REGULAR ARTICLE

Study and Simulation of an FSS for Multiband and Very Wide Band Applications with Double Polarization by a Transverse Wave Formulation

Abdelmalik Mekaoussi[1,2,*], Mohammed Yakhelef[1,2,†], Toufik Smail[3,‡], Hichem Bencherif[4,§]

[1] *Department of Electronics, Faculty of Technology, University of Batna 2 (Mostefa Ben Boulaïd), Batna 05000, Algeria*
[2] *Advanced Electronics Laboratory (LEA), University of Batna 2 (Mostefa Ben Boulaïd), Batna 05000, Algeria*
[3] *Solar Equipment Development Unit, EPST/CDER, RN N°11 BP386 Bou-Ismail, Tipaza 42415, Algeria*
[4] *LEREESI Laboratory, HNS-RE2SD, Batna 05000, Algeria*

(Received 20 August 2025; revised manuscript received 15 December 2025; published online 19 December 2025)

This new article presents a periodic structure of Frequency Selective Surface (FSS) with eight metallic strips, this structure is composed of metallic strips on the X axis and others on Y. The FSS proposed for multiband, Very Wide Band applications (VWB) with double polarization and for military radome applications, the FSS was placed on a dielectric substrate, the structure was excited by a plane wave polarized along X and Y is characterized by the iterative method WCIP (Wave Concept Iterative Procedure). The proposed periodic structure gives four resonant frequencies in the X polarization and four frequencies when it was polarized along Y after the characterization of the latter frequencies have been identified. Therefore, one can determine the resonance frequencies from the variation of the lengths of the metallic strips and the improvement of the bandwidths in the excitation directions X and Y. The results of the simulation by the HFSS Software (High Frequency Structure Simulator) and the WCIP method were compared and a good agreement between the two results was observed.

Keywords: Periodic structure, Metallic strips, VWB, Radome, Double polarization, WCIP method.

DOI: 10.21272/jnep.17(6).06004 PACS number: 07.05.Tp

1. INTRODUCTION

The Frequency Selective Surfaces (FSS) are two-dimensional periodic arrays of metallic patches on a dielectric layer. The FSS acts as a spatial frequency filter. This response depends on the polarization and the angle of incidence of the electromagnetic waves, the geometry of the patch and the periodicity of the unit cells [1], the thickness and permittivity of the substrate.

FSS structures (Frequency Selective Surfaces), are periodic arrays comprising metallic patterns on a dielectric substrate or a dielectric patch in a metallic layer, the purpose of these structures is filtering in the cases of reflection of some frequencies and transmission of others. These periodic FSSs are basic elements in systems with multiband applications, they are used as bandpass or bandstop filters [2]. These periodic surfaces can be as lowpass or highpass filters.

An FSS surface is a three-dimensional structure that presents on two or three directions of periodicities, it is a set of basic pattern elements that repeat regularly on the same periodicity vectors. The periodic structures are excited by a plane wave along the Z direction.

In this work the FSS structure with eight metallic strips is proposed for multiband (VWB) dual polarization applications and other for military radome applications with improved bandwidths [3].

2. THE WCIP METHOD

After Professor Henry discovered the WCIP method, studies were conducted on metallic patterns mounted on a ground plane and multilayer circuits[4], this method is suitable for the study of microwave circuits, frequency selective surfaces FSS and periodic structures [5-6]. Different techniques have been considered after the improvement of this method, technical studies of input impedance, metallic state and spectral connection. The diffracted waves "B" and incident waves "A" are defined on the interface of the circuit between the electromagnetic quantities and the circuit type variables, it is the wave returns to the surface "Ω", this last surface is the interface between the domain "Ω_1" and the domain "Ω_2".

So I have in this figure below Fig. 1. which represents a periodic structure contains a plane "Ω", this plane separates medium 1 and medium 2, the two media are characterized by the magnetic permeability and its electric permittivity, the excitation of our structure by plane waves, we find on the interface "Ω" two waves generated: the reflected and incident waves, these waves are given as a function of the magnetic field $\vec{H}_{T_i}$ and the electric field $\vec{E}_{T_i}$, Z_{0i} designates the wave impedance of medium (i) in the equations (2.1) and (2.2), the current density of

* Correspondence e-mail: am.mekaoussi@univ-batna2.dz
† m.yakhlef@univ-batna2.dz
‡ t.smail@udes.dz
§ bencherif.hichem@hns-re2sd.dz

Cite this article as: A. Mekaoussi et al., *J. Nano- Electron. Phys.* 17 No 6, 06004 (2025) https://doi.org/10.21272/jnep.17(6).06004

the same medium is $\vec{J}_i$ with $\vec{n}$ being the normal vector to the interface in the equations (2.3). These will be reflected to give the new next iteration for both TE, TM polarizations [7].

