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Design and Analysis of a Frequency Selective Radome (FSR) with Wideband Absorbing Properties

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Abstract: A novel frequency selective radome (FSR), which is "transparent" within the operating band of the antenna while absorbing out-of-band incoming waves in a very wide band, is presented in this article. In order to absorb undesired signals out of the band, square loops loaded with lumped resistors are used. The pass-band property is realized by employing meandering square slots with a smaller period to enhance the stability under large incident angles. The equivalent circuit method is introduced to explain the working principles of the FSR and verify the full-wave simulation results based on the FEM codes. The structure's performances under oblique incidences are also investigated.

Keyword: frequency selective surface, radome, equivalent circuit method.

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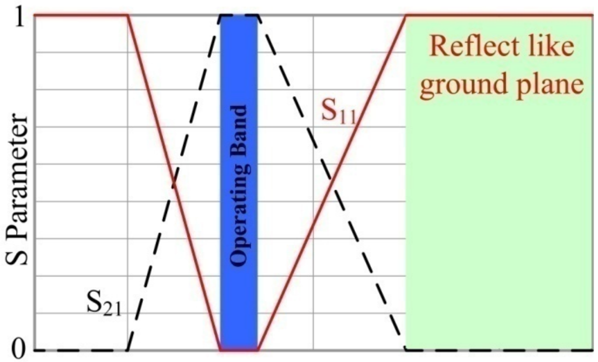
Contents

Introduction

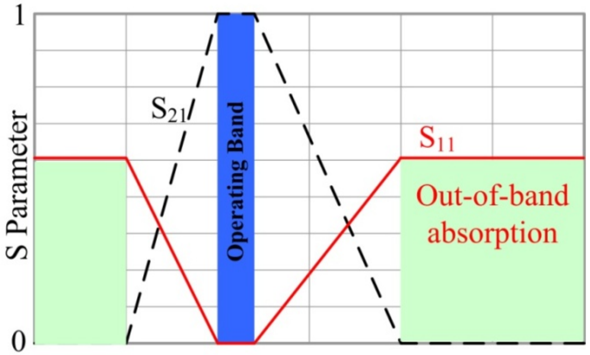
- The frequency selective radome (FSR):
  - "transparent" within the operating band
  - reflect out-of-band incoming waves.



Reduce **monostatic** RCS, but can still be detected by bi-static radars!

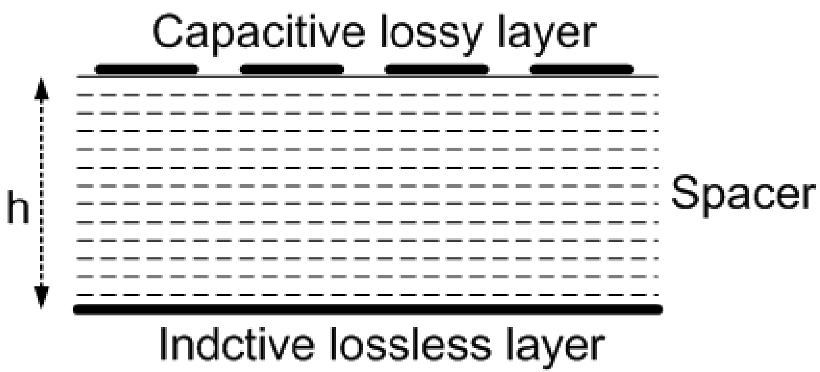
- The frequency selective radome (FSR) with **absorbing** properties:
  - "transparent" within the operating band
  - absorb out-of-band incoming waves.

Reduce **bistatic** RCS!



Introduction

- General configuration:



- Three main parts:
  - Bandpass lossless layer: FSS apertures
  - Lossy layer : FSSs loaded with resistors or resistive FSSs
  - Spacer: substrate to support the layers

Introduction

- Conditions:

1. Bandpass lossless layer should have a wide rejection band

   -out of the operating band

2. Lossy absorbing layer should be transparent

   -within the operating band

Introduction

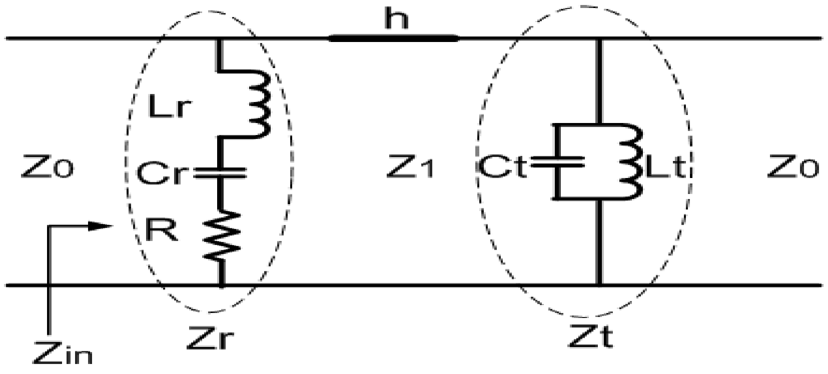
- Advantages:
  - Ensure transmission in band
  - Reduce bistatic RCS by absorbing out-of-band signals

