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Wideband Characterization of Microstrip Technology with Borofloat 33 and Some Classic Transparent Glasses

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Abstract In this work, we made the technical qualification of borofloat 33 glass and also other much cheaper conventional glasses, associated with solid metallization by a broadband characterization method of microstrip technology based on the S-parameters. This made it possible to extract the electromagnetic parameters (dielectric permittivity, tangent loss) necessary for the design and construction of low visual impact antennas. The values of S_{11}, S_{33}, S_{12}, and S_{34} are then extracted on vector network analyzer (VNA). The data of these measurement results are processed and the values of the loss tangent and the dielectric constant are thus measured with ADS software. We have obtained for the classical glass $\varepsilon_r = 6.5$ and $\tan\delta = 0.0206$; for the microscope glass $\varepsilon_r = 6.15$ and $\tan\delta = 0.021$ and at the end for the borofloat 33 glass $\varepsilon_r = 4.5$ and $\tan\delta = 0.012$.

Keywords: *glass, dielectric permittivity, tangent loss, S parameters, transparent antenna*

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1. Introduction

The presence of antennas is becoming more and more frequent on a daily basis with the development of wireless connected objects. The two major challenges to be taken up in particular are, among other things, the integration of antennas into communication devices and the reduction of the visual impact of antennas on the public. Hence the growing need to produce transparent antennas or with low visual impact and at a bearable cost. Whiches will allow implementation antennas on glazed surfaces (glazing of buildings, vehicles, smartphones, etc.) and their installation on historic sites and shopping centers not only to improve network coverage but also for greater discretion to the public thanks to their appearances. Planar antennas are a category of antennas that, in essence, are discrete (due to their form factor, their weight, etc.) [1]. and they also allow the implementation of miniaturization techniques. To design planar antennas, you have to rely on both dielectric and conductive materials. If we are primarily interested in dielectric materials, we find two main categories, glasses, and so-called "plastic" materials.

A second reason for the use of less conventional materials is the development of IoT, connected objects, for all types of everyday applications or in more specific fields (health, industry of the future, automotive, etc.). These connected objects are developed on any type of medium and must be able to communicate with the outside. We must therefore be able to develop antennas on various material supports. We will start with materials whose properties are guaranteed by the manufacturer such as borofloat 33 and which can be confirmed from this work and with slightly more "low cost" solutions for which the transparency properties are guaranteed but for for which no estimate has been made of the value of fundamental electromagnetic parameters for the design of antennas, namely the relative permittivity and the loss tangent of the dielectric substrate.

The electromagnetic characterization of materials has become more and more important or even essential because it makes it possible to size the antennas well and therefore to precisely predict their frequency behaviors before manufacturing [2]. Methods of measuring materials, although numerous, are generally divided into two main groups: broadband (transmission lines) and narrowband (resonant cavity, waveguide, free space).

Narrowband methods use a cavity resonator and can characterize the material at a single frequency or at certain discrete values of frequencies. They are divided into two groups:

- The first is the dielectric resonance technique in which the dielectric material itself acts as a resonant element, but it is limited only to low loss samples.

- The second is the perturbation technique, the presence of a small sample in a resonant cavity causes a field disturbance in the latter, and thus a resonant frequency shift [3]. This technique is suitable for samples with low loss and medium loss.

Wideband methods are done with transmission lines, which allows the measurement over a wide range of frequencies of the transmission and reflection coefficients resulting from characteristic changes in impedance and wave speed. The classification of materials is then done by determining the electromagnetic parameters of the substrate under test from these coefficients.

2. Presentation of the Technology Used

The electromagnetic characterization method used is a broadband measurement method. In this method, only the fundamental waveguide mode (TEM mode in the coaxial lines, quasi-TEM mode in transmission lines and TE_{10} mode in the waveguides) is assumed to propagate. This technique takes into account the fact that the dielectric substrate will be used in microstrip technology for the design of the antenna, ie with metallization above / below.

A measurement using this method involves placing a sample in a section of waveguide line or coaxial line and measuring the diffusion parameters of the two-port complex with a vector network analyzer (VNA) (Figure 1). The method comprises measuring the reflected (S_{11} or S_{22}) and transmitted (S_{21} or S_{12}) parameters. The relevant diffusion parameters are closely related to the complex permittivity and the permeability of the material by equations. For an accurate dielectric measurement, the maximum electric field is required in the sample. Figure 1 illustrates the typical measurement setup with a coaxial cable.