The definition of reflected and incident waves as follows:

$$\vec{A}_i = \frac{1}{2\sqrt{Z_{0i}}}\left(\vec{E}_{Ti} + Z_{0i}\vec{J}_i\right) \tag{2.1}$$

$$\vec{B}_i = \frac{1}{2\sqrt{Z_{0i}}}\left(\vec{E}_{Ti} - Z_{0i}\vec{J}_i\right) \tag{2.2}$$

$$\vec{J}_i = \vec{H}_{Ti} \wedge \vec{n} \tag{2.3}$$

3. THE UNIT CELL OF THE STRUCTURE

In this structure FSS I have a unit cell that I have proposed is presented in Fig. 1. [8], the structure consists of eight metal strips etched on a dielectric substrate of thickness $h = 0.1$ mm, with a relative dielectric constant $\varepsilon_r = 4.4$, the dimensions of the unit cell of this structure are a and b. The dimensions of the unit cell of the FSS are: $a = b = 28$ mm, $L_1 = 25$ mm, $L_2 = 21$ mm, $L_3 = 16$ mm, $L_4 = 13$ mm on the X axis and $L_5 = 24$ mm, $L_6 = 20$ mm, $L_7 = 15$ mm, $L_8 = 12$ mm, on the Y axis, the width of the strips is $w = 1$ mm, the distances between the strips are: $e = 2.5$ mm, $k = 1.8$ mm, $g = 2.1$ mm.

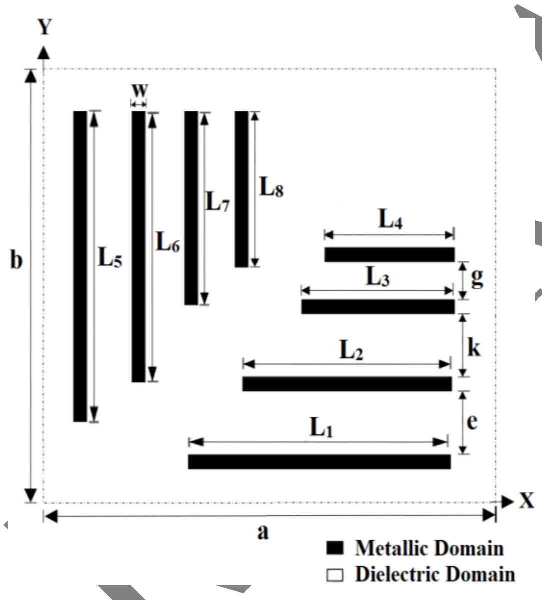

Fig. 1 – Unit cell of the proposed FSS

The cell is excited in both X and Y directions by a plane wave of polarized incidence, a 100 × 100 pixel mesh is used and the program process is stopped after 130 iterations.

4. FSS RESULTS

4.1 Transmitted Power

As shown in Fig. 2. the simulation of the FSS structure by the HFSS software was compared by the WCIP method, in this figure we have the transmitted power as a function of the operating frequency for the X polarization by this FSS [9], we observe four resonance frequencies at 5.1 GHz, 6 GHz, 7.8 GHz, 9.8 GHz, the bandwidths of 750 MHz, 790 MHz, 770 MHz, 990 MHz at -10 dB respectively, in Fig. 3. we found four frequencies at 5.3 GHz, 6.2 GHz, 8.5 GHz, 10.5 GHz, with bandwidths of 700 MHz, 890 MHz, 630 MHz, 850 MHz respectively when the structure is excited in Y.

