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Determination of Reflection and Transmission Coefficient of an Overlay Microstrip Antenna on Duroid Material Using FEM

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Abstract
Knowledge of materials behaviour placed in an electromagnetic field was found to be of immense significance in military hardware, electronics, communication and industrial applications. An overlay microstrip antenna was employed in this study to determine scattering parameters of an overlay microstrip antenna using finite element method (FEM). The substrate thickness used on the microstrip was 10 mm thick and 8 x 12 cm (width and length). All simulation were carried out at X band frequency range (8-12 GHz) using FEM. The result amongst others showed that the transmission coefficient depends on the permittivity of the sample. It also showed that lowest permittivity of material produced the greatest transmission coefficient. It is then concluded that the results obtained for the transmission and reflection coefficients can be used for the prediction of complex permittivity of materials used as overlay on a microstrip antenna.

Keywords: *Microstrip Antenna, Duroid, FEM, Transmission and Reflection coefficients*

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I. Introduction

The dielectric materials plays important role in antenna manufacturing process. In antenna especially in integrated antenna, the dielectric constant varies between 2.2 to 12.0 (Waghmare *et al.*, 2016). The thick substrate with low dielectric constant gives good performance and provides better efficiency, larger bandwidth, but large antenna element. While thin substrate with higher dielectric constant provides smaller element size. However, because of their high loss they are less efficient and have relative smaller bandwidth (Balanis, 2005; Waghmare *et al.*, 2016).

The term surface wave is associated to the flow of energy that is confined to a region next to a surface. These waves are present in microstrip antennas due to the form and to the material used in their compositions. The waves excited in the process of radiation of these antennas are radiated more efficiently into the structure than the air side. This is due to the substrate dielectric constant being greater than 1. Thus, the substrate works as a storage device of propagating modes on the ground plane of the antenna. If the interface between two media is perfectly plane, these waves will not contribute to the radiation process. However, the antenna edges, in this case, diffract or scatter the waves that reach there, giving origin.

The aim of this research is to study the scattering parameters of different substrates thicknesses placed on a microstrip patch antenna. The thickness of the substrates are 10 mm.

Table 1, provides the dielectric constant of duroid material used in this study. The interaction of the electromagnetic waves with material involves phenomena such as induced electronic, atomic, and space charge polarizations. The extent of this interaction depends on the extent of the wave reflection or transmission, respectively (Krivanek, 2008).

Table 1: Dielectric constant of Overlay Used

Sample	Dielectric const.	Loss factors	$\varepsilon_r = \varepsilon' - j\varepsilon''$
Duroid	2.5	0.0030	$2.5 - j \times 0.0030$
Duroid	3.0	0.0025	$3.0 - j \times 0.0025$
Duroid	3.5	0.0020	$3.5 - j \times 0.0020$
Duroid	4.0	0.0010	$4.0 - j \times 0.0010$
Duroid	4.5	0.0005	$4.5 - j \times 0.0005$

Microwave material was the first low loss and low dielectric constant laminate to offer superior electrical and mechanical properties essential in designing complex microwave structures which are mechanically reliable and electrically stable (Yakubu *et al.*, 2020). Some of the features and benefits possessed by duroid materials are; low loss, high frequency performance, good mechanical and electrical properties, low thermal coefficient and dielectric constant, good dimensional stability and ideal for space applications.
Some typical applications of the study material are phased array antennas, ground based and airborne radar systems, global positioning system antennas, power backplanes and high reliability complex multilayer circuits etc.

