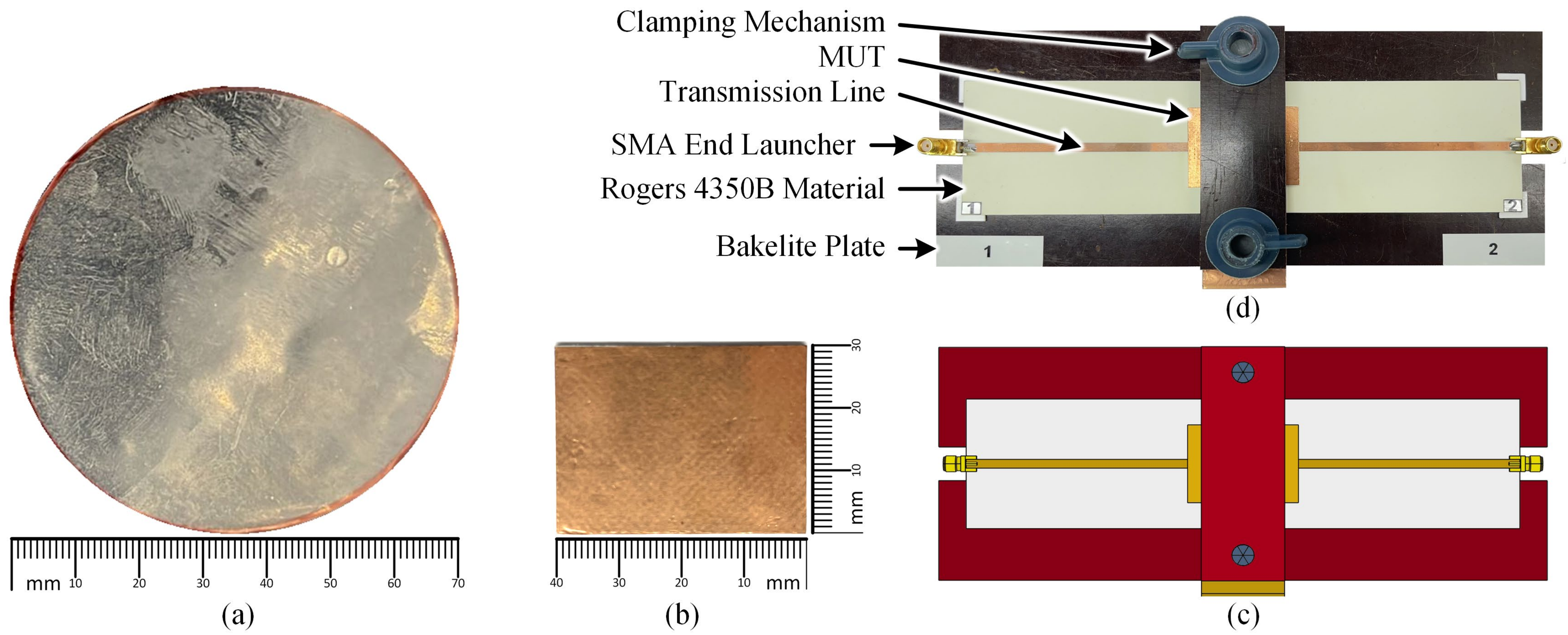

Fig. 1. (a) Sample of Sargassum bioplastic; (b) prepared test sample with copper ground plane attached; (c) COMSOL simulation model of the testing rig; (d) details of the testing rig constructed for the two-layer stripline measurement method.

CONCLUSION

Bioplastic derived from Sargassum alginate was evaluated over 1–10 GHz, showing relative permittivity (ϵ_r) values between 2.65–13.00 and a resonant peak of 89.06 near 6–7 GHz. The material is able to fully decompose within 14 days, and prior studies have established its economic viability. These results highlight Sargassum bioplastic as a promising sustainable substitute for conventional plastics. Future work will expand testing to include varied additive compositions and larger sample sets to model for ϵ_r and develop practical RF applications such as RFID tags and flexible antennas.