- Difficulties:
  - Small insertion loss in band (ohmic loss)
  - Wide absorbing bandwidth out of band

Equivalent Circuit Method (ECM)

The full-wave simulation: cost a lot time and computer memory because the periods of the two layers are dissimilar. Thus, the equivalent circuit method is very advantageous in this case.

The equivalent circuit method: can be used to study parameters' effect and verify the correctness of the full-wave simulation results.



Equivalent circuit of FSR with absorbing properties

Equivalent Circuit Method (ECM)

Transmission and reflection coefficients:

$$S_{21} = \frac{2}{\left(A + B / Z_0^{TE,TM}\right) + \left(Z_0^{TE,TM} C + D\right)}$$

$$S_{11} = \frac{\left(A + B / Z_0^{TE,TM}\right) - \left(Z_0^{TE,TM} C + D\right)}{\left(A + B / Z_0^{TE,TM}\right) + \left(Z_0^{TE,TM} C + D\right)}$$

$$Z_0^{TE} = Z_0 / \cos(\theta) \qquad Z_0^{TM} = Z_0 \cos(\theta)$$

ABCD matrix as the product of three cascaded matrices:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/Z_r & 1 \end{bmatrix} \begin{bmatrix} \cosh(j\theta_1) & Z_1 \sinh(j\theta_1) \\ Y_1 \sinh(j\theta_1) & \cosh(j\theta_1) \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 1/Z_t & 1 \end{bmatrix}$$

$$Z_1^{TE} = \frac{\omega \mu_0 \mu_r}{\beta_1} \qquad Z_1^{TM} = \frac{\beta_1}{\omega \varepsilon_0 \varepsilon_r} \qquad Y_1 = 1/Z_1$$

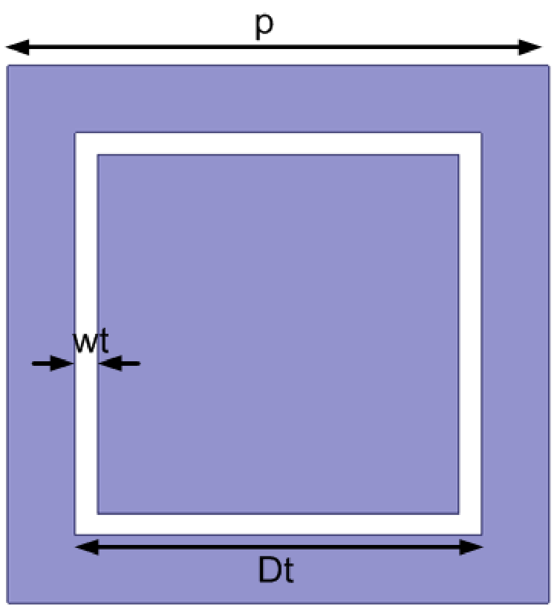
$$\theta_1 = \beta_1 h \qquad \beta_1 = \sqrt{k_1^2 - k_t^2}$$

$$k_t = k_0 \sin(\theta) \qquad k_1 = k_0 \sqrt{\varepsilon_r \mu_r}$$

Percentage of the energies absorbed by the proposed structure

$$\text{Absorption} = 1 - S_{21}^2 - S_{11}^2$$

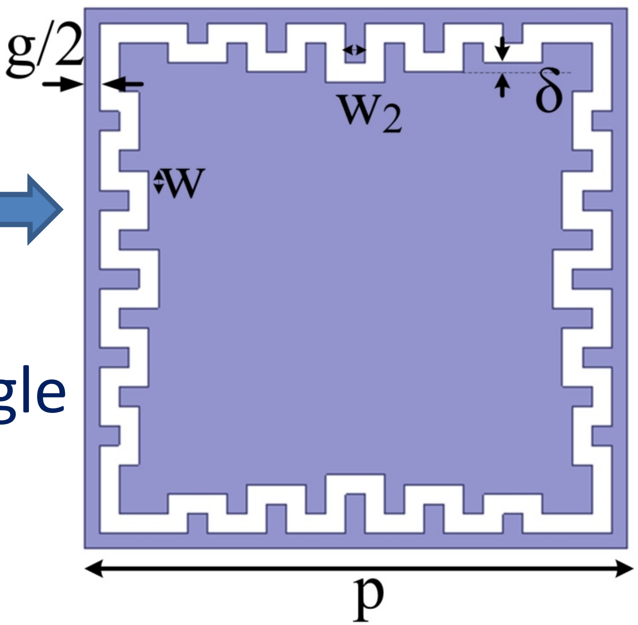
Design of Bandpass Lossless Layer



Single square aperture (SSA)

