



Waveguide Filter Design (WFD) Tool in the Teaching of Microwave Engineering

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Abstract

This paper presents the Waveguide Filter Design (WFD) program using principle of electromagnetic wave theory and Wave Iterative Method (WIM) based on propagation of incident, reflected and transmitted waves in the waveguide for microwave engineering education. After the surveying by questionnaire about the nature in the microwave engineering course, the instructors found that the microwave engineering subject has the difficult and complicate calculation, thus the simulation program is important to use in the teaching of microwave engineering. The structure of developed WFD program menu consists of input, output, and processing part which operate by using GUI (Graphic User Interface) of MATLAB[®]. The simulated results were good agreement in the comparing with theory. The evaluation of ten experts for the quality of WFD program was very good that simulation program can be used in the microwave circuit design as easily and use in the teaching of microwave engineering with efficiency.

Keywords: Microwave Engineering, Waveguide Filter Design, Wave Iterative Method, Simulation Program

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เครื่องมือสำหรับการออกแบบวงจรรองความถี่ในท่อนำคลื่น (WFD) เพื่อใช้ในการเรียนการสอนด้านวิศวกรรมไมโครเวฟ

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บทคัดย่อ

บทความวิจัยนี้เป็นการนำเสนอการใช้โปรแกรมจำลองการออกแบบวงจรรองความถี่ในท่อนำคลื่น(WFD) โดยใช้หลักการทางทฤษฎีของคลื่นแม่เหล็กไฟฟ้าร่วมกับวิธีการคำนวณแบบวนรอบ ที่ประกอบด้วยคลื่นตกกระทบ คลื่นสะท้อนกลับ และคลื่นส่งผ่านที่แพร่กระจายอยู่ภายในท่อนำคลื่น เพื่อนำไปใช้สำหรับการเรียนการสอนในสาขาวิศวกรรมไมโครเวฟ จากการสำรวจโดยใช้แบบสอบถามความคิดเห็นเกี่ยวกับหลักสูตรในวิชาวิศวกรรมไมโครเวฟโดยผู้เชี่ยวชาญพบว่าเนื้อหาในรายวิชาดังกล่าวมีการคำนวณที่ยากและซับซ้อน ควรมีสื่อการเรียนการสอนที่ทำให้ผู้เรียนเข้าใจพฤติกรรมในการคำนวณ ดังนั้นการใช้โปรแกรมจำลองในการเรียนการสอนวิชาวิศวกรรมไมโครเวฟจึงเป็นสิ่งที่สำคัญ โดยโครงสร้างของโปรแกรมจะมีลักษณะเป็นหน้าต่างเมนูเลือกที่ทำงานภายใต้รูปแบบ GUI (Graphic User Interface) ของโปรแกรม MATLAB[®] ที่ประกอบด้วยส่วนรับข้อมูล ส่วนประมวลผล และส่วนแสดงผล ผลของโปรแกรมจำลองที่สร้างขึ้นสามารถวิเคราะห์ห้วงจรรองความถี่ได้ถูกต้องสอดคล้องกับทฤษฎี และผลของการประเมินโดยผู้เชี่ยวชาญจำนวน 10 ท่าน พบว่ามีความเหมาะสมอยู่ในระดับมากที่สุด ดังนั้นสรุปได้ว่าโปรแกรมจำลองนี้สามารถนำมาใช้ออกแบบและวิเคราะห์ห้วงจรไมโครเวฟได้อย่างง่ายดาย และใช้ประกอบในการเรียนการสอนวิชาวิศวกรรมไมโครเวฟได้อย่างมีประสิทธิภาพ

คำสำคัญ: วิศวกรรมไมโครเวฟ, การออกแบบวงจรรองความถี่ในท่อนำคลื่น, วิธีการวนรอบของคลื่น, โปรแกรมจำลอง

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1. Introduction

With the technology evolution of MIC's and microwave applications have come to dominant the global industry. The education, research and development of modern microwave circuits are much stronger influences within the microwave engineering [1-4]. Software tools are indispensable in microwave engineering [1-2], so the researchers and educators rely on simulation program such as Advanced Design System (ADS) by Agilent Technologies (Hewlett Packard), IE3D by Zeland Software and Microwave Office (MWO) by Applied Wave Research. However, most of the microwave circuit simulations cannot be used to design several circuit structure complexity and the students cannot understand the program structure description to edit and develop.