The advantages of using the transmission / reflection line include:

- Coaxial lines and waveguides are commonly used to measure samples with medium or high loss;
- They make it possible to more easily determine the permittivity, the permeability and the loss tangent of the material tested.

However, this broadband measurement technique also presents some constraints:

- The precision of the measurements is limited by the effects of the air gap.
- It is limited to low precision when the length of the sample is the multiple of half the wavelength of the material.
- The preparation of samples is relatively difficult because of its different stages of realization.

The propagation constant γ is related to the attenuation coefficient α and the phase constant β by the relation

$$\gamma = \alpha + j\beta. \tag{1}$$

For a dielectric material, the propagation coefficient of a wave in a transmission line is related to the complex permittivity of the filler material through the relation [4]:

$$\gamma = j\sqrt{\frac{\omega^2\mu_r\varepsilon_r}{c^2} - \left(\frac{2\pi}{\lambda_c}\right)^2} \tag{2}$$

Where ω is the angular frequency, μ_r is the permeability of the material which is equal to 1, c is the speed of light and, λc is the cutoff wavelength of the transmission line. In case of a coaxial transmission line supporting TEM propagation the cutoff wavelength is taken to be equal to infinity. $\varepsilon_r = \varepsilon_r^{'} + j\varepsilon_r^{''}$; is the complex permittivity of the material filling the line where, $\varepsilon_r^{'}$ is the dielectric constant and $\varepsilon_r^{''}$ is the dielectric loss of the medium. From equation 1 it becomes possible to extract the complex permittivity of the material filling the transmission line.

$$\varepsilon_r^{'} = \left(\frac{c}{\omega}\right)^2\left[\left(\frac{2\pi}{\lambda_c}\right)^2 - \alpha^2 + \beta^2\right] \tag{2}$$

$$\varepsilon_r^{''} = 2\alpha\beta\left(\frac{c}{\omega}\right)^2 \tag{3}$$

This technique is relatively easy to be implemented both in measurement and in the process of extracting parameters.

For TEM mode, the complex relative permeability and permittivity can be found as [6]:

$$\varepsilon_r = \frac{Z_0\gamma\lambda}{jZ_s 2\pi} \tag{5}$$

$$\mu_r = \frac{Z_s\gamma\lambda}{jZ_0 2\pi} \tag{6}$$

Where Zs is the characteristic impedance of the sample, Z0 is the characteristic impedance of air for the same dimensions, λ is the wavelength of free space, and γ is the propagation constant which is determined by function of the S parameters as follows:

$$\gamma l = \cosh^{-1}\left(\frac{1 - S_{11}^2 + S_{21}}{2S_{21}}\right) \tag{7}$$

l is the thickness of the sample.

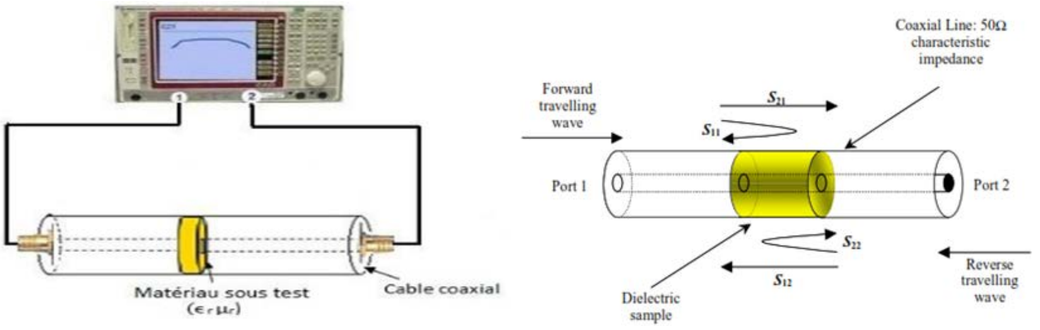


Figure 1. Measurement technique of a dielectric substrate taking into account the application to which it is intended i.e. antenna design [5]