P_{SSA}=16.5 mm

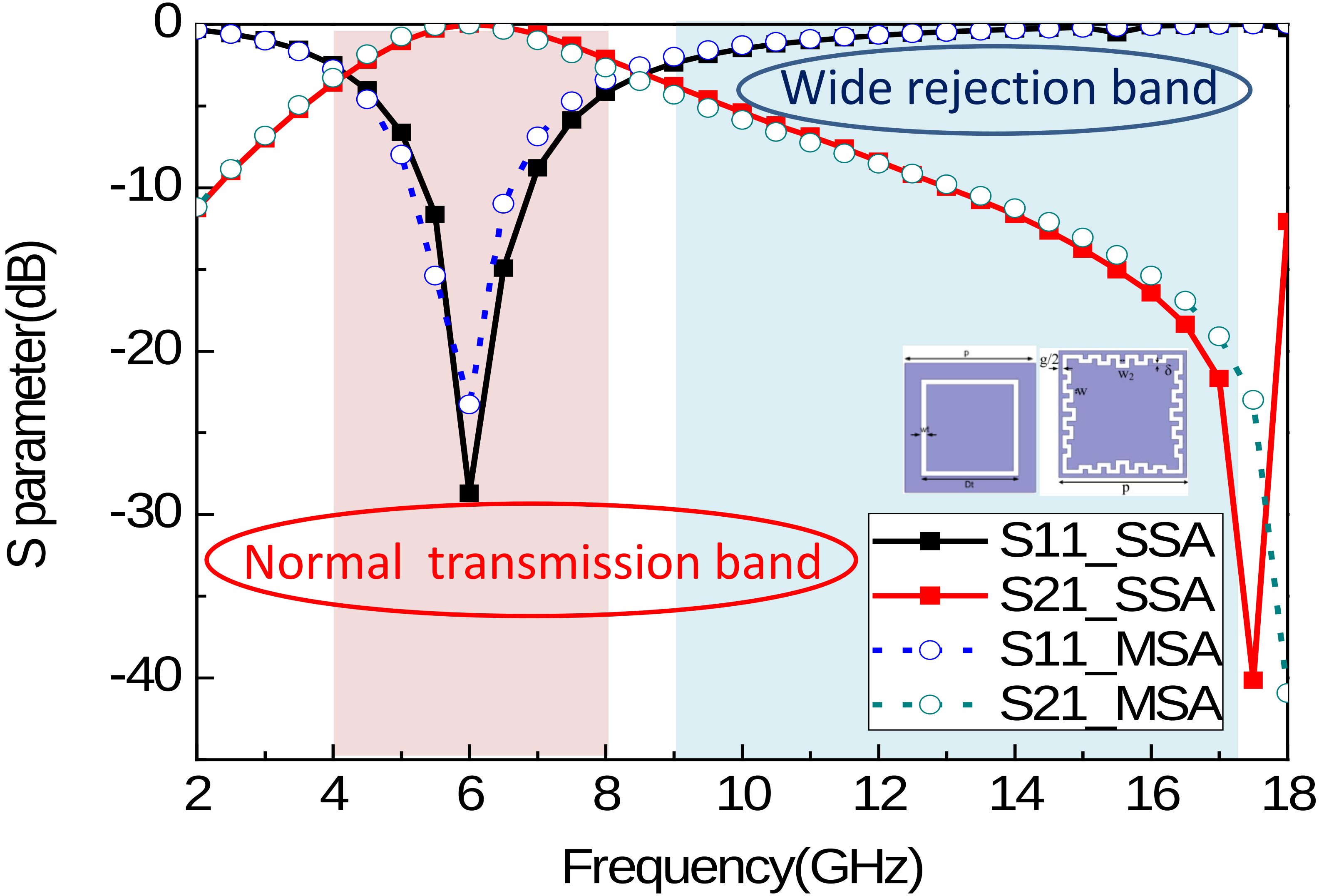
- Smaller size
- More stable in angle and polarization