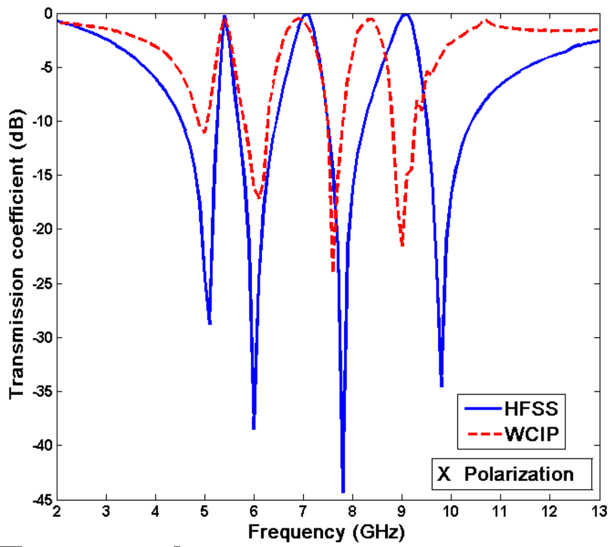

Fig. 2 – Transmitted power as a function of frequency following polarization X

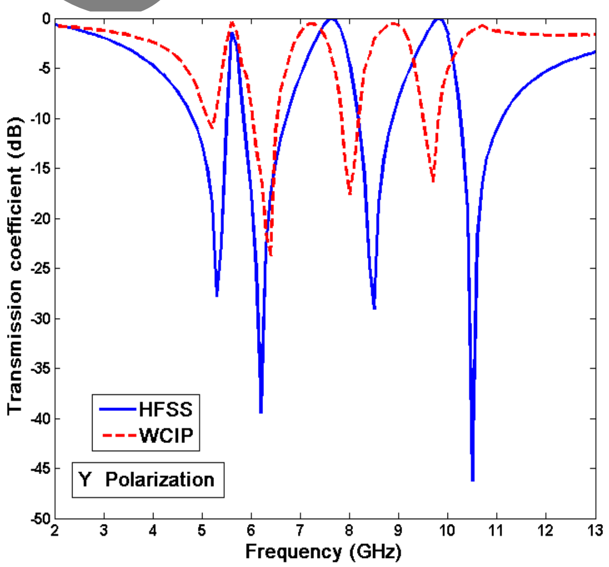

Fig. 3 – Transmitted power as a function of frequency following polarization Y

4.2 The Radiation Pattern

A volume containing the radiating elements must be defined to simulate the far field under HFSS, this volume of the field must be distant from the elements by a distance between 1/4 and 10 of the wavelength. The radiation describes the spatial distribution of the antenna power. Fig. 4 below shows the 3D radiation pattern on a remote area of the antenna [10], also represents the total field modulus E in the E and H planes ($\varphi = 0$ and $\theta = 90°$), for the simulated FSS structure, I see in this figure Fig.5. that the maximum value of the total field is 2.4875 × 10^3 mV, the radiation pattern[11] allows the determination of a radiating aperture of 155° along X, 148° on Y, 180° towards Z of the power which corresponds to – 3 dB and a total gain value of 1.4548 × 10^2 dB which was represented in Fig. 5.

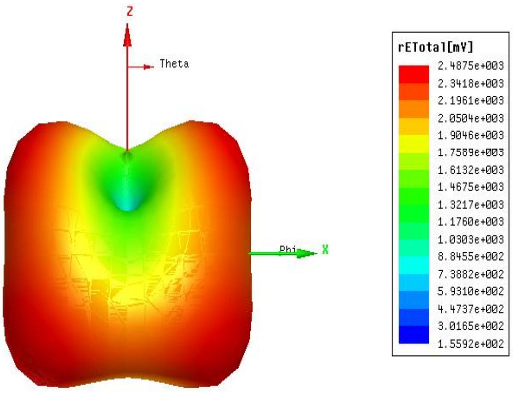

Fig. 4 – The 3D radiation pattern, The total field

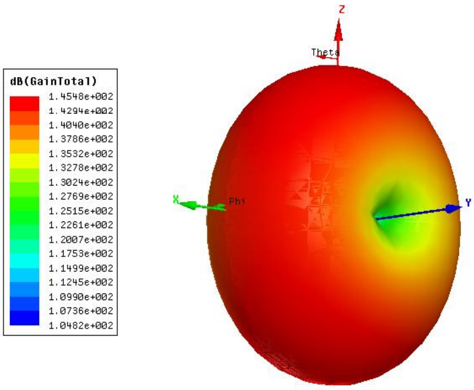

Fig. 5 – The 3D radiation pattern, The total gain

4.3 The Variation of Distances *e*, *k*, *g*

We observe in Fig. 6. which represents the transmission coefficients as a function of the operating frequency for different values of the distance e, the variation of e is adjusted by the resonance frequencies, the variation of this distance results in a change in the frequency.

