A Multi-layer Tunable Frequency Selective Surface with Highly Selective Response Based on Varactor Diodes

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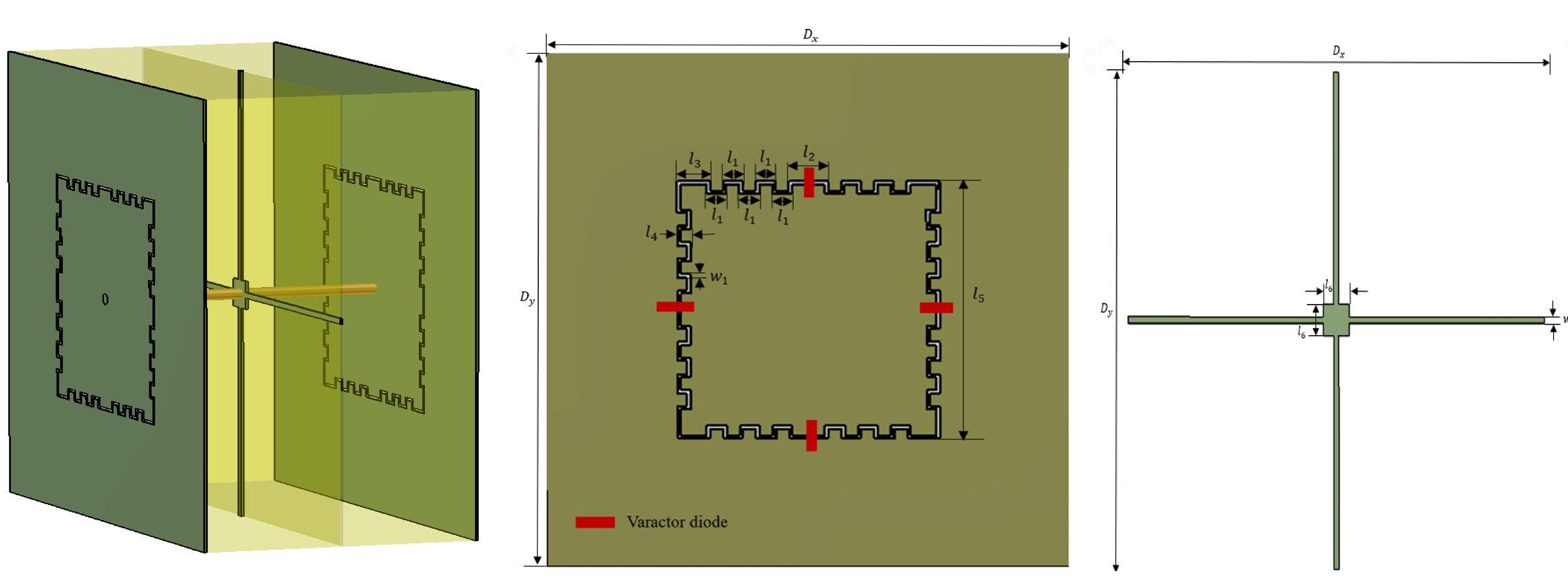
ABSTRACT

This article presents a highly selective Tunable Frequency Selective Surface (TFSS) based on varactor diodes. The multi-layer structure generates multiple resonance frequencies and transmission poles to suppressing the passage of out-of-band electromagnetic waves. In addition, it is used to improve the roll-off characteristics of TFSS. The simulation results show that TFSS can be resistively tuned between 10.33 and 11.12 GHz with a insertion loss between 0.17 and 0.03dB. The select characteristic relative bandwidth of multi-layer TFSS is T1 = 5.2% and T2 = 4.97%. Compared with the single-layer FSS, the proposed TFSS is increased by 84.4% and 83.6%, which verified the effectiveness of this method.



(a) (b) (c)

Fig. 1.(a)The structure of the proposed TFSS. (b) The first and third layer of the proposed TFSS. (c) The second layer of the proposed TFSS

TFSS DESIGN AND SIMULATION RESULTS

Fig.1 (a) displays the component of TFSS unit. The top and bottom metal layer units are the same. The thickness of the FSS layer is h1=0.035mm, and the patch material is copper. The three layers of metal are connected through the metal vias in the middle. The top and bottom layers are cascaded band-pass layers, and the middle metal layer is the feeder layer. The gap in the top FSS is a bent square ring, and four varactor diodes are respectively loaded on both ends of the gap, and the equivalent total capacitance is changed by tuning the varactor diodes. The feeder layer is composed of a cross ribbon patch and a square patch in the middle. The dielectric substrate adopts Rogers RT5880 lossy dielectric board which relative permittivity is 4.3, loss tangent equal to 0.0009. The thickness of substrate h is 2.00 mm.

Fig.2 presents the simulation results that the transmission pole of the single-layer FSS is 10.35GHz. The 3dB frequency points are 9.96GHz and 10.77GHz. The 20dB insertion loss frequency points are 7.11GHz and 15.01GHz. The steep cut-off bandwidth M1 is 2850MHz and M2 is 4250MHz, the select characteristic relative bandwidth T1 is 33.4%, T2 is 30.3%.