Meandering square aperture (MSA)

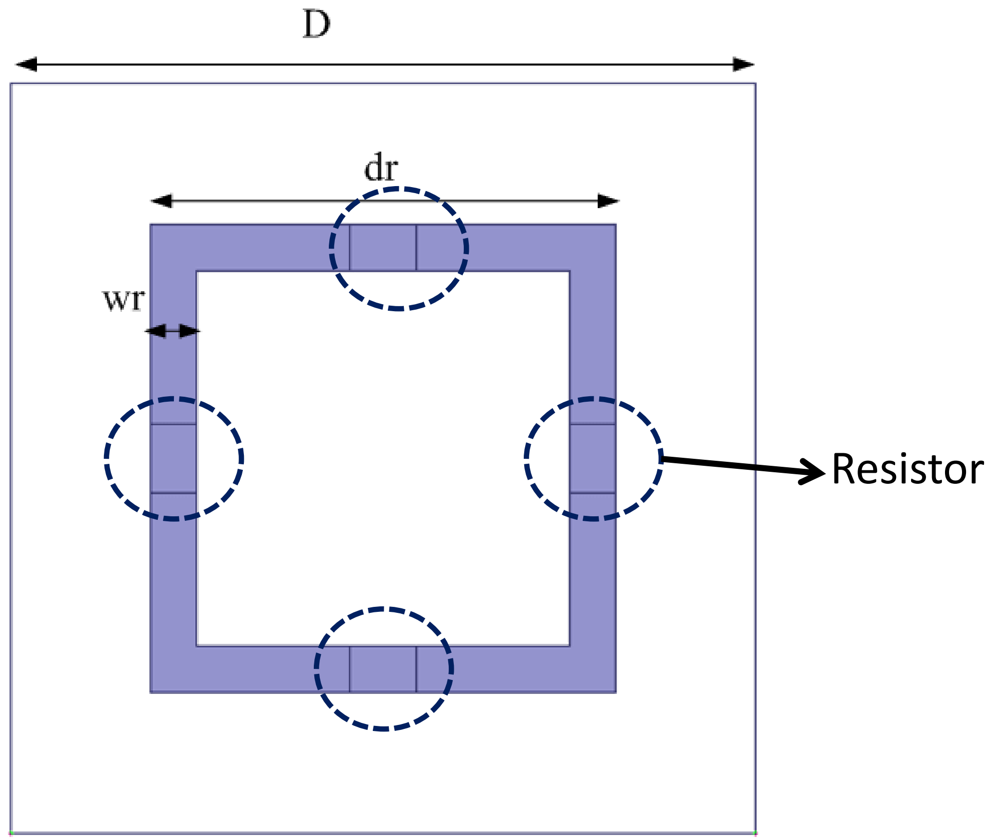
P_{MSA}=11 mm

Design of Bandpass Lossless Layer



Reflection and transmission curves of the band-pass structure.

