Amirkabir University of Technology
(Tehran Polytechnic)

Impedance Surface Waveguide:Theory and Simulation

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Introduction

Impedance Surface Waveguides:

- Structures designed to confine electromagnetic waves along their surfaces.
- Characterized by surface impedance Z_s that controls wave propagation.

Surface Waves

Definition:

- Surface waves are electromagnetic waves that are confined to the interface between two media[1].
- They decay exponentially perpendicular to the surface, ensuring energy confinement near the interface.

Key Characteristics:

- Exist in structures where the surface impedance Z_s supports bound wave modes.
- Propagation is tangential to the surface with wavevectors satisfying $k^2 = k_x^2 + k_z^2$.
- Common in transverse magnetic (TM) modes.

Surface Waves

Key Equations[2]:

$$\psi_1(x,z) = Ae^{-\nu x}e^{i\beta z}, \tag{1}$$

$$\beta^2 - \nu^2 = k^2, \tag{2}$$

$$E_z(x,z) = -\nu^2 e^{-\nu x}Ae^{i\beta z}, \tag{3}$$

$$H_y(x,z) = -i\omega\epsilon\nu Ae^{-\nu x}e^{i\beta z}, \tag{4}$$

$$\frac{E_z}{H_y} = Z_s, \tag{5}$$

$$\nu = i\omega\epsilon Z_s. \tag{6}$$

Surface Impedance Analysis:

- If the surface impedance Z_s is purely imaginary and inductive ($Z_s = -iX_i$):
  - ν becomes a positive real number.
  - This ensures exponential decay along x

Structure Used

High Impedance Guide:

- The waveguide consists of a high-impedance surface surrounded by two low-impedance regions.
- These regions are planar with vacuum above the plane, ensuring wave confinement.

Key Properties:

- The high-impedance surface supports TM surface waves with controlled propagation characteristics.
- Surface impedance is engineered to achieve desired wave confinement and dispersion.

Structure

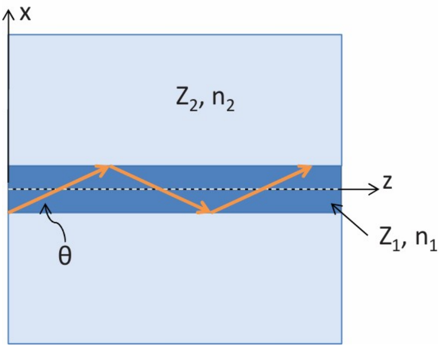

Figure: Structre's model

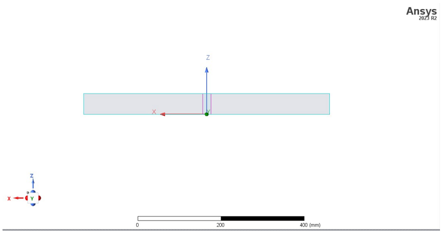

Figure: Structre's model in HFSS

Paper's Theory

Equations:

$$Z_i = Z_0\sqrt{1 - n_i^2}, \tag{7}$$

proof:

$$K_x = K_0 n_i, \tag{8}$$

$$K_z = K_0\sqrt{1 - n_i^2}. \tag{9}$$

since Propagation is tangential:

$$sin\theta = 1 \tag{10}$$

Surface Impedance for TM Modes:

$$Z_s = Z_0\frac{K_z}{K} \tag{11}$$

$$Z_s = Z_0\sqrt{1 - n_i^2}. \tag{12}$$

Dispersion Relation and Boundary Conditions

Wavevector Relationship:

$$K_x^2 + K_y^2 + K_z^2 = K_0^2. \tag{13}$$

Component Expressions:

$$K_y = K_0\sqrt{1 - n_i^2}, \tag{14}$$

$$K_x = \frac{\pi m + \phi}{d}. \tag{15}$$

Field Continuity Equations:

$$H_{t,i} + H_{t,r} = H_{t,t}, \tag{16}$$

$$E_{t,i} + E_{t,r} = E_{t,t}. \tag{17}$$

Surface Impedance Definition:

$$Z_s = \frac{E_t}{H_t}. \tag{18}$$

Wave Propagation in Surface Waveguides

Reflection Coefficient and Phase:

$$R = \frac{n_1 Z_2 \cos\theta_i - n_2 Z_1 \cos\theta_t}{n_1 Z_2 \cos\theta_i + n_2 Z_1 \cos\theta_t}, \tag{19}$$

$$\phi = \angle(R). \tag{20}$$

Dispersion Equation:

$$\left(\frac{wn_1}{c}\right)^2 - \left(\frac{\pi m + \phi}{d}\right)^2 - K_z^2 = 0. \tag{21}$$

Steps for Simulation:

- Define the geometry of the waveguide.
- Assign the surface impedance Z_s .

Dispersion

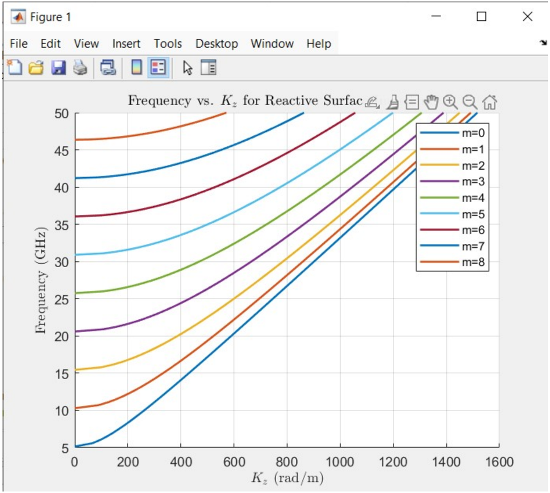

Figure: Dispersion Plot[3]

HFSS Results

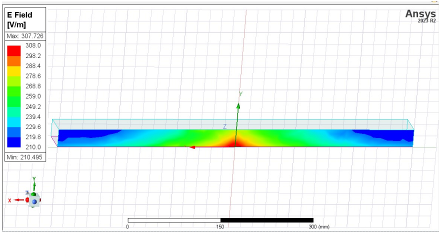

Figure: Magnitude Of Electric Field

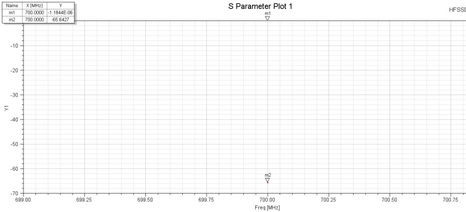

Figure: Scattering Parameters

Conclusion

Summary:

- Impedance surface waveguides provide a versatile platform for confining and controlling electromagnetic waves.
- Surface impedance Z_s is critical for waveguide design.
- Simulations facilitate detailed analysis and practical implementation.

Future Work:

- Explore advanced materials with tunable Z_s.
- Optimize designs for higher frequencies (e.g., THz range).

[1] D.Sievenpiper R.Quarfoth. *Impedance Surface Waveguide Theory and Simulation*. 2011 IEEE International Symposium on Antennas and Propagation (APSURSI), 2011.

[2] Kamal Sarabandi. “Foundation of Applied Electromagnetics”. In: (2022).

[3] Mohammad Mahdi Elyasi. “github link”. In: URL: https:github.com/MohammadMahdiElyasi/Impedance-Surface.

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Thank you for your attention!

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