Impedance matching of a pyramidal horn antenna by inserting organic dielectric slabs

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Abstract

A comparison of impedance matching parameters from 6.565 to 13 GHz was performed when samples of agricultural wastes as Opuntia Ficus-Indica cladodes, Agave Atrovirens branches and Cocos Nucifera L. husk were inserted at the flare section of a pyramidal horn antenna. S_{11}, Voltage Standing Wave Ratio, and impedance were measured and compared to evaluate antenna performance in the presence of them and in order to develop low-cost and eco-friendly devices for antenna matching and other electronics purposes. Particularly, Cocos Nucifera L. husk had the most appropriate features in terms of impedance matching, offering average values of $|S_{11}|$, Voltage Standing Wave Ratio and $|Z|$ of 0.229, 1.871, and 57.647 Ω respectively.

Keywords— Impedance matching parameters, pyramidal horn, organic dielectric slab

I Introduction

In recent times, the care of the environmental quality is crucial, so it is important to mention that only recently attention has been given to the waste problems in agriculture [1], and within these recent years, it has been known that agriculturally related pollution is not minor and deserves the attention of scientists and engineers interested in the use of agricultural waste so that find low-cost and eco-friendly applications [2], mainly for electronics which is an industry that generates a lot of pollution [3]. Our country is not oblivious to this situation, where a lot of wastes are not reused in a correct manner, for example Opuntia Ficus-Indica (OFI) or cactus pear [4], Agave Atrovirens (AA) or maguey [5] and Coco Nucifera L. (CN) [6] are among the most common agricultural wastes. Dry samples of OFI cladodes, AA branches, and CN husk are the target of this work, due to their relative abundance in Mexico, and like all organic matter, they have a high carbon content, an element that favours the absorption of electromagnetic waves in the microwave region [7, 8]. These three materials come under the category of agricultural waste and have a great potential of being used as impedance matching devices, which are essential elements for applications in electronics and telecommunications such as antennas and radars [9, 10, 11]. Syntetic material polyurethane (Poly) is used as an absorber and installed on the walls of anechoic chambers to avoid echoes [12]. In this case it is included to be compared with organic materials to find out its impaedance matching properties when it is also inserted inside the flare section of a pyramidal horn antenna

The three proposed organic materials are an alternative to commercial synthetic materials, since it was found that agricultural wastes like banana leaves, sugarcane bagasse and rice husk can be used for the same purpose [13, 14, 15]. These alternatives are based on renewable materials which eliminate the toxic gas release problem observed in commercial materials such as Poly under high power test conditions. They are cost-effective materials and can be used to make eco-friendly microwave matching devices with acceptable results [16, 17]. In this work, a comparison of the performance of a pyramidal horn antenna at microwave frequencies by inserting three different organic dielectric slabs at the flare section was performed, to find out the one that offers the most appropriate behavior in terms of impedance matching.

II Materials and Methods

To get the comparison of the impedance matching parameters for a pyramidal horn antenna by the insertion of three organic materials (OFI, AA, and CN), one-port measurements were carried out, which constitute the methodology of the present study. The experimental setup consisted of a pyramidal horn antenna with samples and sample holder whose dimensions agreed with those of the cross-section for a WR90 waveguide (1.016 cm wide and 2.286 cm high) which is part of the antenna.

The samples were 0.6 cm thick and the sample holder was placed just before the antenna flare section. The organic samples were made of powdered and dry organic materials which were compacted in the sample holder. The powdered materials were moistened to make a coir paste filling the sample holder while it was on a flat surface; pressure and heat were applied to dehydrate at 180°C and then a brick whose dimensions were the same as those of the sample holder was created. The flare length, width and height were 7.62, 9.144 and 7.366 cm respectively. The antenna port was connected to one of the ports of an N5222A Keysight Vector Network Analyzer [18], using SMA connector and low-loss 50 Ω coaxial transmission line. The VNA was calibrated using an 85521A Keysight 3.5 mm Cal Kit [19] from 6.565 to 13 GHz to measure S_{11}. The lowest frequency for measurements was chosen to be higher than the TE10 cutoff frequency for WR90 waveguides, a type of waveguide which is included as part of the pyramidal horn. Also, to compare with commercial and synthetic materials such as a Poly, a sample of this material was also considered. Figure 1 shows the experimental set up for the pyramidal horn antenna and its components.