Generally, teaching and learning for content of microwave engineering focus to calculate, to analysis and to design the microwave circuits such as microstrip line, planar circuits, filters and waveguide circuits. Microwave engineering is often perceived as highly mathematical and difficult subject to comprehend [3]. After the surveying by using questionnaire and interview of teaching and learning conditions of microwave engineering for 10 instructors and 40 students shown in the figure 1, they found that microwave engineering is the most essential and important subject which can apply to be the radio-frequency ICs or microwave devices. Current teaching of microwave engineering will focus on the facilitating teacher-centered learning. The teaching and learning activities will depend on teachers. Most teaching will be use the teaching media that consists of the textbook, blackboard and Microsoft power point program or transparency sheets.



Figure 1 Learning of microwave engineering course

The microwave education curriculum needs to emphasize are: 1) facilitating student-centered learning model including the efficiency instruction package; 2) simulation program that needs to be used as a critical and efficient tool for microwave education; and 3) instruction media integration such as experiment set and demonstration set which describe the phenomenon of complex content.

In this paper we present the simulation program for waveguide filter design (WFD) that can be used for both research and microwave education. This program can also be used for illustration of the properties of an iris circuit in the waveguide by monitoring the 2.5D electromagnetic wave. All these environments are evaluated from educational viewpoint.

2. Wave Iterative Method (WIM)

The calculating concept for the electromagnetic wave propagation in the waveguide is based on the Wave Iterative Method (WIM) [5-7]. The process, shown in figure 2, presents the amplitude and direction of the incident, reflected, and transmitted wave which propagate in the waveguide iris circuit. On the iris circuit, the wave is calculated in the real domain (or pixel domain) and the wave in the free space is calculated in the spectrum domain (or

mode domain). The alternating between both domains, we use the Fast Fourier Transform (FFT) for the fast computation time.

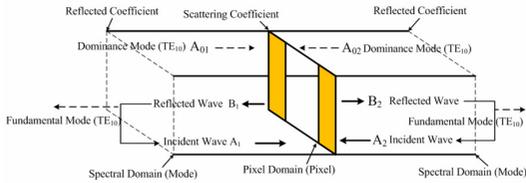


Figure 2 Wave Iterative Method (WIM)

In the figure 2, the first step, the TE_{10} mode which is the dominant mode propagates into the iris circuit, then the higher order mode of waves caused by the scatter on the conductor surface will incident and reflect within the waveguide. Finally the calculation of waves will use the principle of mode matching at input and output port of waveguide.

The initial value of dominant mode is,

$$A_{0i} = -\sqrt{\frac{2}{ab}} \sin\left(\frac{\pi x}{a}\right) \quad (1)$$

The reflected wave (B_i) on the iris circuit is,

$$B_i^{(n)} = S A_i^{(n-1)} \quad (2)$$

The incident wave (A_i) will though feedback into the waveguide, the equation is,

$$A_i^{(n)} = \Gamma B_i^{(n)} + A_{0i} \quad (3)$$

Therefore, the relation of incident waves at n iteration is,

$$A_i^{(n)} = (\Gamma S)^{(n-1)} A_i^{(n-1)} + A_{0i} \quad (4)$$

When a and b are the dimensions of waveguide, n is the number of iteration, i is the number of waveguide port, Γ is the reflection coefficient at input/output port and S is the scattering parameter of iris circuit.

The scattering parameter (S) of wave in the pixel domain for two ports network can be written as follow,

$$[S] = \begin{bmatrix} -H_M & H_D \\ H_D & -H_M \end{bmatrix} \quad (5)$$

when H_M equal 1 for conductor area and H_D equal 1 for free space.

The reflection coefficient (Γ) of wave in spectrum domain (mode) at input and output port of waveguide can be written as the following equation.

$$\Gamma_{mn}^{TE/TM} = \frac{1 - Z_0 Y_{mn}^{TE/TM}}{1 + Z_0 Y_{mn}^{TE/TM}} \quad (6)$$

when Z_0 is the intrinsic Impedance of dominant mode, and Y_{mn} is the TE/TM mode admittance in mn order mode.

3. Waveguide Filter Design (WFD)

The iris circuit structure of low pass filter, high pass filter, band pass filter, and band stop filter in the waveguide are displayed as figure 3.

