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Double EBG Waveguides for a Contactless Estimation of the Surface Impedance

S.Rodini [(1)], S.Genovesi[(1)], G.Manara[(1)], F.Costa[(1)],
(1) Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Pisa, Italia

Abstract

Surface impedance value is an important parameter for the radio frequency characterization of materials. Many techniques have been proposed in order to estimate the surface impedance value of materials but most of them require an electrical contact with the sample under test. Here, a contactless method is proposed in order to have an accurate estimation of the surface impedance value of a thin sheet of material.

1 Introduction

Surface impedance estimation is an important aspect for the materials characterization. In the realization of sensors the knowledge of the surface impedance of the sensitive materials is an essential element. Usually, the surface impedance of a thin sheet of material is determined by the four-point method [1]. In this case, a direct contact with the material is required and this may damage it. In general, contactless characterization of the materials [2] is extremely useful in the context of Non Destructive Testing (NDT) which allow the screening of components or systems without damaging or permanently altering the sample [2, 3]. In the realization of sensors, being able to make a contactless measurement is a very important aspect. For example, in case one has to work with stretchable materials, a non-contact measurement is necessary to be able to make the measurement while the material is being stretched. Also in the case of termo-resistive materials it is useful to be able to estimate the variation of the surface resistance of the material as the temperature varies without having contact with the sample under test. Microwave methods are often used for the estimation of the surface impedance [4–7]. Among microwave methods, non-resonant techniques offer the possibility of estimating the surface impedance of a material in a simple way. Some techniques are defined in the literature as non-contact approach even if they do not really offer a real contactless measurement [4, 8]. A method for the estimation of the sheet impedance of an ink deposited on a dielectric substrate has been proposed [9]. The approach relies on a waveguide measurement and an inversion procedure based on a simple transmission line formulation is adopted to derive the surface impedance from the measured scattering parameters. The approach clearly is not correctly working if the two waveguides are disconnected since the air gap let the electromagnetic energy to flow out from the guided structure. A good starting point for characterizing the open ended waveguides is provided by [10] where a characterization of the junction due to the presence of the substrate is provided. However, also in [10], the material is in contact with the flange of the waveguide and this does not make it possible to stretch the material during the characterization of the sample. A completely unconnected setup has been proposed in [11] in which the measurement of the surface impedance is made without any contact between the sample under test and the two rectangular waveguides. To take into account the electromagnetic field leakage that takes place in the gap between the two waveguides, an electromagnetic band-gap (EBG) surface is applied on the flange of the first waveguide [12]. The presence of the EBG surface prevents the field radiation through the air-gap. This method offers a good estimate of the real part of the surface impedance while there is a considerable error on the imaginary part. In this work we try to improve the previous method by introducing a second EBG surface on the second waveguide in order to make the system symmetrical and to reduce the error on the imaginary part.

2 Proposed Experimental setup

In this work an improvement for the contactless characterization of thin fabric is proposed. Starting from [12], it is proposed to modify the system by introducing another EBG surface on the second waveguide. The new experimental setup is shown in Fig. 1. The setup consists of two rectangular waveguide, appropriately spaced in order to guarantee a contactless measurement of the surface impedance and two EBG surfaces.

The design of the EBG surface consists in optimizing the geometrical and electrical parameters for achieving the bandgap of the EBG surface in correspondence of the waveguide frequency band. More details of the EBG design can be found in [12]. The setup employing two EBG surfaces has the advantage of being symmetrical and consequently the mathematical model is simplified with respect to that in [12]. The equivalent circuit of the proposed setup is shown in Fig. 2. In this configuration, it is possible to assume that the two series impedances (Z) are equal and at the same time also the two parallel admittances (Y) are the same. The method that allows to obtain the surface impedance of the thin sheet consists of two steps. In the first step an empty measurement is carried out to obtain the cali-