II. Theory of Scattering Parameter (FEM)

Scattering parameters S_{11} and S_{21} can be calculated from the reflection and transmission coefficients of an overlay Microstrip using FEM analysis as also used by (Kingsley *et al.*, 2019; & Yakubu *et al.*, 2020).

$$S_{11} = S_{22} = \frac{\gamma(1 - Z^2)}{1 - \gamma^2 Z^2} \quad (1)$$

$$S_{21} = S_{12} = \frac{Z(1 - \gamma^2)}{1 - \gamma^2 Z^2} \quad (2)$$

Where;

$$\gamma = \frac{Z_s - Z_0}{Z_s + Z_0} \quad (3)$$

$$Z = -je^{\gamma l} \quad (4)$$

Where
Z_s, Z_0, l *and* γ, are characteristic impedance of the measurement system, input impedance, sample length and propagation constant, respectively.
For the simulation, the solution time to calculate the S_{11} and S_{21} using COMSOL is strongly influenced by mesh properties or number of elements such as geometry conformity, mesh density and element quality.
Adequate estimate of the problem area is required for the geometry conformity of such area defined by the mesh elements. Minimization of the discretization error and achieving accurate solutions can be assured by having the mesh with large magnitude and size that are sufficiently high and small respectively (Yakubu *et al.*, 2020).

III. Methodology

In the FEM, parameters were assigned in the 3D work plane before going into the RF module, where electromagnetic wave was selected for harmonic waves. The dimension of the sample, axis grids, parameter constants, cut-off frequency, and frequency range were all assigned in the module. After all input have been made, the microstrip with an overlay substrate of 10 mm thickness is meshed with high mesh density. Shown in Figure 1 is the meshed microstrip antenna.

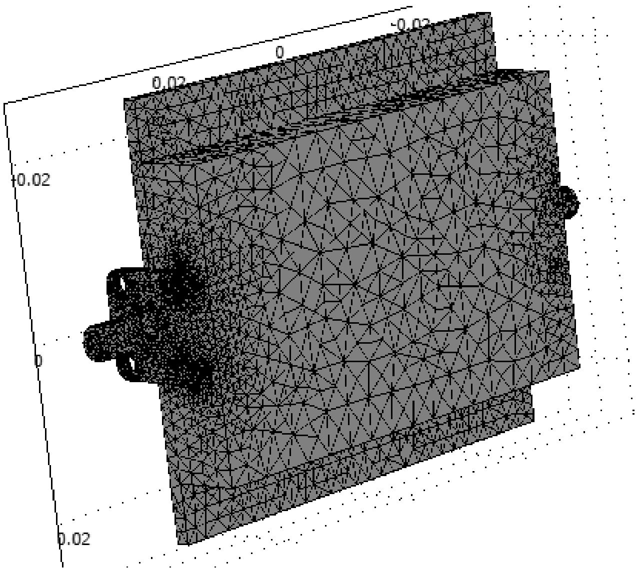

Figure 1: High Mesh Density of an Overlay Microstrip Antenna

The next step is to calculate the values of scattering parameters (S_{11} and S_{21}) using the COMSOL software. The key equation in the simulator is the wave equation shown in (5) (Yakubu *et al.*, 2014; & Yakubu *et al.*, 2020);

$$\nabla \times (\mu_r^{-1} \nabla \times E_x) - \left(\varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0}\right) k_0^2 E_x = 0 \qquad (5)$$

Where;

μ_r is relative permeability, k_0 is free pace wave number, j is imaginary unit, σ is conductivity, w is angular frequency, ε_r is relative permittivity and εo is permittivity of air.

However, the fundamental electrical properties through which interaction are described is the complex relative permittivity of the materials, ε_r. It is mathematically expressed as in the equation given by (Venkatesh & Raghavan, 2005; Krivanek, 2008);

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \qquad (6)$$

The scattering parameters at 201 steps between 8 to 12 GHz is then calculated using parametric solver under the linear Direct (SPOOLES) linear system solver.

IV. Result

Observation on Figure 2 shows that S_{21} decreases with increasing frequency, at 8 GHz, S_{11} and S_{21} were 0.067358 and 0.896926, respectively. There was significant decrease in S_{21} as the frequency increases, while S_{11} has a ripple like structure which might be attributed to impedance mismatch (Pozar, 2013). The result obtained at this permittivity is in conformity with theory that states that low permittivity materials produces high transmission (Pozar, 2009).