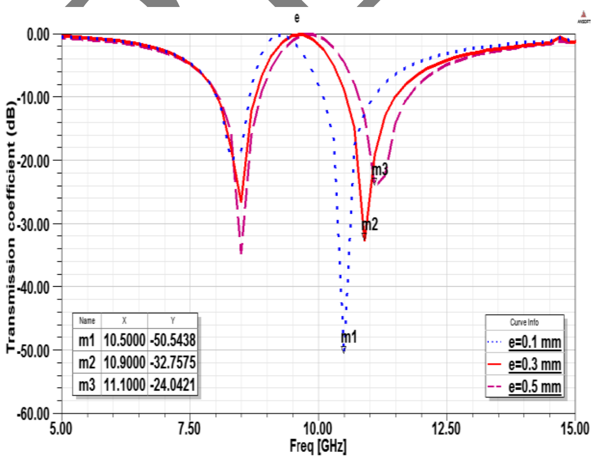

Fig. 6 – Transmission coefficients as a function of operating frequency with different values of *e*

When the distance increases the resonance frequency increases from the lowest frequency of 10.5 GHz to 11.1 GHz as shown in this figure Fig. 6.

We can say that the variation of the distance k between the two strips 2 and 3 in Fig. 7. which represents the different values, this distance increases with the increase of the frequency for 1.6 mm to 1.8 mm but for $k = 2$ mm the resonance frequency decreases to 16.2 GHz

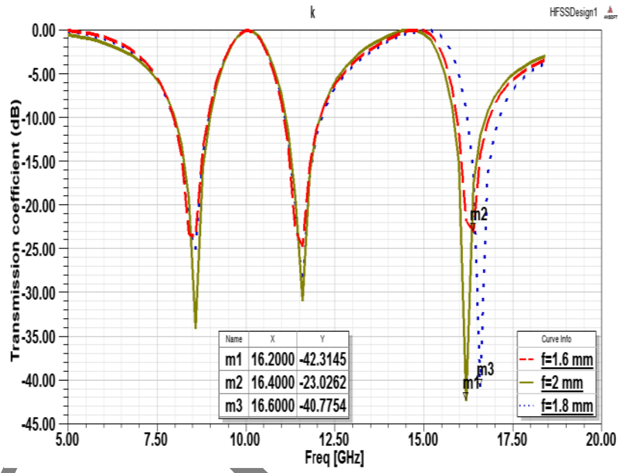

Fig. 7 – The transmission coefficients as a function of the frequency with different values of *k*

In Fig. 8. shows the variation of the frequency for the different values of the distance g, we notice that the frequency increases when the distance has also increased from 20.6 GHz to 21 GHz but remains fixed for $g = 2$ mm at the frequency 21 GHz.

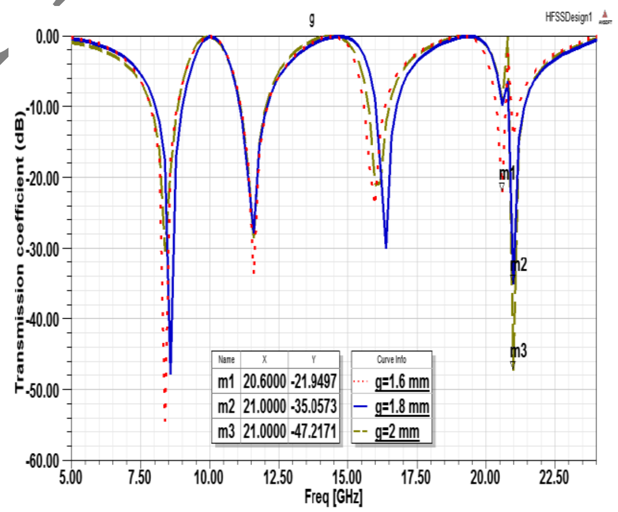

Fig. 8 – The transmission coefficients as a function of the operating frequency for different values of *g*

4.4 The Errors

From Fig. 9 the relative error in the resonance frequency obtained is presented with respect to the results of the frequency of each metal strip varies from 0 % to 11.43 % and 0.1 mm to 2.5 mm respectively, so the values of 1.6 mm, 2.1 mm, 2.2 mm, 2.4 mm, 2.5 mm are taken as distances for a zero relative error.

