Application of MRTD on Novel Ultra-wideband Bandpass Filter

*Mu-Jie FAN

Changchun Normal University, China

fanmujie@126.com

*Corresponding author

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Abstract. A novel compact asymmetrical coplanar waveguide (ACPW)-fed ultra-wideband (UWB) bandpass filter is proposed in this paper, and the application of multiresolution time-domain (MRTD) formulation technique to the modeling of UWB ACPW filter is facilitated. The numerical and measured results demonstrate the advantages of MRTD over conventional FDTD method with respect to memory and mesh requirements and execution time, the correctness and effectiveness of MRTD method are verified by the results.

Introduction

Since C. P. Wen advanced CPW, coplanar waveguides have predominantly been used in microwave and millimeter-wave integrated circuits, however, the overall layout of microwave devices is restricted because that the slot width of CPW must be same. The layout of microwave devices may be flexible with ACPW getting rid of the restriction. ACPW is a new type of transmission line compared to CPW, the gap width of ACPW between center and conduction band on both sides of the ground is different. CPW can be thought of as a special form of ACPW. It is more flexibility in connection with both ends of the device for ACPW because the two wide slots of ACPW can be different, and it is helpful to design circuit layout of irregular shape. At the same time, the better performance will be obtained easily because the degree of freedom of ACPW is better than CPW when microwave devices are optimized. The popular methods are used to compute ACPW such as mapping technique, FDTD method and wavelet method [1-4].

FDTD is a very effective method for solving electromagnetic problems. However, the mesh size must satisfy the stability conditions in order to avoid numerical dispersion. Computer memory and calculation time will be required when physical size to be computed is large. In recent years, the wavelet analysis methods used in the numerical calculation of the magnetic field obtained are developed quickly. In 1996, MRTD method was used to solve Maxwell equation by Krumpholz. The mesh space of MRTD method is similar with the traditional format of Yee-FDTD, not only good dispersion characteristics but also the calculation memory and computing speed is obtained. The mesh numbers needed by MRTD algorithm are less than that needed by traditional FDTD algorithm [5-7]. The numerical dispersion of the MRTD algorithm is smaller than that of the ordinary FDTD method compared with the traditional FDTD method.

The formula of MRTD algorithm and PML absorbing boundary condition are given by this paper, a novel structure filter based on asymmetric coplanar waveguide is presented and analyzed with MRTD method compared with traditional FDTD algorithm.

MRTD Method

According to Maxwell's equations:

$$\nabla \times \vec{H} = \varepsilon \frac{\partial \vec{E}}{\partial t} + \sigma_e \vec{E} \quad (1)$$

$$\nabla \times \vec{E} = -\mu \frac{\partial \vec{H}}{\partial t} - \sigma_m \vec{H} \quad (2)$$

The electric and magnetic fields are expanded using MRTD method as followed:

$${}_{k+1}E_{l+1/2,m,n}^{\phi x} = \frac{2\varepsilon - \sigma_e \Delta t}{2\varepsilon + \sigma_e \Delta t} {}_kE_{l+1/2,m,n}^{\phi x} + \frac{2\Delta t}{2\varepsilon + \sigma_e \Delta t} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l+1/2,m+i+1/2,n}^{\phi z}}{\Delta y} - \sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l+1/2,m,n+i+1/2}^{\phi y}}{\Delta z} \right) \quad (3)$$

$${}_{k+1}E_{l,m+1/2,n}^{\phi y} = \frac{2\varepsilon - \sigma_e \Delta t}{2\varepsilon + \sigma_e \Delta t} {}_kE_{l,m+1/2,n}^{\phi y} + \frac{2\Delta t}{2\varepsilon + \sigma_e \Delta t} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l,m+1/2,n+i+1/2}^{\phi x}}{\Delta z} - \sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l+i+1/2,m+1/2,n}^{\phi z}}{\Delta x} \right) \quad (4)$$