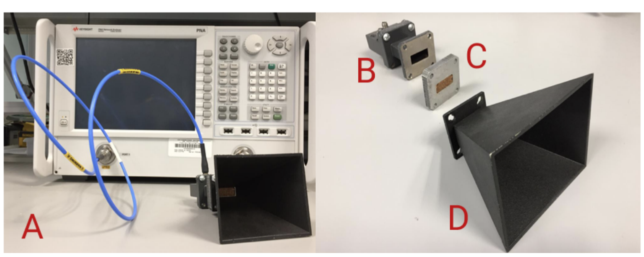

Figure 1: *(A) Experimental set up, (B) Waveguide WR90, (C) Sample holder, (D) Pyramidal horn antenna*

To show the performance of the pyramidal horn antenna in terms of its maximum total gain before and after inserting a synthetic absorber material, a modelling using advanced electromagnetic simulation software based on the finite element method was carried out. The simulation included a pyramidal horn antenna with the same dimensions set to coincide with measured counterpart (WR90 waveguide). The inserted material that was modelled was a Poly sample. The simulation was performed at 10 GHz which is within the range where S-parameters were measured and beyond the cutoff frequency for the TE10 mode. The simulation considered a wave port for which an integration line was defined and an input power of 1W for the selected mode was set. Material for the sample was defined considering frequency-dependent dielectric properties reported in [20].

III Results and Discussion

As described in Section II, results obtained for the antenna measurement are presented, this to compare antenna performance when each of the three organic materials is inserted. Poly and the empty antenna (no sample, free space) are also included in the comparison so that the effects due to the organic materials are observed with respect to the original antenna and with a synthetic commercial material.

Based on the experimental setup that contemplates the pyramidal horn antenna, one-port measurements were performed as a function of frequency, which showed a clear dependence on the material inserted at the antenna flare section, where it can be noticed that the case without sample is the original case corresponding to a horn antenna formed by a widened waveguide.

Analysing the results obtained by measuring the one-port network parameters for the horn antenna, the presence of the materials can be verified by the changes observed in the magnitude of S_{11}, the value of VSWR and the complex impedance, parameters in which the relative degree of impedance matching between the antenna and the 50-ohm transmission line can be observed. Inserted materials that cause a higher impedance matching imply a lower reflection towards the transmission line (S_{11}).

Figures 2, 3 and 4 shows the comparison of the parameters S_{11}, VSWR and complex impedance respectively.

In Figure 2, the reflection characteristics (S_{11}) of the three organic materials considered, Poly and the empty antenna are shown.

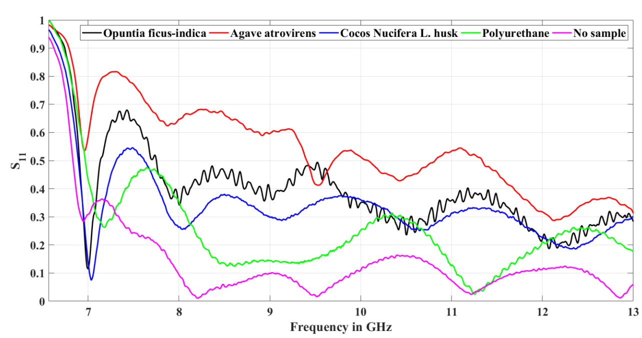

Figure 2: *Reflection characteristics (S_{11}) of the different materials considered*

Figure 3 shows the VSWR, where it can be noticed that for the case of CN, a value of around 2 was measured, what in practical terms is an acceptable impedance matching. The poly sample is characterized by a VSWR usually lower than 2.