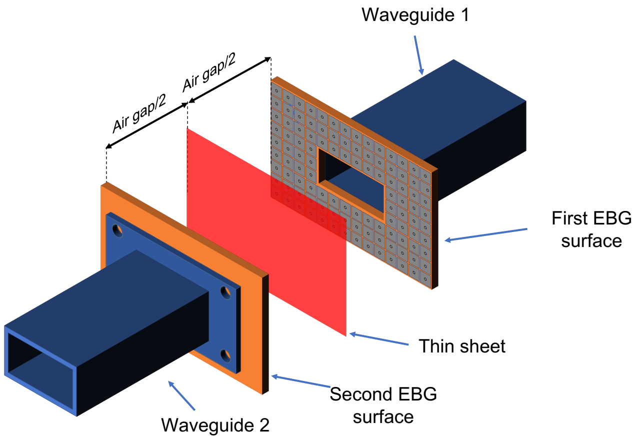


Figure 1. Proposed experimental setup using two rectangular waveguides, two EBG surfaces and a thin sheet of material placed in the middle.

bration parameters (Z, Y). In order to obtain the calibration parameters, we start from the *ABCD* matrix corresponding to the circuit in Fig. 2-a.

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ Y & 1 \end{pmatrix} \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ Y & 1 \end{pmatrix} = \begin{pmatrix} 1+2ZY & 2Z \\ 2Y(ZY+1) & 1+2ZY \end{pmatrix} \quad (1)$$

By exploiting the equivalence between the scattering parameters and *ABCD* parameters, Z and Y are obtained. Once computed the calibration parameters, the sheet is introduced in the middle of the two unconnected waveguides.

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ Y & 1 \end{pmatrix} \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ Y_s & 1 \end{pmatrix} \begin{pmatrix} 1 & Z \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ Y & 1 \end{pmatrix} \quad (2)$$

By exploiting the new matrix *ABCD* of the circuit in Fig. 2-b and by using an inversion procedure, the analytical expression of Z_s is obtained as follow:

$$Z_s = -\frac{Z(1+\alpha+ZY)+Z_0(ZY+ZY\alpha+1)+\frac{Z^2}{Z_0}}{4ZY+\frac{2Z}{Z_0}+2Z_0Y\alpha-\frac{2}{S_{21}^{\prime}}+2} \quad (3)$$

where $\alpha = ZY + 1$ and Z_0 is the characteristic impedance of the TE_{10} mode in the waveguide. The inversion procedure is based on the analytical solution of the π junction in Fig. 2-b and is similar to the one proposed in [11].

The estimated value Z_s depends on the calibration parameters (Z,Y), which are considered to be constant before and after the insertion of the sheet, and on the scattering parameter S_{21}.

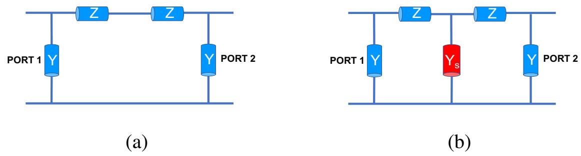


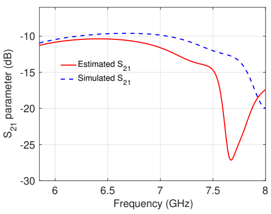
Figure 2. Equivalent circuit model. Calibration circuit (a) and circuit with thin sheet (b).

3 Numerical results

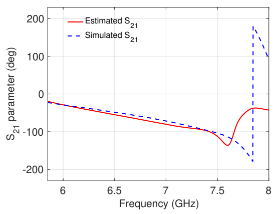
Numerical electromagnetic simulations were carried out using the CST Studio Suite software in order to evaluate the actual advantage in using the double EBG surface. In accordance with the above described procedure, an empty simulation was initially carried out to obtain the calibration parameters of the circuit reported in Fig. 1-a. This simulation was performed for an air-gap value equal to 5mm. In the second simulation, a thin sheet with known surface impedance value was introduced. From the scattering parameters obtained from the second simulation, the surface impedance value is obtained by using (3).

The method proposed in [12] offers a good estimate of the real part of the surface impedance, with an error of less than 3% over a wide range of resistance values. A significant error, on the other hand, is found in the imaginary part. In particular, the error on the imaginary part increases as the absolute value of the real part increases. In order to demonstrate the improvement in the estimation of the surface impedance due to the introduction of the second EBG, it is possible to compare the scattering parameters estimated by the model and those obtained from the full wave simulations with single EBG and with double EBG and the obtained surface impedance estimation according to the analytical inversion of the calibration circuit. Observing the scattering parameters reported in Fig. 3 for the case of a sheet characterized by a surface impedance of Z_s=100 Ω/sq, it is apparent that in case of double EBG there are peaks due to interference between the two EBG surfaces facing each other. It is therefore expected that some resonant peaks are observable also in the reconstructed surface impedance. However, it can also be observed that there is a narrow band between 6 GHz and 7 GHz in which the overlap of the scattering parameters improves thanks to the double EBG. The phase of the scattering parameters in this band is completely overlapped, therefore in this narrow range it is expected that the model with the double EBG is able to estimate the imaginary part of the Z_s more accurately.