$${}_{k+1}E_{l,m,n+1/2}^{\phi z} = \frac{2\varepsilon - \sigma_e \Delta t}{2\varepsilon + \sigma_e \Delta t} {}_kE_{l,m,n+1/2}^{\phi z} + \frac{2\Delta t}{2\varepsilon + \sigma_e \Delta t} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l+i+1/2,m,n+1/2}^{\phi y}}{\Delta x} - \sum_{i=-L}^{L-1} a(i) \frac{{}_{k+1/2}H_{l,m+i+1/2,n+1/2}^{\phi x}}{\Delta y} \right) \quad (5)$$

$${}_{k+1/2}H_{l,m+1/2,n+1/2}^{\phi x} = \frac{2\mu - \Delta t \sigma_m}{2\mu + \Delta t \sigma_m} {}_{k-1/2}H_{l,m+1/2,n+1/2}^{\phi x} - \frac{2\Delta t}{2\mu + \Delta t \sigma_m} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l,m+i+1,n+1/2}^{\phi z}}{\Delta y} - \sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l,m+1/2,n+i+1}^{\phi y}}{\Delta z} \right) \quad (6)$$

$${}_{k+1/2}H_{l+1/2,m,n+1/2}^{\phi y} = \frac{2\mu - \Delta t \sigma_m}{2\mu + \Delta t \sigma_m} {}_{k-1/2}H_{l+1/2,m,n+1/2}^{\phi y} - \frac{2\Delta t}{2\mu + \Delta t \sigma_m} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l+1/2,m,n+i+1}^{\phi x}}{\Delta z} - \sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l+i+1,m,n+1/2}^{\phi z}}{\Delta x} \right) \quad (7)$$

$${}_{k+1/2}H_{l+1/2,m+1/2,n}^{\phi z} = \frac{2\mu - \Delta t \sigma_m}{2\mu + \Delta t \sigma_m} {}_{k-1/2}H_{l+1/2,m+1/2,n}^{\phi z} - \frac{2\Delta t}{2\mu + \Delta t \sigma_m} \left(\sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l+i+1,m+1/2,n}^{\phi y}}{\Delta x} - \sum_{i=-L}^{L-1} a(i) \frac{{}_kE_{l+1/2,m+i+1,n}^{\phi x}}{\Delta y} \right) \quad (8)$$

Absorbing Boundary Condition

The boundary is always open with calculation of electromagnetic radiation and scattering. the effective boundary conditions must be set in the truncation because electromagnetic field will occupy the infinite space. In this paper, the perfectly matched layer (PML) absorbing boundary condition is used. PML absorbing boundary condition was proposed by Berenger. The reflection wave is reduced when electric and magnetic field components are devised in absorb boundary region. Take and as an example, the component and the Maxwell equation is split into: $E_x = E_{xy} + E_{xz}$, difference equation with PML absorbing boundary condition is:

$${}_{k+1/2}E_{l+1/2,m,n}^{\phi xy} = \frac{2\varepsilon - \sigma_y \Delta t}{2\varepsilon + \sigma_y \Delta t} {}_kE_{l+1/2,m,n}^{\phi xy} + \frac{\Delta t}{2\varepsilon + \sigma_y \Delta t} \frac{\Delta t}{\varepsilon \Delta y} \sum_{i=-L}^{L-1} a(i) {}_kH_{l+1/2,m+i+1/2,n}^{\phi z} \quad (9)$$

$${}_{k+1/2}E_{l+1/2,m,n}^{\phi xz} = \frac{2\varepsilon - \sigma_z \Delta t}{2\varepsilon + \sigma_z \Delta t} {}_kE_{l+1/2,m,n}^{\phi xz} - \frac{\Delta t}{2\varepsilon + \sigma_z \Delta t} \frac{\Delta t}{\varepsilon \Delta z} \sum_{i=-L}^{L-1} a(i) {}_{k+1/2}H_{l+1/2,m,n+i+1/2}^{\phi y} \quad (10)$$

MRTD method is based on Daubechies functions wavelet. The conductivity distribution function

is $\sigma_i(r) = \int_{m-8}^{m+8} \sigma_{\max} (1 - \frac{r}{\delta})^2 \phi(r) dr$, δ is thickness of PML medium. The max conductivity distribution is $\sigma_{\max} = \frac{m+1}{150\pi\Delta\sqrt{\varepsilon_r}}$, and m is order of conductivity distribution. Outside medium is ideal conductor. Other electric and magnetic field component can be obtained by using similar method based on PML absorbing boundary condition.