It is clear to see that the transmission poles of the TFSS are 10.63GHz and 10.79GHz. The transmission bands($|S_{21}|\geq-3$dB) range from 10.44GHz to 10.98GHz. The 20dB insertion loss frequency points are 9.91GHz and 11.54GHz. At this time, the steep cut-off bandwidth M1 is 530MHz and M2 is 560MHz; the select characteristic relative bandwidth T1 is 5.2%, and T2 is 4.97%, It is seen that compared to the single-layer FSS, the multi-layer TFSS is 84.4% and 83.6% higher respectively. Therefore, we can conclude that the proposed TFSS has higher selectivity.

In addition, the steep cut-off bandwidth M1 are 570MHz and 510MHz, M2 are 590MHz and 520MHz for C_{v1}=0.15pF and C_{v1}=0.19pF. The select characteristic relative bandwidth T1 is 5.45% and 5.1%, T2 is 5.08% and 4.7% respectively.

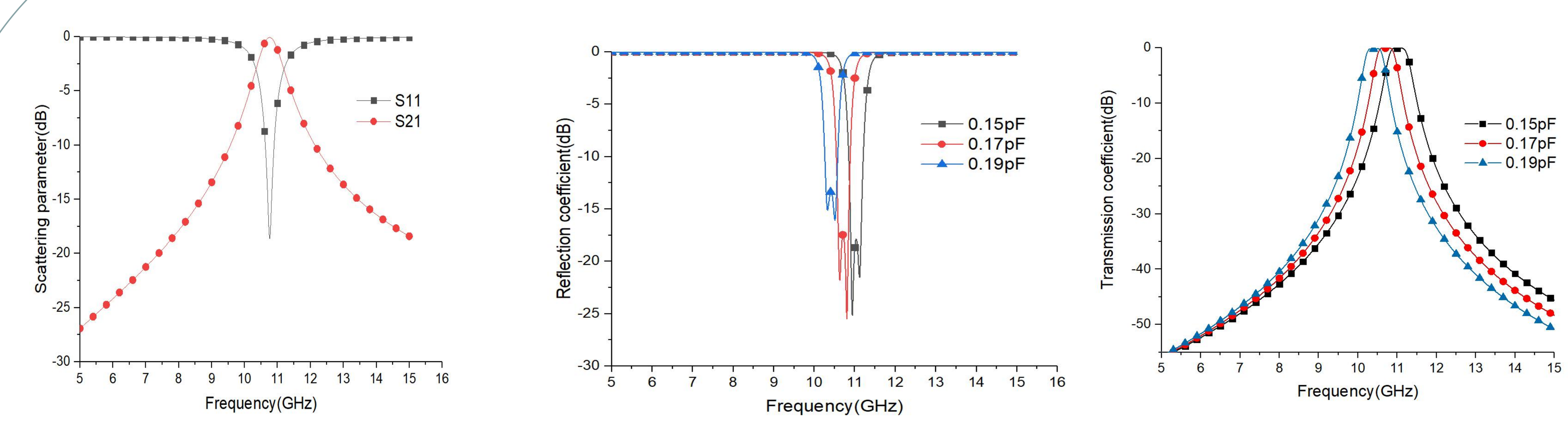
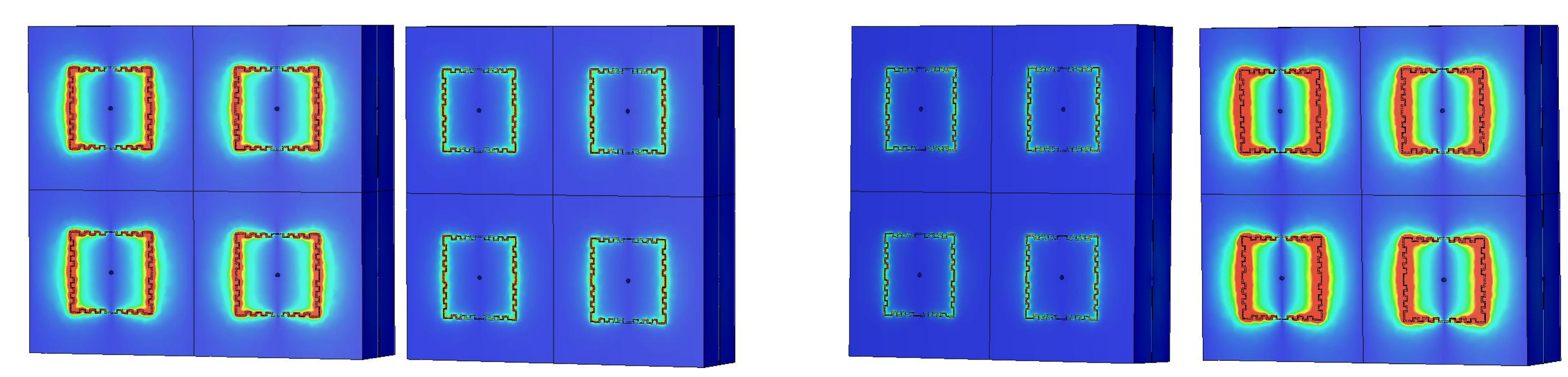
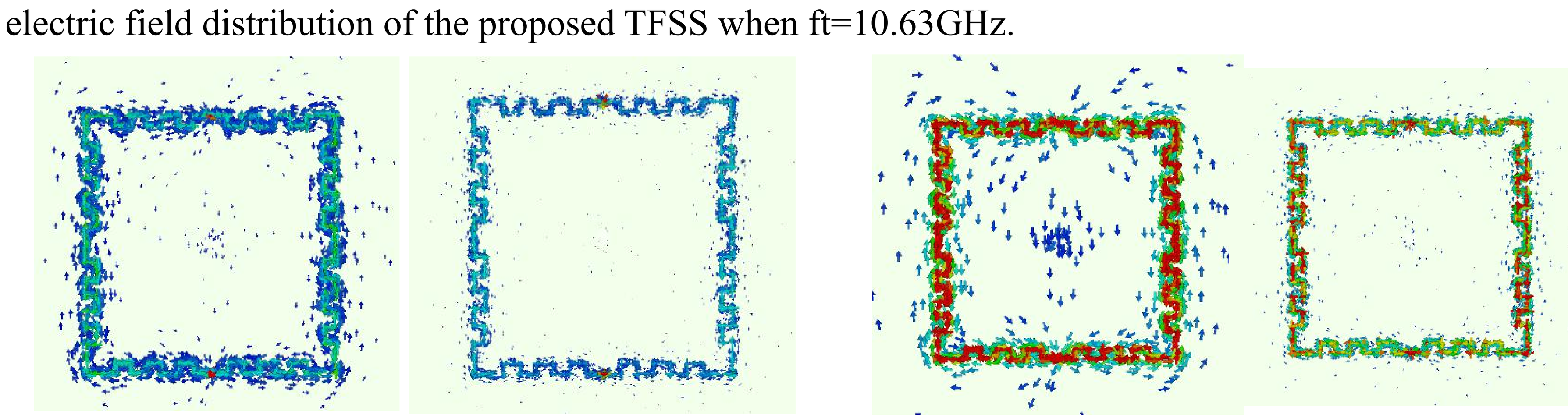


