Design and Analysis of Reconfigurable Frequency Selective Surfaces using FDTD

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Outlines

- Introduction
- Analysis of Skewed Grid Periodic Structures
- Motivation
- The New Reconfigurable FSS
- Numerical Results
- Conclusion
Introduction

What is an FSS?

Periodic structure that exhibit total reflection or transmission for certain frequency range.

In what application such structures are used?

Electromagnetic (EM) filters, radomes, absorbers, artificial electromagnetic band gap materials, and many other applications.

What is a reconfigurable FSS (RFSS)?

It is an FSS which has a frequency response that can be shifted or altered altogether while in operation.
Different Techniques for RFSS

How can the response of the FSS be alerted or shifted during operation?

This can be accomplished by mainly three techniques as follows:
1. By changing the electromagnetic properties of the FSS screen or substrate.
2. By altering the geometry of the structure.
3. By introducing elements into the FSS screen that vary the current flow between metallic patches.

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Periodic Boundary Conditions (PBC)

Various implementations of PBCs have been developed such that only one unit cell needs to be analyzed instead of the entire structure.

Floquet Theory: \( E(x, y = 0, z) = E(x, y = P_y, z) \times e^{ik_y P_y} \).
Field transformation methods are used to eliminate the need for time-advanced data.

Direct field methods, work directly with Maxwell’s equations and there is no need for any field transformation.
Electric field in frequency domain can be written as:

$$E(x = 0, y, z) = E(x = P_x, y, z) \times e^{jk_x P_x}.$$  

Frequency domain to time domain

$$E(x = 0, y, z, t) = E(x = P_x, y, z, t + \frac{P_x}{C} \sin \theta).$$

Fix $k_x$ in FDTD simulation instead of the angle $\theta$. $k_x = k_0 \sin \theta$

Frequency domain to time domain

$$E(x = 0, y, z, t) = E(x = P_x, y, z, t) \times e^{jk_x P_x}.$$
Skewed Grid Approach

Using the same constant horizontal wavenumber method one can easily simulate periodic structure with skewed grid.
Constant Horizontal Wavenumber for Skewed Grid

So to update $E_x$ at the boundary $y = 0$

For $i + (S_x / \Delta x) \leq n_x$

$$H_z^{n+1/2} (i, 0, k) = H_z^{n+1/2} (i + \frac{S_x}{\Delta x}, n_y, k) \times e^{jk_x S_x} \times e^{jk_y P_y}.$$ 

For $i + (S_x / \Delta x) > n_x$

$$H_z^{n+1/2} (i, 0, k) = H_z^{n+1/2} (i + \frac{S_x}{\Delta x} - n_x, n_y, k) \times e^{jk_y (S_x - P_y)} \times e^{jk_y P_y}.$$ 

To update $E_x$ at the boundary $y = P_y$

For $i - (S_x / \Delta x) \leq 0$

$$E_x^{n+1} (i, n_y + 1, k) = E_x^{n+1} (i - \frac{S_x}{\Delta x}, 1, k) \times e^{jk_x S_x} \times e^{-jk_y P_y}.$$ 

For $i - (S_x / \Delta x) > 0$

$$E_x^{n+1} (i, n_y + 1, k) = E_x^{n+1} (i - n_y \frac{S_x}{\Delta x} - P_y, 1, k) \times e^{-jk_x (S_x - P_y)} \times e^{-jk_y P_y}.$$ 

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Motivation

Skew angle of 90° and 63.43°

Reflection coefficient for dipole FSS normal incident TEz plane wave with skew angle of 90° and 63.43°.
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This RFSS has two control parameters which increase the degree of freedom of the reconfigurability.

The first control parameter is the diode which has two states, ON or OFF

\[ I_d = I_0 \left[ e^{\left(\frac{qV_d}{kT}\right)} - 1 \right], \]  

Diode Current Equation.

The second control parameter is the movements of different rows of the FSS
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Numerical Results

Normal incident \((k_x = k_y = 0 \text{ m}^{-1})\) with different skew angles

Oblique incident \((k_x = 20 \text{ m}^{-1}, k_y = 0 \text{ m}^{-1})\) with different skew angles
## Numerical Data

### Different simulation cases

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Diode State</th>
<th>Skew Angle</th>
<th>Incident $k_x$ (m⁻¹)</th>
<th>Position of Reflection Coefficient Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OFF</td>
<td>90° Normal</td>
<td>$k_x = 0$</td>
<td>13.36 GHz</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>90° Normal</td>
<td>$k_x = 0$</td>
<td>7.53 GHz</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
<td>75.06° Normal</td>
<td>$k_x = 0$</td>
<td>13.92 GHz</td>
</tr>
<tr>
<td>4</td>
<td>ON</td>
<td>75.06° Normal</td>
<td>$k_x = 0$</td>
<td>7.69 GHz</td>
</tr>
<tr>
<td>5</td>
<td>OFF</td>
<td>68.19° Normal</td>
<td>$k_x = 0$</td>
<td>14.37 GHz</td>
</tr>
<tr>
<td>6</td>
<td>ON</td>
<td>68.19° Normal</td>
<td>$k_x = 0$</td>
<td>7.83 GHz</td>
</tr>
<tr>
<td>7</td>
<td>OFF</td>
<td>90° Oblique</td>
<td>$k_x = 20$</td>
<td>13.27 GHz</td>
</tr>
<tr>
<td>8</td>
<td>ON</td>
<td>90° Oblique</td>
<td>$k_x = 20$</td>
<td>7.54 GHz</td>
</tr>
<tr>
<td>9</td>
<td>OFF</td>
<td>68.19° Oblique</td>
<td>$k_x = 20$</td>
<td>14.32 GHz</td>
</tr>
<tr>
<td>10</td>
<td>ON</td>
<td>68.19° Oblique</td>
<td>$k_x = 20$</td>
<td>7.84 GHz</td>
</tr>
</tbody>
</table>
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- A new RFSS design was introduced.
- The reconfigurability of the design is based on two techniques:
  - Controlling a diode state
  - Controlling a mechanical movement to change the skew angle of the FSS grid.
- The design was simulated using FDTD/PBC algorithm (full-wave EM simulator), while taking into account the actual model of the diode and different skew angles.
- The simulations were efficient in both memory usage and computational time.
Thank you for Listening

Any Questions??