3. Materials and Methods

This broadband microstrip characterization technique was first applied to two conventional glasses (typically microscope glass and classic glass) and whose transparency is around 90% in the visible range, then to borofloat 33 which has 92% transparency (supplier data). The idea is to work with transmission lines of clearly different impedance than 50 Ohms in order to generate sufficiently clear mismatches to be able then to associate a model with the measurement and to identify the values of the parameters ε_r and tan_δ which allow to fit the model to measure. On each glass, we put two metallizations with copper 35um thick. The upper metallization comprises two lines and the lower metallization constitutes the ground plane. On each line we have two 50 Ohm ports. One of the 0.4 mm wide lines has an impedance greater than 50 Ohms and the second, 8 mm wide, has an impedance less than 50 Ohms (Figure 2).

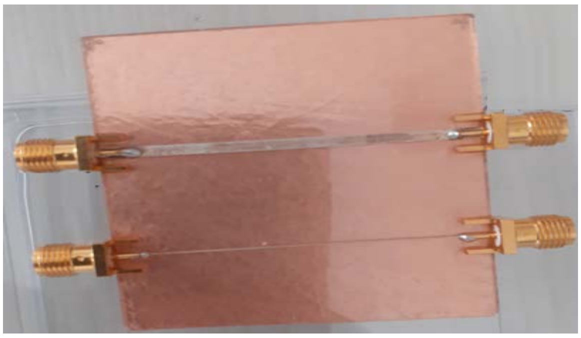


Figure 2. Realization of lines

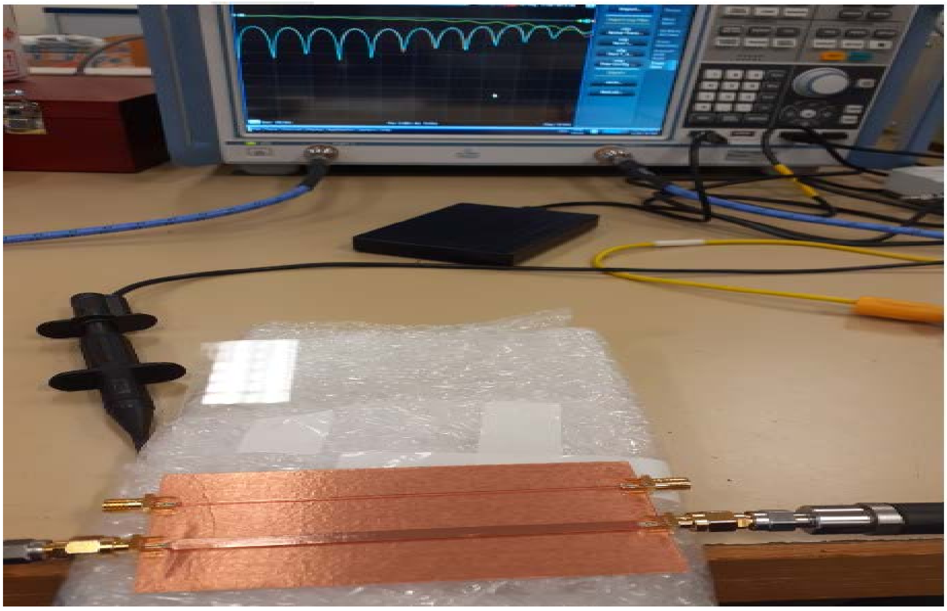


Figure 3. a) measurement configuration on VNA

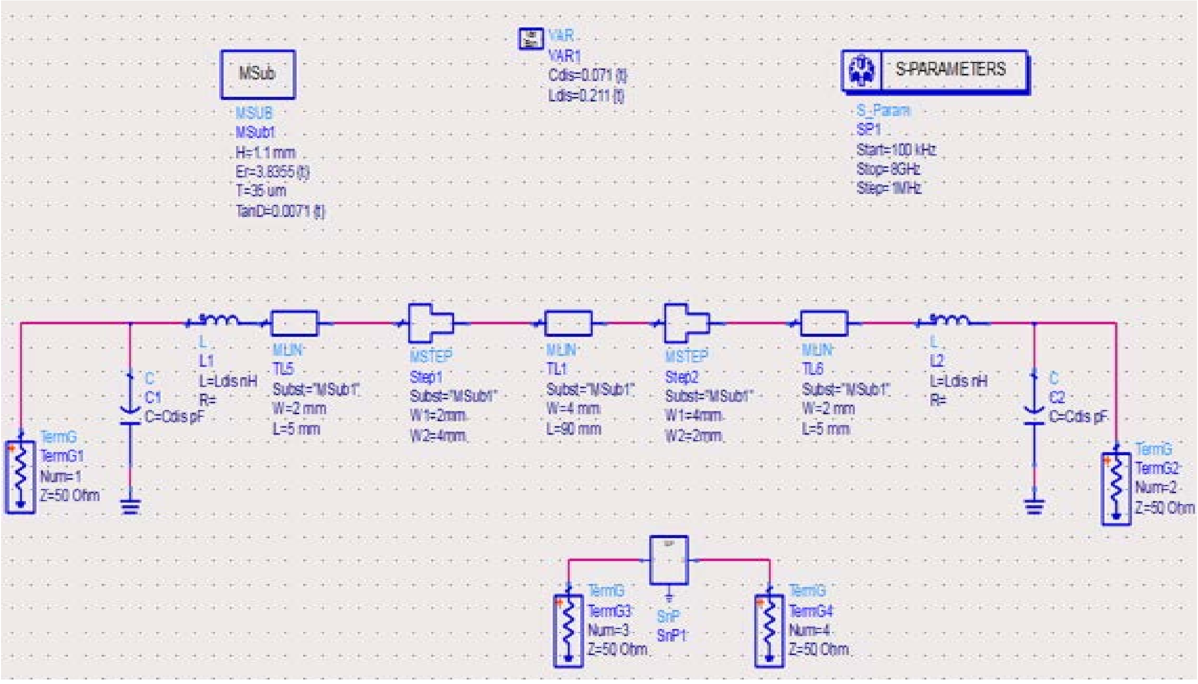


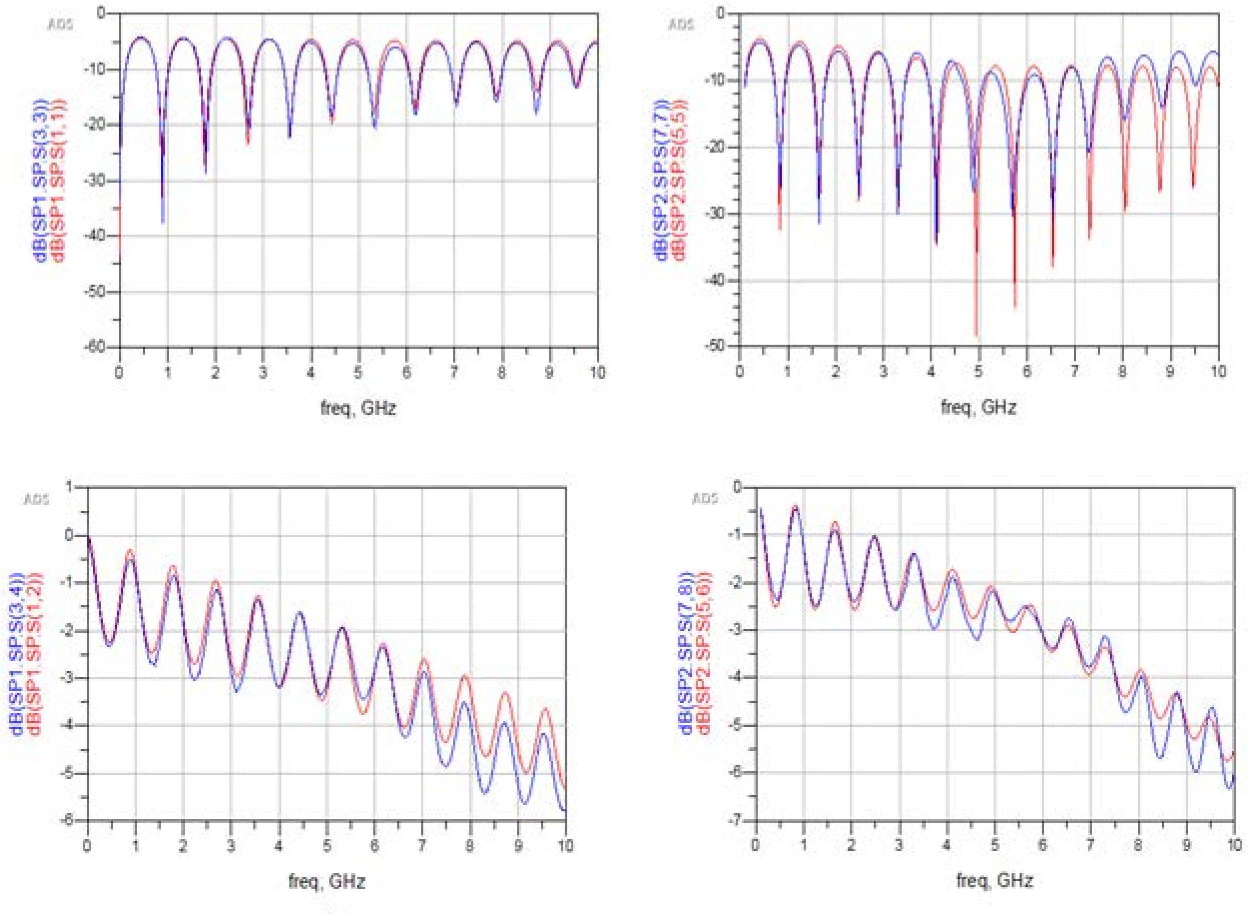
Figure 3.b) Modeling on ADS

The measurements of the reflection and transmission coefficients or parameters S were carried out on a network analyzer (VNA) after calibration. A first calibration step is necessary for various but well known terminations (such as an open load, a short circuit or a 50 ohm load for example). The practical values of the parameters S are thus measured for each of the lines connected to the VNA (Figure 3a). The lines produced are then modeled on 1D ADS (Advanced Design System) simulation software. The equivalent model is designed according to the shape and dimensions of the lines produced. At the two accesses of each line, we have two 50 Ohm ports which are modeled by two 50 Ohm generators (Figure 3b) each connected to a capacitor C and an inductor L. Each port is connected to a 50 Ohm line. Then, a different 50 Ohm impedance line connects the two 50 Ohm lines connected to the two ports. The values of the electromagnetic parameters (ε_r and tanδ) and the values (C and L) of the components used in the port models are adjusted so as to make the theoretical (on ADS) and practical (on VNA) response curves coincide. The values of the loss tangent and of the dielectric constant of the material used are thus extracted.

4. Simulation and measurement Results

4.1. Classic Glass

A classic glass is an inexpensive glass that can be easily found. It has been characterized, the measurement results are below (Figure 4). The curves in blue represent the practical results carried out on the VNA, those in red are those of the modeling with ADS.



a)

b)