Fig. 2. (a) Simulated S-paramaters of the proposed single-layer FSS design when Cv1=0.17pF. (b) Simulated reflection coefficients of the proposed multi-layer TFSS design by varying Cv1. (c) Simulated transmission coefficient of the proposed multi-layer TFSS design by varying Cv1.



(a) f1=9.91GHz (b) ft=10.63GHz

Fig. 3. (a) Surface electric field distribution of the proposed TFSS when f1=9.91GHz. (b) Surface electric field distribution of the proposed TFSS when ft=10.63GHz.



(a) f1=9.91GHz (b) ft=10.63GHz

Fig. 4. (a) Surface current field distribution of the proposed TFSS when f1=9.91GHz. (b) Surface current field distribution of the proposed TFSS when ft=10.63GHz.

MECHANISM ANALYSIS

To further validate the operating principle the transmission characteristics and absorption mechanism of highly selective TFSS, the surface electric field and surface current analysis will be proposed.

A. Analysis of the surface electric field

It can be seen from the Fig.3(a) that the electric field energy is mainly concentrated at both ends of the gap in the top FSS layer for f1= 9.91GHz. Moreover, a large amount of energy of the incident EM waves is reflected.Fig.3(b) demonstrates that the incident waves pass through the top FSS layer , causing a large amount of electric field energy to gather near the gap of the top FSS layer at 10.63GHz.

B. Analysis of the surface current

From the Fig.4(a), the electromagnetic wave only generates a small amount of current on both sides of the gap in the top FSS layer. A small amount of electromagnetic waves pass through the top FSS layer, the bottom FSS layer generates less surface current.Fig.4(b) shows that a large amount of surface current is generated on both sides of the gap of the top FSS layer, and almost no energy consumption is generated. Electromagnetic waves generate only a small amount of surface current in the middle layer , a large amount of surface current is generated on both sides of the gap of the bottom FSS layer.

CONCLUSION

This article uses the multi-layer cascaded TFSS to generate multiple resonant frequency points which also combines with the method of bending and miniaturization, therefore, the selection characteristics have been improved. A prototype of the proposed TFSS is measured, which exhibits that the passband of this structure is continuously tunable from 10.33GHz to 11.12GHz, and the transmission pole insertion loss is reduced to 0.17dB. Compared to the single-layer FSS, the select characteristic relative bandwidth is 84.4% and 83.6% higher for Cv1 = 0.17pF while ensuring the original tunable characteristics.