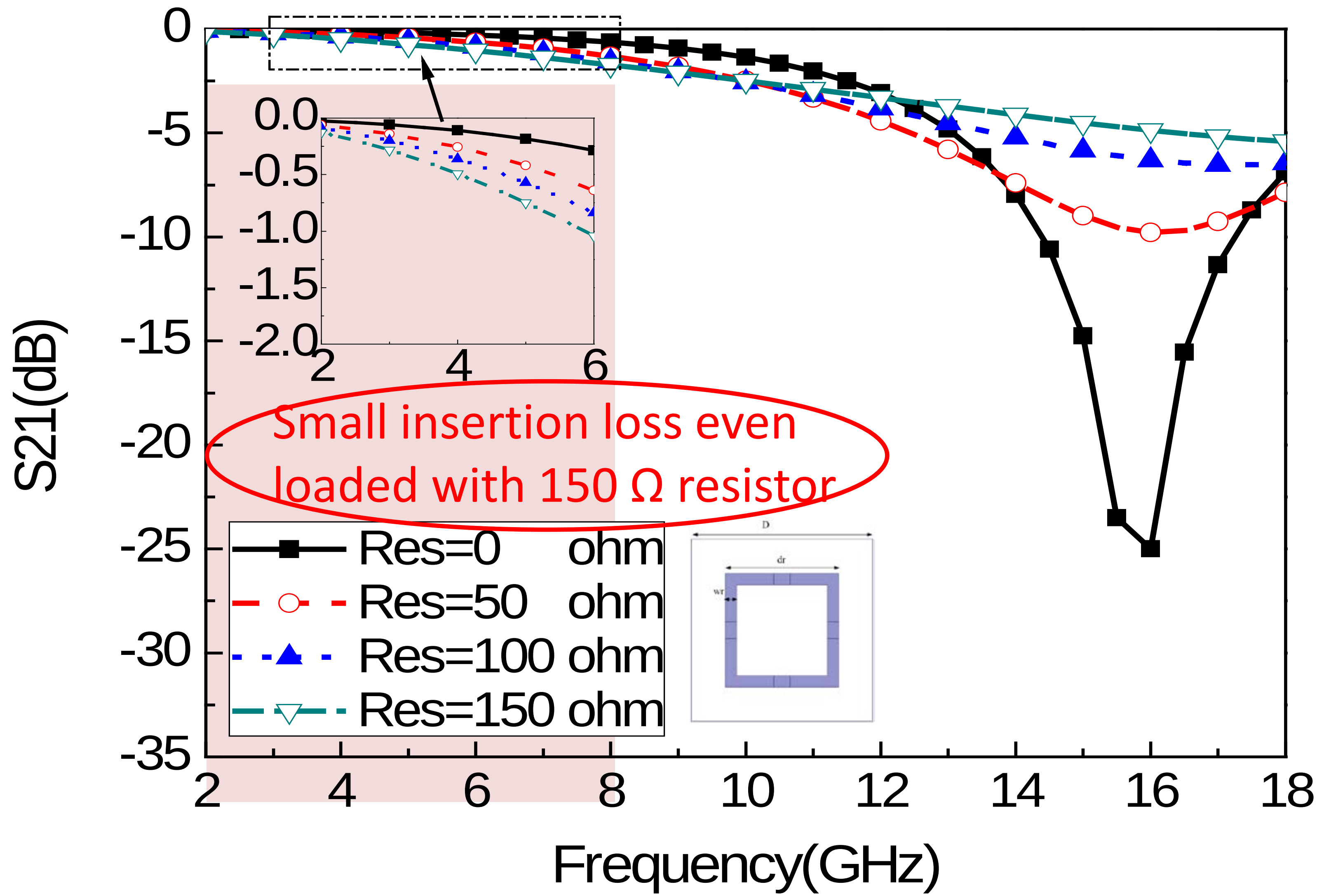
Design of Lossy Layer with Lumped Resistors



Lossy layer with lumped resistors

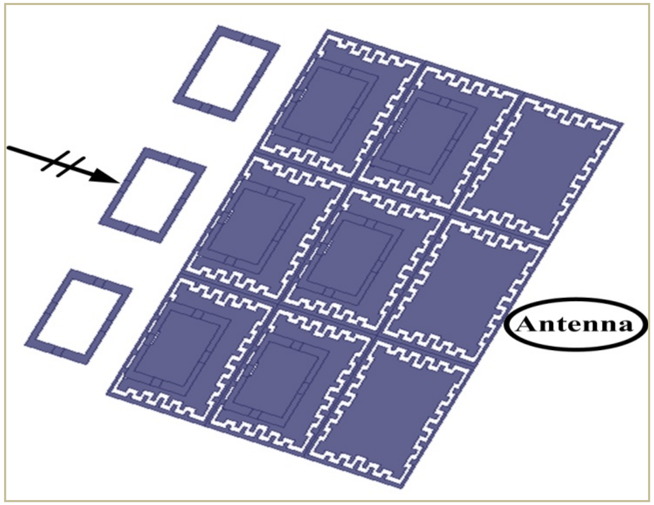
D=11 mm

Design of Lossy Layer with Lumped Resistors

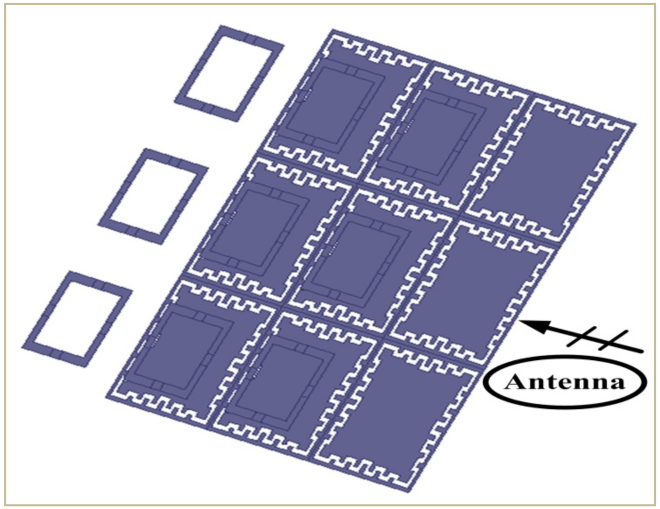


Transmission characteristics of the lossy layer studied under different resistor values.