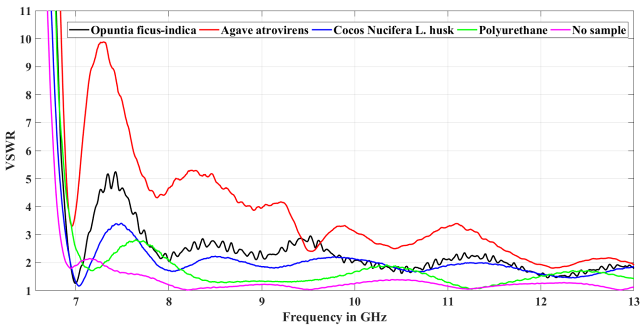

Figure 3: *VSWR measurements*

In the case of impedance plotted in Figure 4, CN is also the material that leads to having an impedance magnitude closer to 50 ohms. Table 1 shows a comparison of the behaviour in terms of average values for the materials inside the horn antenna from 8.005-13 GHz, where this information is summarized.

Table 1: *Behaviour in terms of average values for the different materials inside the horn antenna from 8.005-13 GHz*

Material	$\lvert\overline{S_{11}}\rvert$	$\overline{VSWR}$	$\overline{R}(\Omega)$	$\overline{X}(\Omega)$	$\lvert\overline{Z}\rvert(\Omega)$
Air	0.084	1.188	49.703	-5.3	50.236
Poly	0.187	1.482	47.252	-4.989	49.056
CN	0.229	1.871	52.437	-6.387	57.647
OFI	0.346	2.103	52.314	-7.446	59.57
AA	0.485	3.099	52.36	-8.147	68.035

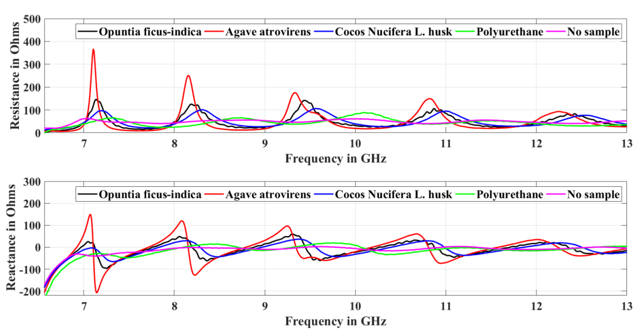

Figure 4: *Complex impedance of the materials*

Table 2 also shows that CN provides the best impedance matching to 50 Ω at the first work frequency, while AA sowed the worst. Values of S_{11} and VSWR are also shown for OFI, Poly and empty waveguide (Air) at their first work frequencies.

IV Conclusions

Commercially, Poly is used in the manufacture of absorbers that are placed in anechoic chambers and other industrial electronics applications. In this research a comparison of electromagnetic parameters is carried out with samples of three different

Table 2: *Impedance matching to 50 Ω for different materials*

Material	Freq.	S_{11}	VSWR	Re(Z)	Im(Z)
CN	7.033	0.074	1.16	51.902	-7.362
AA	6.961	0.534	3.296	19.152	24.086
OFI	9.997	0.114	1.258	42.329	7.32
Poly	7.258	0.289	1.814	63.773	-31.244
Air	6.493	0.284	1.794	53.777	-30.522

organic absorber materials in order to apply them in electronics and particularly in antenna impedance matching. Such materials were OFI cladodes, AA branches and CN Husk which were compared with the case without material sample (free space) and Poly.

In this comparison, parameters S_{11}, VSWR and impedance for a pyramidal horn antenna with samples inside were measured. It was observed that for CN husk a very similar performance compared to Poly and a little better than the OFI was observed, while AA was somewhat remote in performance. In this work, it is concluded that organic waste materials from agriculture such as CN husk and OFI cladodes are good candidates for the manufacture of low-cost and eco-friendly impedance matching devices, contributing to the reuse of waste and to the improvement of the care and quality of the environment. As future work is visualized the manufacture of antenna tuning devices based on these two organic materials through the use of molds and a binder that does not significantly alter its properties to prevent them from crumbling and can be handled.

Finally, to sustain the results obtained by measurements, the simulation of the antenna gains at 10 GHz showed that there were not considerable differences between the case of inserting the organic material (Poly) and not, from which is concluded that the main impact is on impedance matching. Such a difference was 0.09 dBi.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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