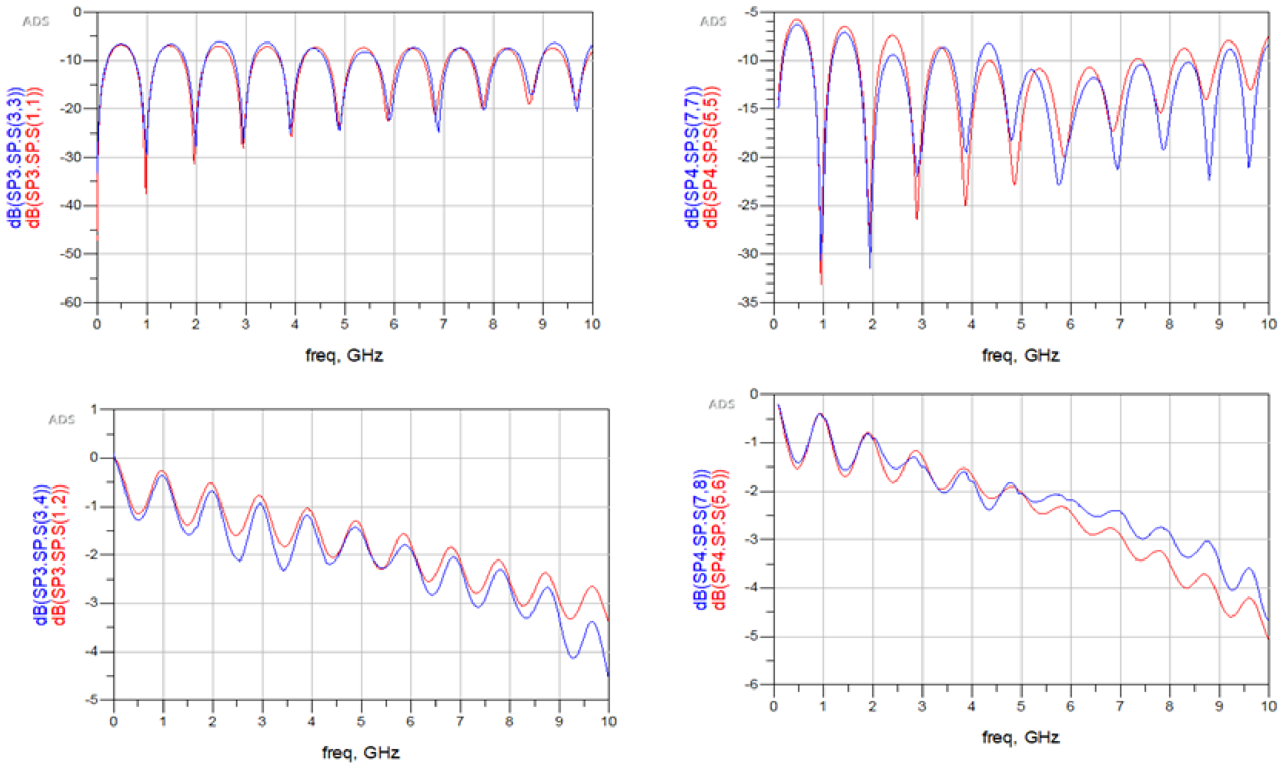
Figure 4. Frequency responses of conventional glass. a) the impedance line Z <50 Ohm (8mm); b) the line of impedance Z> 50 Ohm (0.4mm)

The model is good up to 8 GHz because it allows a good correlation with the measurement. The extraction of electromagnetic parameters such as the relative permittivity and the loss tangent are sufficiently precise to then allow a quality antenna design in this frequency band. We obtained a dielectric permittivity of 6.5 and a loss tangent of 2.06 10^{-2}. These values remain high for the design of the antenna, in particular tanδ.