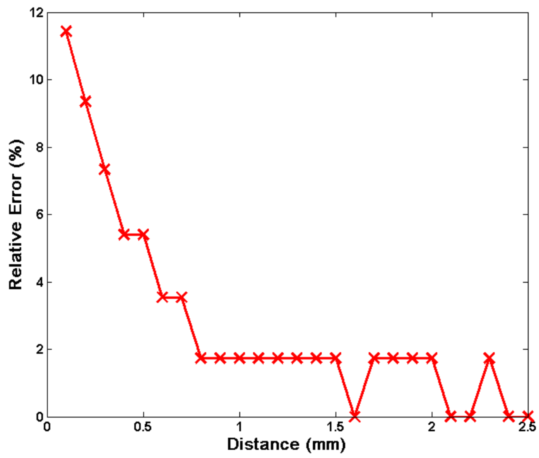

Fig. 9 – The relative error as a function of the distance

The error at each variation of the distance between the strips is presented in Fig. 10. below, in the resonance frequency obtained with respect to the results of the frequency of each metal strip varies from 0 GHz to 11.7 GHz and 0.1 mm to 2.5 mm respectively, the values closer than the uncoupled frequencies are 1.6 mm, 2.1 mm, 2.2 mm, 2.4 mm, 2.5 mm, because the errors of these distances are zero.

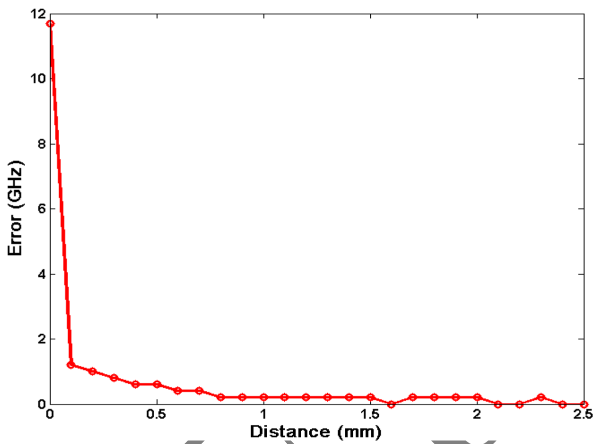

Fig. 10 – The error as a function of the distance

4.5 The Table of Resonant Frequency and Bandwidth

In this Tab. 1 below I present the resonance frequencies and bandwidths of each metal strip for both polarization X and Y, I observe a very wide band (VWB) in the second strip for frequencies 6 GHz, 6.2 GHz arrives at 790 MHz, 890 MHz respectively. The resonance frequencies of 9.8 GHz and 10.5 GHz concerning the fourth strip, the bandwidths that we found are 990 MHz, 850 MHz for both polarization X and Y respectively.

Table 1 – The resonance frequency and bandwidth for each strip following X and Y

Resonances	f_n / BW_n	Pol X	Pol Y
First resonance	f_1 (GHz)	5.1	5.3
	BW_1 (MHz)	750	700
Second resonance	f_2 (GHz)	6	6.2
	BW_2 (MHz)	790	890
Third resonance	f_3 (GHz)	7.8	8.5
	BW_3 (MHz)	770	630
Fourth resonance	f_4 (GHz)	9.8	10.5
	BW_4 (MHz)	990	850

Pol X, Pol Y: Polarization X, Polarization Y.
f_n: The resonant frequency corresponding to strip *n*, (*n* = 1, 2, 3, 4).
BW_n: The Bandwidth for strip *n*, (*n* = 1, 2, 3, 4).

5. CONCLUSION

In this article we proposed the FSS type of a structure with metallic strips in parallel for multiband and very wide band (VWB) applications with double polarization for military radome applications, the proposed structure presents four resonance frequencies for the polarization X at 5,1 GHz, 6 GHz, 7.8 GHz, 9.8 GHz, the widths of the bandwidths 750 MHz, 790 MHz, 770 MHz, 990 MHz at -10 dB respectively, we also found four resonance frequencies at 5.3 GHz, 6.2 GHz, 8.5 GHz, 10.5 GHz, with bandwidths of 700 MHz, 890 MHz, 630 MHz, 850 MHz, respectively for the excitation of the Y structure.