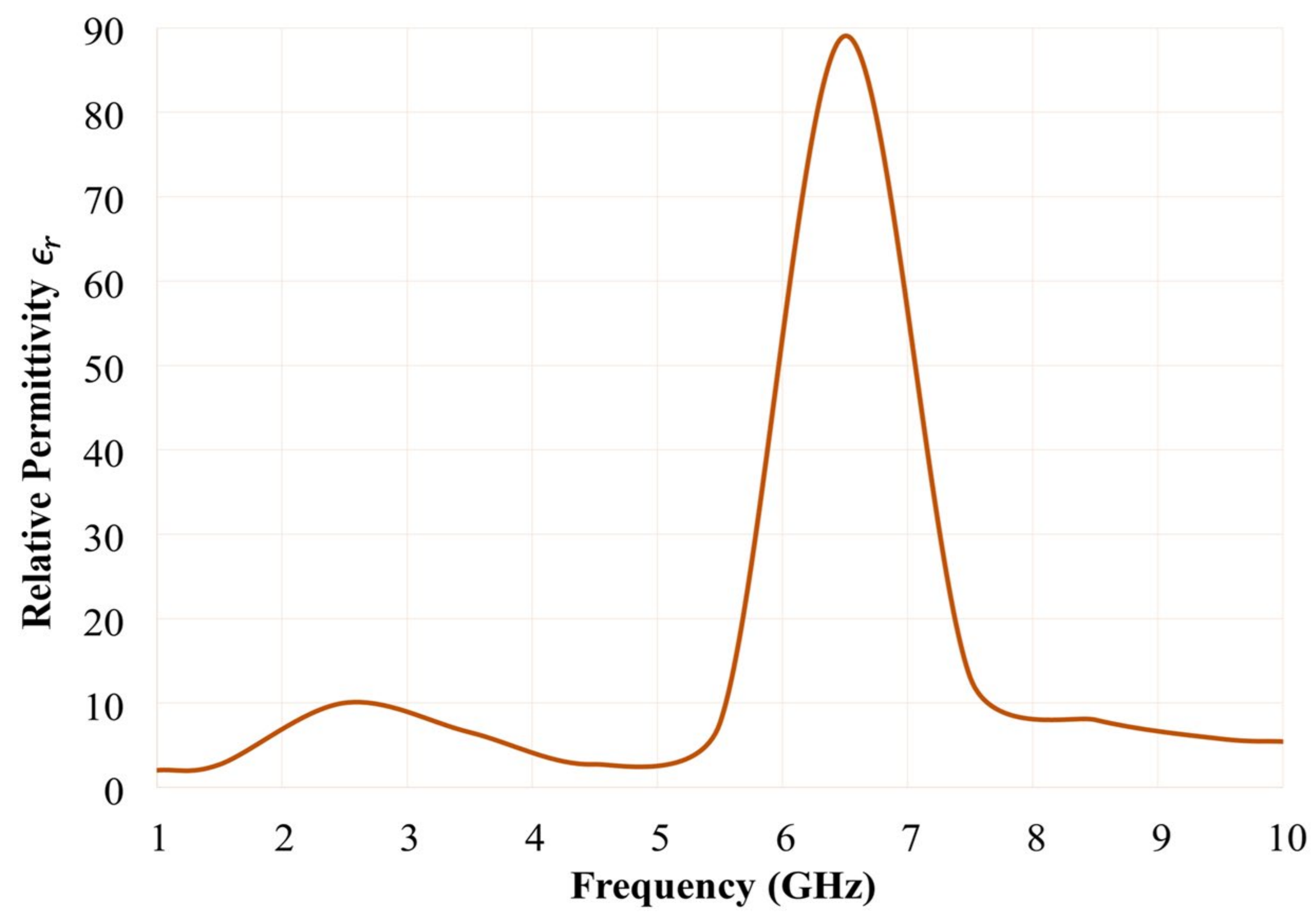

Fig. 2. Plot of the measured ϵ_r vs frequency (GHz) for the bioplastic samples.

Table 1. Measured ϵ_{effs} and ϵ_r

Frequency (GHz)	ϵ_{effs}	ϵ_r
1-2	3.24	2.68
2-3	5.45	9.99
3-4	4.39	6.51
4-5	3.25	2.70
5-6	4.72	7.59
6-7	29.36	89.06
7-8	6.35	12.99
8-9	4.84	7.98
9-10	4.16	5.73