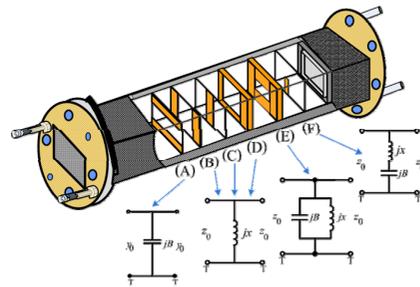
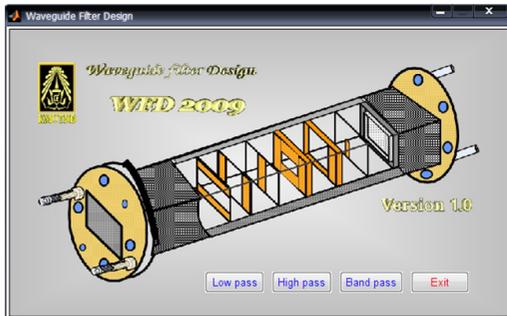


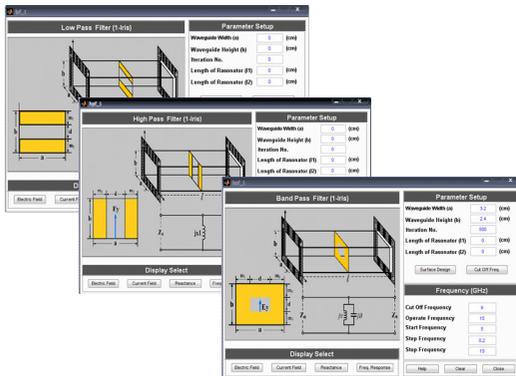
Figure 3 Iris circuit in the waveguide

The developed waveguide filter simulation program based on wave iterative method which is called WFD 2009 (Waveguide Filter Design 2009), consists of main menu, parameter setup, design and display window, as shown in the figure 4 (a)-(e). The WFD is constructed by using GUI (Graphic

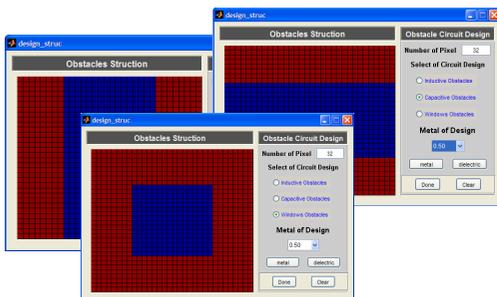
User Interface) of MATLAB®. The user can input the initial values that used for calculating of two ports network, calculate the properties of microwave filter and select the display windows of simulated results. The simulation program is possible to analyses, design the waveguide filter, and visualize the distribution of 2.5D electric fields and current distribution.



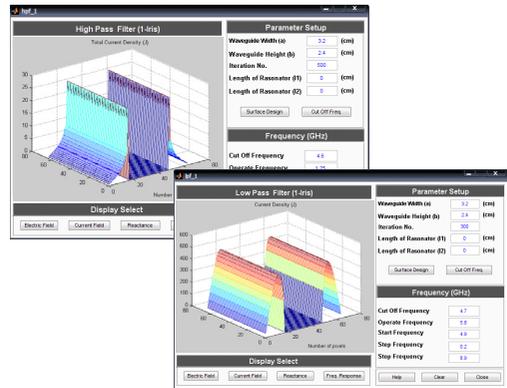
(a) Main Window



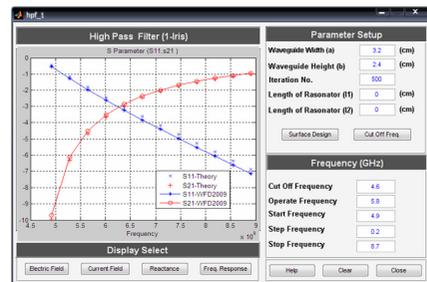
(b) Parameter Setup Windows



(c) Design Window



(d) Electromagnetic Field Display



(E) Frequency Response Display

Figure 4 Waveguide Filter Design (WFD) Tool

4. Results and Discussion

In this paper, we present a simple band pass filter of the rectangular obstacle in the waveguide by using WFD program. Finally, the environments of simulation tool are evaluated from educational viewpoint.

A. Band Pass Filter Simulation

To verify the developed WFD program, the simple example of filter circuit was presented. The dimensions of the rectangular waveguide consist of the width (a) equal 3.2 cm., the height (b) equal 2.4 cm. and the length of waveguide equal 8 cm. The width of iris window equal 1.6 cm. as displayed in figure 5. The equivalent circuit consists of the capacitor and inductor in parallel circuit.