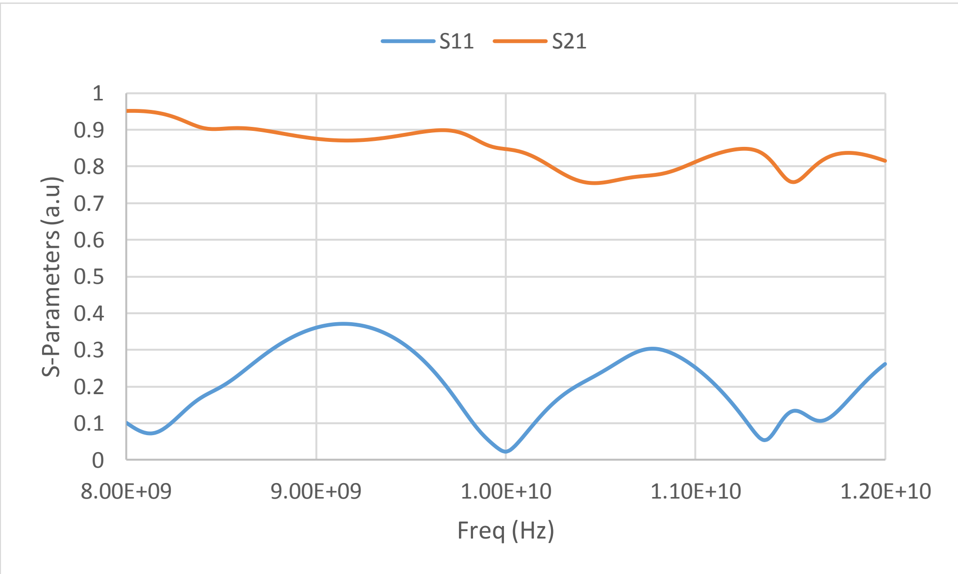

Figure 2: S-Parameter of Duroid at 2.5 Permittivity

In Figure 3, the values of S_{21} is greater than S_{11} throughout the whole frequency range. The lowest value for S_{21} is 0.442055 while the highest value for S_{21} is 0.850033. It is reported in Sohaib and Tripathy (2014), that performance of antenna improves when the value of dielectric constant reduces. As it is also confirmed by (Waghmare *et al.*, 2016)

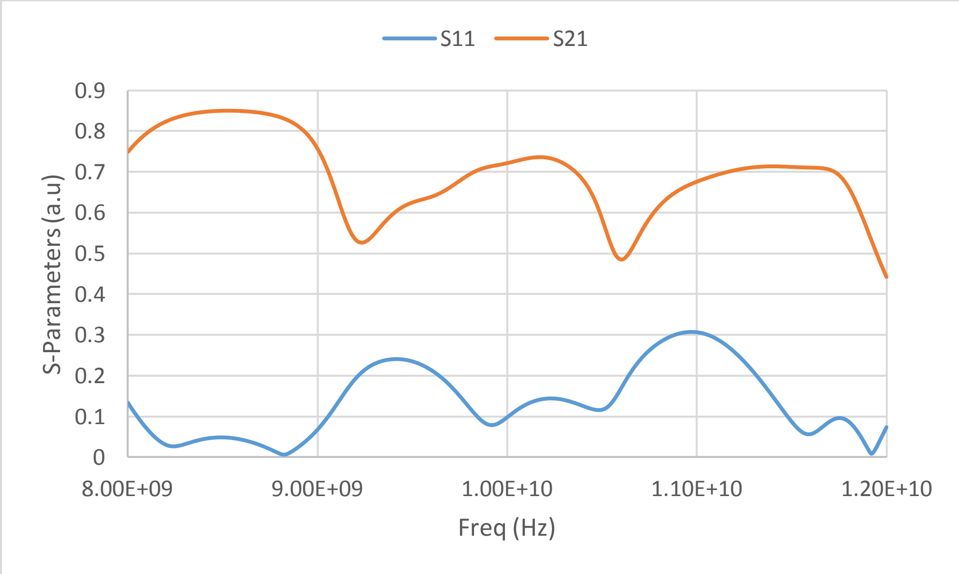

Figure 3: S-Parameter of Duroid at 3.0 Permittivity

In Figure 4, observations shows that, as the permittivity of duroid increases the S_{11} increases supporting the effective medium theory (Yakubu *et al.*, 2014).