A high value of the dielectric permittivity strongly contributes to the miniaturization but this affects the radiation.

4.2. Microscope Glass

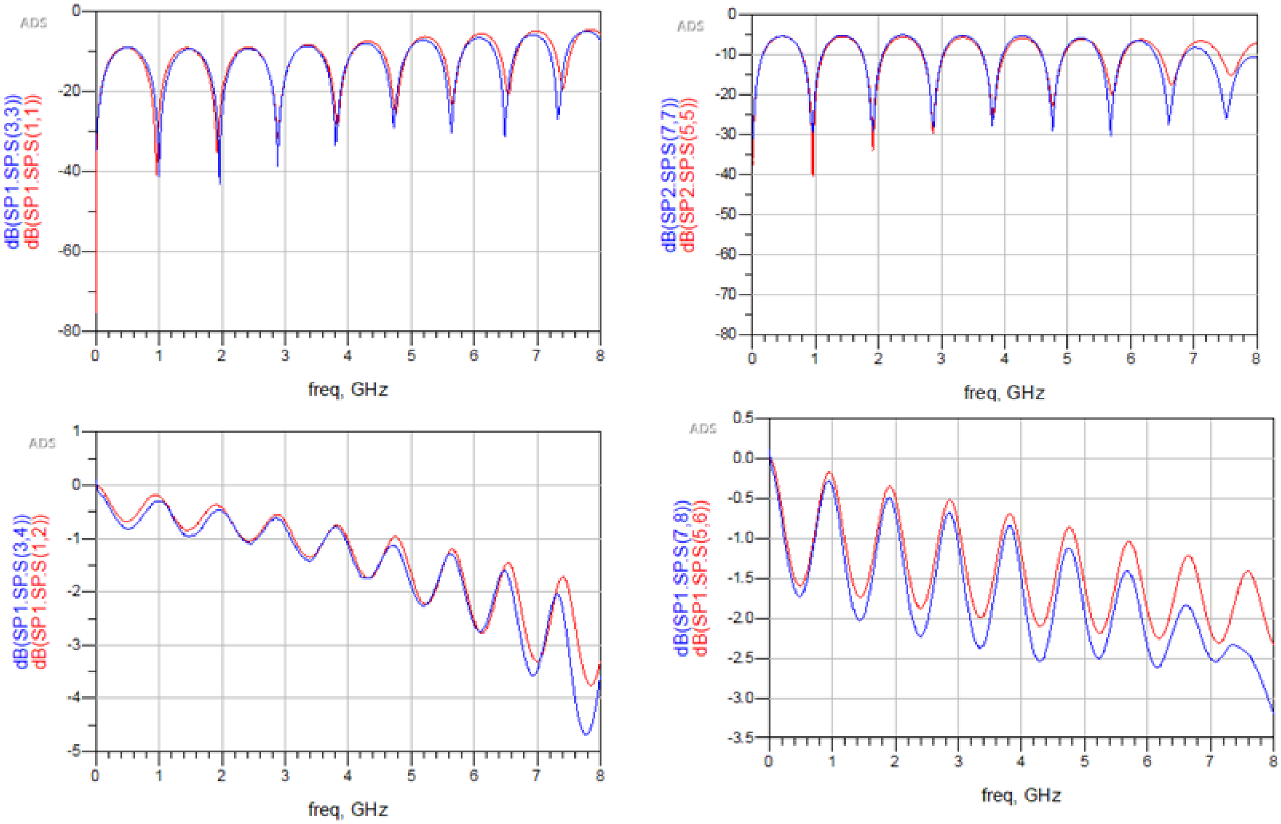
As with conventional glass, we made the same measurements with a glass used in microscopy. We obtained a relative dielectric constant $\varepsilon_r = 6.15$, which is relatively smaller than that of conventional glass and a loss tangent tanδ = 2.1 10^{-2}. The resonance curves of the S parameters are shown in Figure 5.