We can adjust the resonance frequencies and the bandwidths by varying the lengths of the metallic strips, the characterization of this structure by bandwidths improved to 176.92 % in the two polarization directions X and Y and for a zero relative error (0 %) in the resonant frequency obtained compared to the results of the frequency of each metallic strip. The results of the WCIP method and the HFSS Software are compared and a good agreement is found.

REFERENCES

1. P. Francisco, C.G. da Silva Segundo, A. Luiz P.S. Campos, A.G. Neto, M. de O. Alencar, *J. Microwave, Optoelectron. Electromagn. Appl.* **18** No 3, 328 (2019).
2. R. Shavit, *Frequency Selective Surfaces (FSS) Radomes* In *Radome Electromagnetic Theory and Design*, 39 (Wiley-IEEE Press: 2018).
3. C. Girard, *Hybridation de méthodes numériques pour l'étude de la susceptibilité électromagnétique de circuits planaires, PhD Thesis* (Toulouse National Institute of Technology (INP)) (2014).
4. L. Feng, Y. Zhen, P. Xiaoyu, *2023 6th World Conference on Computing and Communication Technologies (WCCCT)*, 57 (2023).
5. D. Li, Z. Shen, E.P. Li, *IEEE Trans. Antennas Propag.* **67** No 2, 1065 (2019).
6. W. Wang, J. Dong, J. Mo, *2020 Cross Strait Radio Science & Wireless Technology Conference (CSRSWTC)* (2020).
7. P. Jiang, W. Jiang, W. Hu, S. Gong, *IEEE Antennas Wireless Propag. Lett.* **21** No 5, 1027 (2022).
8. M.J. Duarte, J.G.D. Júnior, V.P. da S. Neto, *Sensor. Actuat. A: Phys.* **378**, 115763 (2024).
9. L. Yan, Y. Shijia, L. Da, Z. Ling, L. Enxiao, L. Erping, *J. Phys. D: Appl. Phys.* **58** No 1, 015110 (2024).
10. I. Surjati, S. Alam, L. Sari, Y.K. Ningsih, A. Elishabet, S.M. Putri, Z. Zakaria, T. Firmansyah, *J. Nano- Electron. Phys.* **16** No 2, 02009 (2024).
11. A. Ambika, Sivashanmugavalli, N. Parthiban, S. Chandran, S. Das, R.K. Mahapatra, *J. Nano- Electron. Phys.* **16** No 4, 04038 (2024).

Дослідження та моделювання FSS для багатодіапазонних і дуже широкосмугових додатків з подвійною поляризацією за формулюванням поперечної хвилі

Abdelmalik Mekaoussi[1,2], Mohammed Yakhelef[1,2], Toufik Smail[3], Hichem Bencherif[4]

[1] *Department of Electronics, Faculty of Technology, University of Batna 2 (Mostefa Ben Boulaïd), Batna 05000, Algeria*
[2] *Advanced Electronics Laboratory (LEA), University of Batna 2 (Mostefa Ben Boulaïd), Batna 05000, Algeria*
[3] *Solar Equipment Development Unit, EPST/CDER, RN N 11 BP386 Bou-Ismail, Tipaza 42415, Algeria*
[4] *LEREESI Laboratory, HNS-RE2SD, Batna 05000, Algeria*

У цій новій статті ми пропонуємо періодичну структуру частотно-селективної поверхні (FSS) із восьмома металевими смужками, ця структура складається з металевих смужок на осі X та інших на Y. FSS, запропонована для багатодіапазонних, дуже широкосмугових програм (VWB) з подвійною поляризацією та для застосування у військових обтекателях FSS поміщали на діелектричну підкладку, структуру збуджували плоскою хвилею, поляризованою вздовж X та Y характеризується ітераційним методом WCIP (Ітераційна процедура хвильової концепції). Запропонована періодична структура дає нам чотири резонансні частоти в X-поляризації та чотири частоти, коли вона була поляризована вздовж Y після визначення характеристик останніх частот. Тому ми можемо визначити резонансні частоти за зміною довжини металевих смужок і покращенням смуги пропускання в напрямках збудження X і Y. Результати моделювання за допомогою програмного забезпечення HFSS (Симулятор високочастотної структури) і методу WCIP спостерігалося хороше узгодження між двома результатами.

Ключові слова : Періодична структура, Металеві смужки, VWB, Радом, Подвійна поляризація, Метод WCIP.