Implementation of FSR with Absorbing Properties



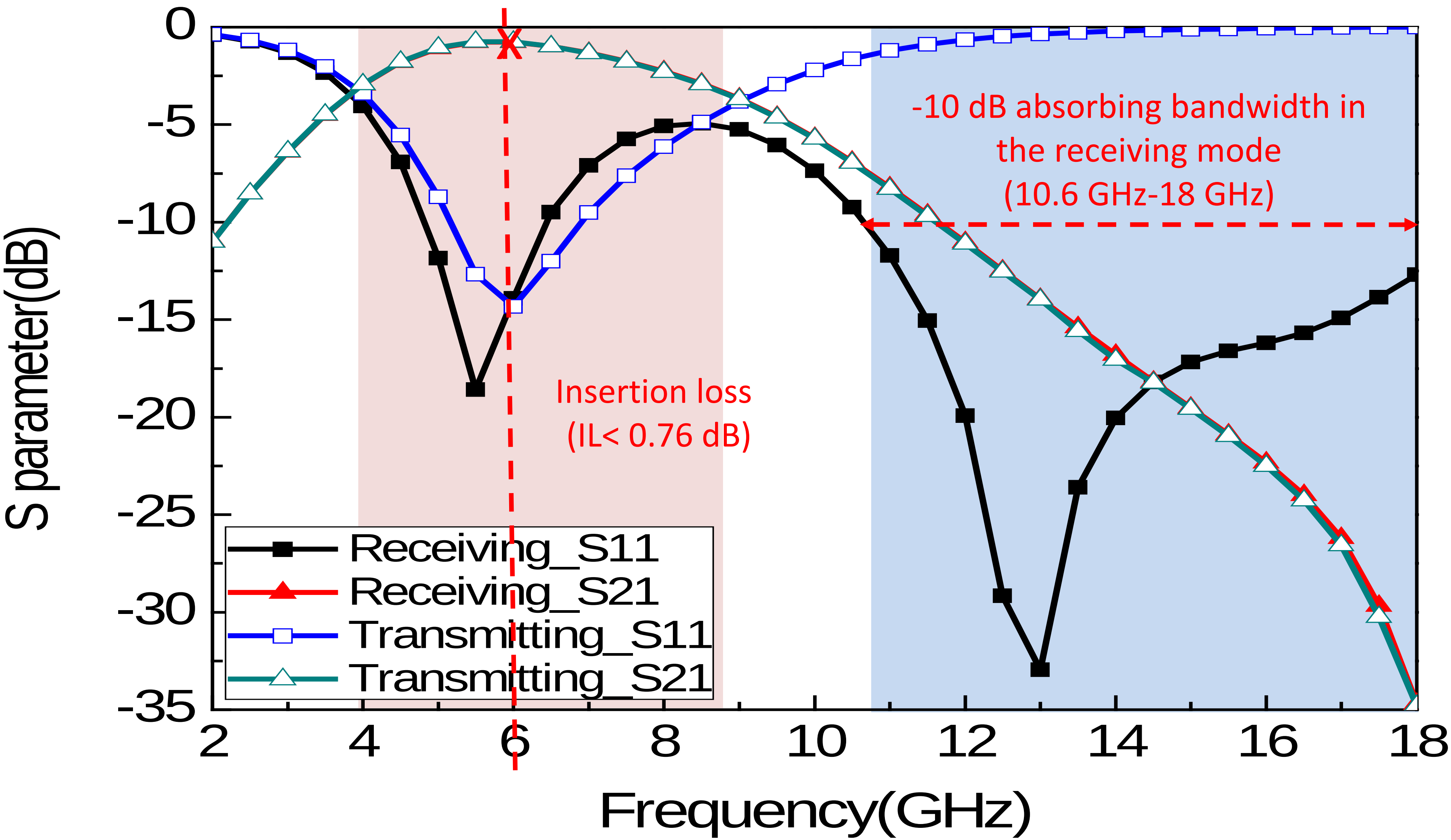
Receiving mode



Transmitting mode

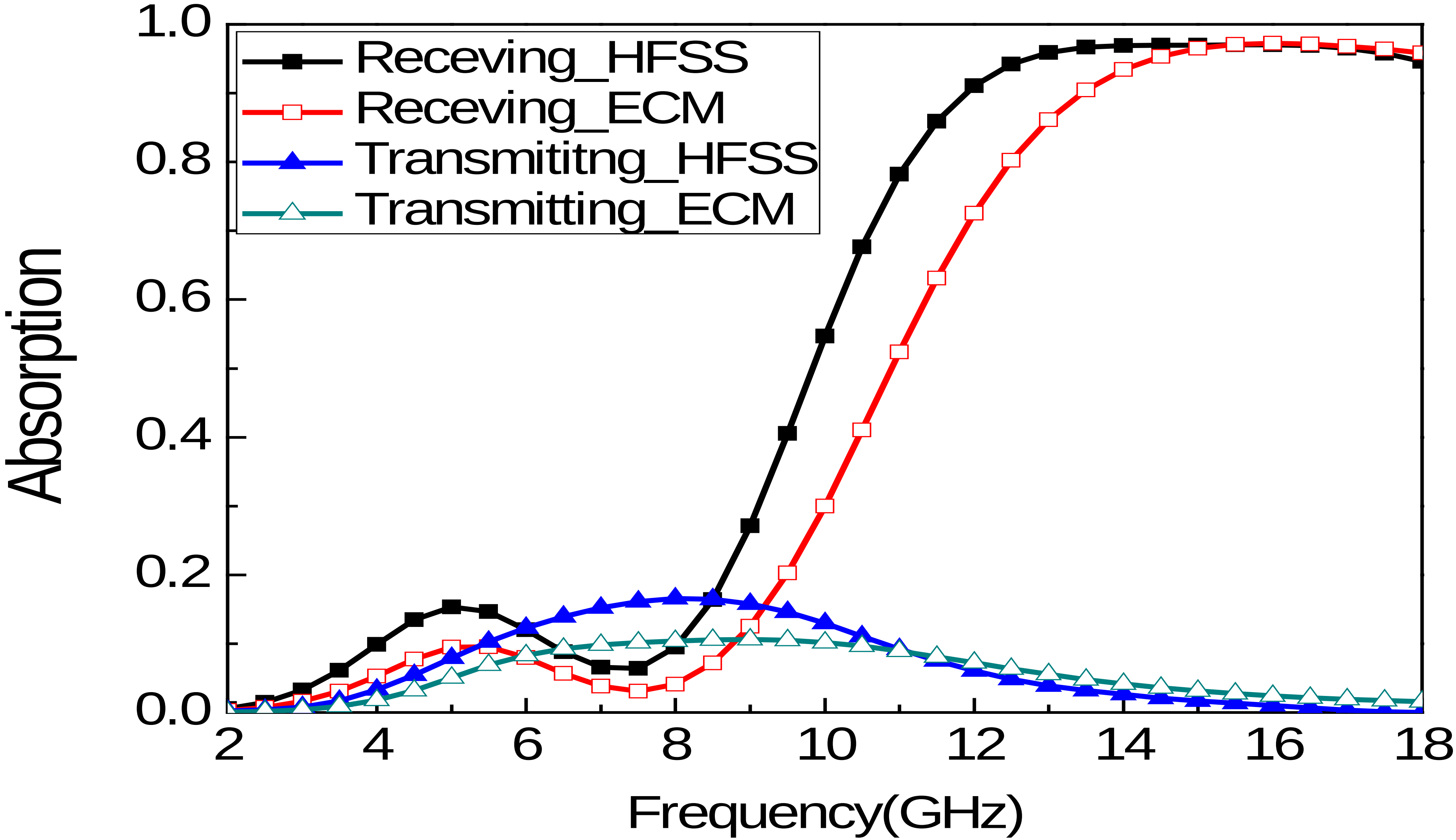
- Receiving mode: the wave radiates to the lossy layer.
- Transmitting mode: the band-pass FSS structure is radiated by the wave from the antenna inside.

Implementation of FSR with Absorbing Properties



Transmission and reflection coefficients in both receiving and transmitting modes.