a) b)

Figure 5. Frequency responses of the microscope glass a) the impedance line Z <50 Ohm (8mm) b) the impedance line Z> 50 Ohm (0.4mm)

The electromagnetic parameters of this type of glass are close to those of conventional glass in terms of loss, as are the resonance curves of the S parameters. The microscope glass can therefore be used in the same devices as conventional glass.



a) b)

Figure 6. Frequency responses of borofloat 33 glass. a) the impedance line Z<50 Ohm (8mm), b) the impedance line Z> 50 Ohm (0.4mm)

4.3. Borofloat 33 Glass

By the same method as above, Figure 6 shows us the reflection and transmission coefficient resonance curves of borofloat 33. These resonance curves of the S parameters offer good performance in the 0.1 GHz - 8 GHz band. We obtained $\varepsilon r = 4.5$ as the value of the dielectric permittivity and $\tan\delta = 0.012$ as the value of the loss tangent. Boroflaot 33 has a dielectric permittivity and a loss tangent lower than those of the first two glasses (Table 1).

Table 1. Comparison between the values of the electronic parameters of some glasses

Glasses	Frequency band (GHz)	ε_r	$tan\gamma$
Classic glass	0 à 8	6.5	$2.06.10^{-2}$
Microscope glass	0 à 8	6.15	$2.1\ 10^{-2}$
Borofloat 33 glass	0 à 8	3.9	$1.2\ 10^{-2}$

5. Conclusion

This article allowed us to find the dielectric parameters of some glasses for the realization of antennas with low visual impact and low production cost. On the one hand, it presents the electromagnetic characterization method that was used to characterize the glass substrates used in the design of transparent antennas. This method has several advantages. It is broadband and thus makes it possible to extract parameters such as the relative dielectric permittivity and the loss tangent of the dielectric substrate over a frequency band of several GHz. This extraction can be done on a more or less important frequency band according to the precision of the model used. In addition, the extraction of the parameters of the substrate is done in the configuration / technology which will be retained subsequently for the design of the antennas. In this sense, it is almost more of a characterization of the technology used to design the antennas than a characterization of the substrate alone as is the case with some characterization techniques. On the other hand, this article presents the relative values of permittivity and loss tangent that can be expected from this type of material, whether on very standard glasses or on glasses intended for RF applications. Among these glasses, borofloat 33 is the best alternative with its low dielectric permittivity and its reasonable loss tangent for the realization of an antenna with low visual impact and at low cost.

Acknowledgments

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