In Fig. 4 it is possible to observe the difference in the surface impedance estimation between the two proposed methods for different values of the surface impedance. In presence of the two EBGs, the error on the real part always is slightly higher than the single EBG case but remains below 8%. On the contrary, concerning the imaginary part, a significant improvement is observed thanks to the introduction of the second EBG surface. It can be observed that in the case where the EBG surface is used on both flanges of the waveguide the imaginary part remains almost constant at zero.



(a)



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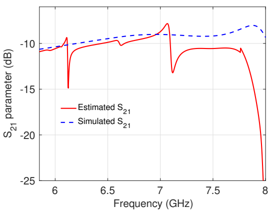

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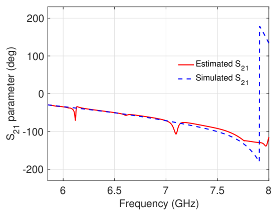

(d)

Figure 3. Comparison between simulated and estimated S_{21} parameters: (a) amplitude in a single EBG configuration (b) phase in a single EBG configuration using Z_s=100 Ω/sq (c) amplitude in a double EBG configuration (d) phase in a double EBG configuration and Z_s=100 Ω/sq.

4 Conclusion

An improved method for the estimation of the surface impedance of a thin sheets has been proposed. The proposed approach allows determining the impedance of the material in a completely contactless way. The procedure consists of an initial calibration step to model the gap between the two waveguides through a π circuit. Subsequently, the calibration parameters are assumed to be constant and this allows to estimate the surface impedance of the sample. The use of the EBG surface on both waveguides provides a considerable improvement in the estimation of the imaginary part of the surface impedance without significantly altering the accuracy in the estimation of the real part. Another advantage of this new configuration consists in having a more simplified model given the symmetry of the new circuit due to the presence of the EBG surface on both waveguides.

5 Acknowledgements

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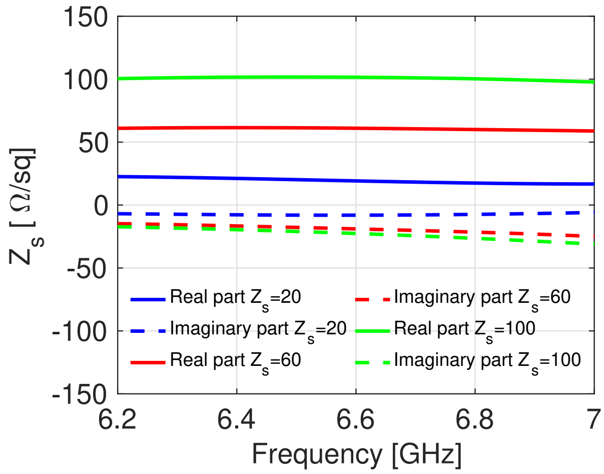
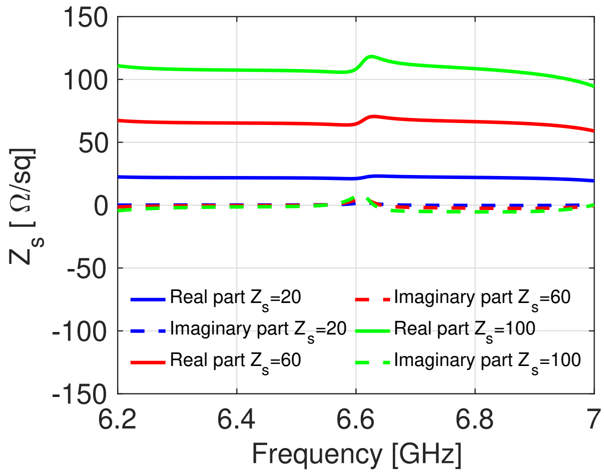


(a)



(b)

Figure 4. Comparison between the estimated surface impedance by using a single EBG configuration (a) and (b) surface impedance estimation by using double EBG configuration for different value of Z_s.

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