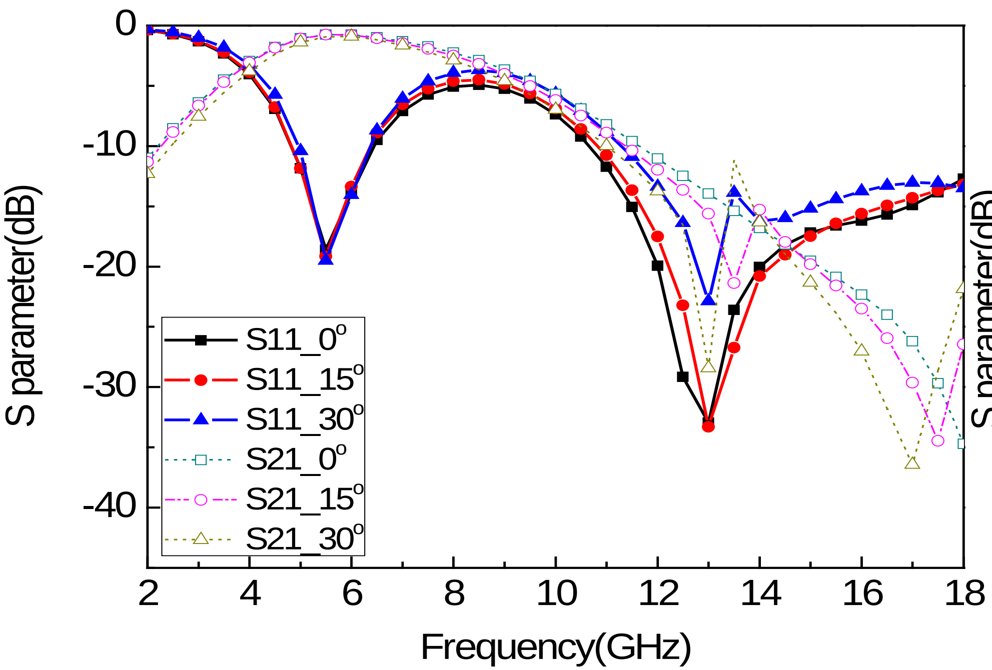
Implementation of FSR with Absorbing Properties



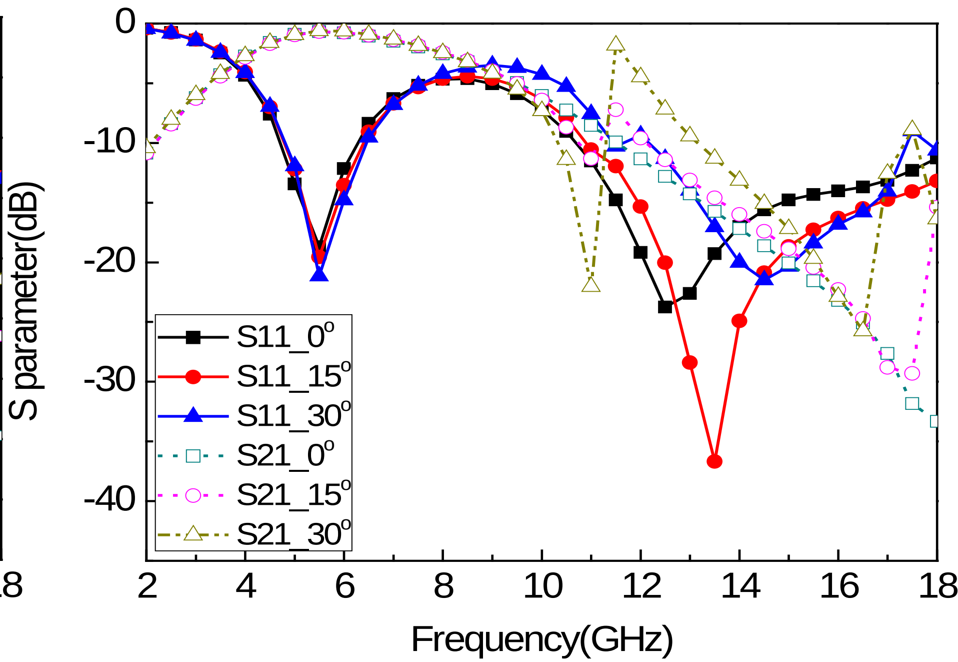
Absorption of the FSR when illuminated by the normal plane wave in both receiving and transmitting modes.

Implementation of FSR with Absorbing Properties

- Oblique situations:



(a) TE polarization



(b) TM polarization

Transmission and reflection coefficients for oblique situations in the receiving mode

Implementation of FSR with Absorbing Properties

- Size and performance comparison:

Paper	Period (λ_0)	Fractional Bandwidth	Layer	Thickness (λ_0)	Period of To Layers
[1]	0.253	57.1%	2	0.077	Dissimilar
[2]	0.05	25.1%	9	0.135	Dissimilar
This paper	0.22	53.1%	2	0.074	Similar

Conclusion

- An FSR with wide absorbing properties is proposed, and the design procedure is detailed
- The FSR has normal transmission in band, with low insertion loss (IL< 0.76 dB) at the operating frequency
- The FSR has low bistatic RCS out of band with wide absorbing bandwidth (10.6 GHz-18 GHz)
- The “Absorption” results simulated in HFSS is verified by the ECM method

Thank you!