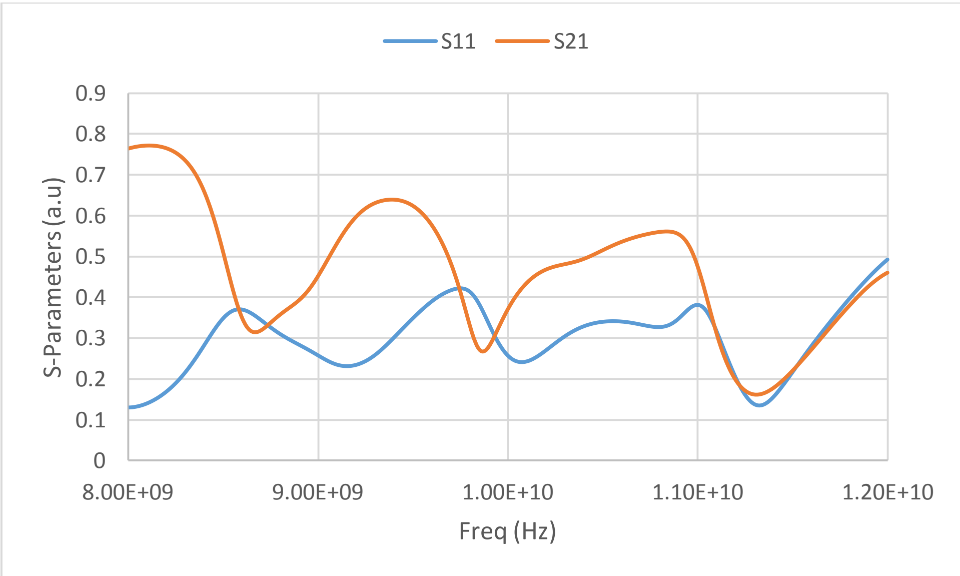

Figure 4: S-parameter of Duroid at 3.5 Permittivity

The pattern exhibited by both S_{21} and S_{11} in Figure 5 might be related to the number of mesh size used for the simulation. It is reported that the mesh size affects the S-parameter of materials under investigation due to the processing capacity of computer (Irena *et al.*, 2012). In the overall, the values obtained for the scattering parameter are in agreement with the result obtained for the 3.5 permittivity. And this result is conformity with that obtained Nickel Zinc Ferrite as reported in