Numerical Analysis

UWB components has been developt worldwide since FCC announced unlicensed UWB band for short-range communication, and the key components in the UWB communication system is the band pass filter[5-6]. A new type of ultra wide band ACPW bandpass filter is proposed in this paper.

The width of ACPW slot can be adjusted by fixing another slot width for better performance, the design parameters are optimized for the filter.

The MRTD algorithm and the PML boundary conditions are applied to the asymmetric ACPW and calculation of relevant parameters of coplanar waveguide filter to verify the correctness and superiority of the algorithm comparing with the traditional FDTD algorithm. The ACPW structure is shown in Fig.1, in which, for s_1 is 0.6mm, s_2 is 0.3mm, w is 0.4mm, and thickness of medium is H .

Fig. 1 Structure of ACPW

The characteristic impedance of ACPW were calculated by FDTD and ADI-MRTD, PML boundary is 4 layers, boundary wall is PEC boundary, the excitation source with pulse excitation as $\psi = \exp[-(n\Delta t - 200\Delta t)/(100\Delta t)]^2$, the computing parameters are shown in Tab. 1.

Tab. 1 Compute parameters

Method	mesh number	steps	computer time
MRTD	40*40*70	1200	13 [minutes]
FDTD	100*100*120	1200	6[minutes]

The number of computational grid can be reduced by increasing the mesh size, and computing memory and computing speed are obtained with MRTD method compared with FDTD method in the same conditions of calculation accuracy. A new structure of ACPW broadband filter as shown in Fig. 2, and the photo of filter is shown in Fig.3. The filter is calculated and analyzed in order to further validate the effectiveness of the MRTD and PML boundary conditions.

Fig. 2 Structure of ACPW filter

Fig. 3 Photo of Ultra-wideband ACPW filter

A slot line on both sides of the center of the conduction band width is different. In ACPW, the design of ultra wideband ACPW filter is obtained by adjusting the slot width. one side of the slot width is fixed while adjusting the other side slot width. The adjusting of S2 will affects the level of the two passband edge characteristics, and the width of S1 will affect the low frequency passband edge only. The specific dimensions of the optimized ultra wideband ACPW filter are shown as

follow: $w=1.23\text{mm}$, $g=0.4\text{mm}$, $w_1=1.7\text{mm}$, $L_1=5.7\text{mm}$, $w_2=2\text{mm}$, $w_1+g=3.8\text{mm}$, $L_2=6.8\text{mm}$, $w_3=1\text{mm}$, $L_3=1.8\text{mm}$, $s_0=0.1\text{mm}$, $s_1=0.3\text{mm}$, $s_2=0.6\text{mm}$. The filter structure shown in Fig.3.

Fig. 4 Calculation and test results

As shown in Fig. 4, deviation exists between measurement values and numerical values because the frequency is too high. However, the simulation results obtained by FDTD and MRTD are consistent, which further verify the effectiveness of the MRTD method.

Conclusions

The computing memory and time are significantly reduced with MRTD method comparing with traditional FDTD method by the calculation of ACPW. MRTD algorithm with PML boundary condition is effective to solve complex size model when electromagnetic fields are computed. MRTD method is proposed. The detailed illustration of MRTD method is given. A novel UWB band pass filter based on asymmetrical coplanar waveguide is analyzed with MRTD method. The correctness and effectiveness of MRTD method are verified by the results Compared with traditional FDTD method.

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