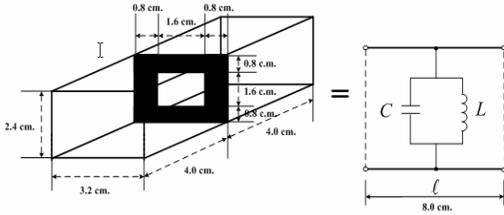


Figure 5 Band Pass Filter Circuit

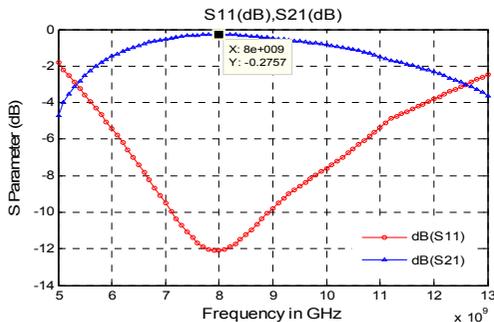
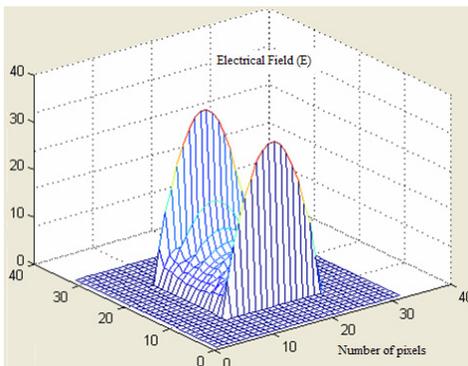
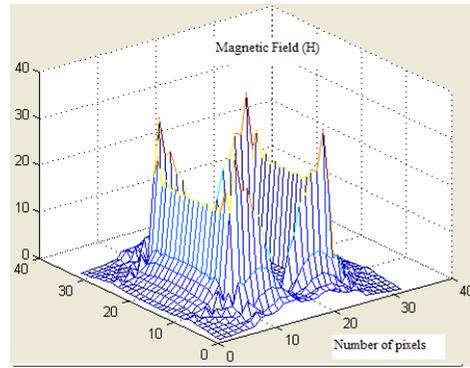


Figure 6 dB(S11) and dB(S21) of band pass filter

The simulated result in the figure 6 shows the dB(S11) and dB(S21) response of band pass filter circuit for 5-13 GHz of operating frequency. The lower and upper -3 dB cutoff frequency is 5.4 GHz and 12.5 GHz respectively. Figure 7 shows the 2.5D electric field and current distribution on the iris circuit which are agreements with electromagnetic field theory. The field distribution can be used efficiently to learn qualitatively about the iris's operating behavior for waveguide filter design.



(a) Electric field



(b) Current distribution

Figure 7 Electromagnetic field illustration

B. Evaluation of Program

The evaluated result of usage of WFD program for ten experts who are researchers and educators shows that: 1) appropriation of program structures is at very high level ($\bar{x} = 4.60$); 2) appropriation of content and user manual is at high level ($\bar{x} = 4.40$); and 3) appropriation of usage of program and applications is at very high level ($\bar{x} = 4.52$). The total average appropriation of the WFD program is at very high level ($\bar{x} = 4.51$) as shown in table 1. In conclusion, the developed WFD program is a good simulation tool which can be used in the teaching with efficiency.

Table 1 Result of evaluation by 10 experts

No.	Opinion	\bar{X}	S.D.	Level
1.	Appropriation of program structures	4.60	0.51	very high
2.	Appropriation of content and user manual	4.40	0.53	high
3.	Appropriation of usage of program and applications	4.52	0.55	very high
Average		4.51	-	very high



Figure 8 Evaluation of WFD program.

Figure 8 shows the sampling group to find out the student satisfaction after using the developed WFD program. The student satisfaction is at high level in the most convenient user-friendly interface.

5. Conclusions

This paper has presented the Waveguide Filter Design (WFD) tool for microwave engineering education by using Wave Iterative Method (WIM). The proposed approach based on the wave concept can be used the design and illustration of the properties of an iris circuit in the waveguide by monitoring the 2.5D electromagnetic wave. The benefits of this research can be used in the teaching that the learners can understand the calculating behavior of microwave circuits.

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