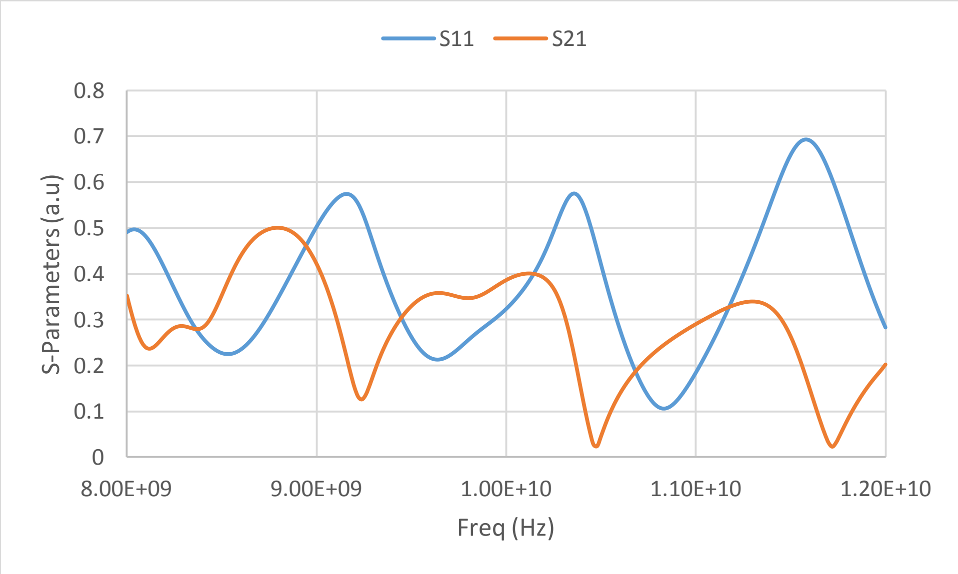

Figure 5: S-Parameter of Duroid at 4.0 Permittivity

In Figure 6, S_{11} is maximum at 11 GHz (0.729471), while the maximum value of S_{21} was observed at 8.58 GHz (0.173066). The behavior of both S_{11} and S_{21} are in sequence with earlier results where increase in permittivity increases S_{11} (Pozar, 2009; Yakubu *et al.*, 2014).

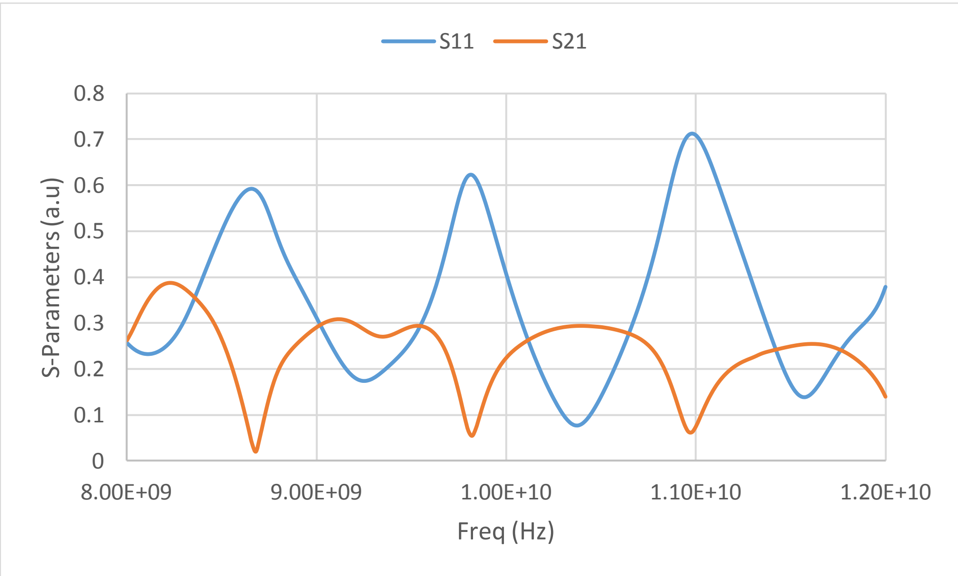

Figure 6: S-Parameter of Duroid at 4.5 Permittivity

V. Conclusion

In this work, simulation of scattering parameters for duroid material of different dielectric constant with the same thickness was done using FEM. It is found that the higher the permittivity of material used the lower the S_{21} and vice versa. Based on the findings obtained in this work, materials complex permittivity suitable for radiation absorption can be predicted. In conclusion, it is suggested that FEM is suitable in microwave characterization for simulations that involve the determination of scattering parameters of material.

LIST OF ABBREVIATIONS

FEM – Finite Element Method
GHz – Gigahertz
ε_r – Relative permittivity
ε' – Real part of permittivity
ε'' – Imaginary part of permittivity
S_{11} – Reflection coefficient
S_{21} –Transmission coefficient

Z_s – Characteristic impedance
Z_o – Input impedance
l – Sample length
γ – Propagation constant
3D – Three Dimension
RF – Radio Frequency
mm – Millimetre
j – Imaginary unit
σ – Conductivity
k_o – Free space wave number
μ_r – Relative Permeability
S-Parameters – Scattering Parameters
et al., **-** And others

DECLARATIONS

Availability of data and materials

All data used in the work are generated by authors through measurement and simulation. All data used in the work are available.

Competing interests

The authors declare that they have no competing interests

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Author's contributions

SS determined and interpreted the results obtained for scattering parameters of an overlay microstrip antenna on a duroid materials of different dielectric substrates. AY provided designed of an overlay microstrip antenna used for this work. SS and AY are the major contributors in writing the manuscript. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

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