Three-Dimensional FDTD Simulation of Stacked Microstrip Patch Antenna

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Abstract Based on the Maxwell' s equation, the finite-difference time-domain method presented in this paper is efficient and accuracy for modeling and analyzing the micro-electro-mechanical systems multiplayer microstrip patch antenna studied by our lab. The antenna characteristic parameters are discussed by the result of simulation. It implements relatively compatible absorbing boundary conditions. Saving the computer memory and CPU time.

Key words micro-electro-mechanical systems; microstrip patch antenna; radio frequency; broadband; finite-difference time-domain method; absorbing boundary conditions

三维层叠微带天线的FDTD模拟

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【摘要】借助Maxwell方程组，将时域有限差分法应用于实验室研制的新型层叠式微机械微带贴片天线的建模和分析，并根据数值模拟结果讨论了天线的特性参数。根据实际情况，灵活地给出了各边界的近似吸收边界条件，有效地减少了存储空间和计算时间。

关 键 词 微光机电系统; 微带贴片天线; 射频; 宽带; 时域有限差分法; 吸收边界条件

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Antenna miniaturization is one of the key technologies in the miniaturized radio transceiver. Microstrip antenna has lighter weight, smaller size, lower manufacture cost than conventional antennas, but it has a distinct drawback of narrow bandwidth. Recently some technologies have developed to overcome this disadvantage. For a serial of salient features, the microstrip antennas are used widely in the communication and other applications.

Micro-electro-mechanical system (MEMS) technology used in antenna and other radio frequency (RF) devices, is a novel technology. It can downsize communication systems drastically, improve their reliability and efficient, and extend lives. Finite-difference time-domain (FDTD) method associated with Fourier transition is an excellent analysis tool for parameters of the MEMS microstrip patch antenna.

This paper has presented a miniaturized broadband microstrip patch antenna, and FDTD method was utilized to analyze and simulate it. Associated with practical model, a kind of approximate absorbing boundary condition

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(ABC) was developed, then the practical microstrip patch antenna was precisely simulated. During the quantitatively analysis procedure of the antenna, optimized methods have been taken to save memory space, accelerate speed and improve precision of computation.

1 Three-Dimensional FDTD Algorithm

1.1 Stacked Microstrip Patch Antenna

The 1 900 MHz stacked microstrip patch antenna studied by our project group is shown in Fig.1. Because silicon-based micromaching process is compatible with standard IC technology, and prone to integration with other components, silicon wafer (e_r =11.7) was selected as a layer of microstrip substrate. Between the ground plate and the wafer, there is a layer of air which could suppress surface wave, as a result, the efficiency and the bandwidth of the antenna were increased. A layer of TEFLON (e_r =2.3) was sandwiched between the driven and parasitic patch. By adopting stacked structure and adding passive parasitic patch, the bandwidth of the microstrip was efficiently broadened, while by setting a short wall at one end of the patch, the antenna was greatly miniaturized.

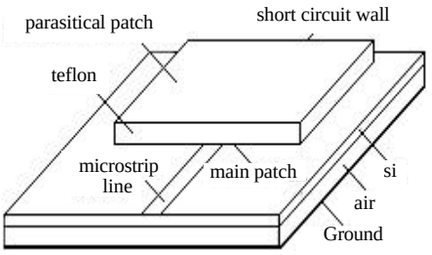

Fig.1　Stacked microstrip patch antenna

1.2 FDTD Equations

The Maxwell equations are the basic laws of the electromagnetic field. K. S. Yee used discretization in time and space to calculate Maxwell' s curl equations directly in the time domain, corresponding FDTD equations are[1]

$$E_x^{n+1}(i,j,k)=E_x^n(i,j,k)+\frac{\Delta t}{e}\times \left[\frac{H_z^{n+1/2}(i,j,k)-H_z^{n+1/2}(i,j-1,k)}{\Delta y}-\frac{H_y^{n+1/2}(i,j,k)-H_y^{n+1/2}(i,j,k-1)}{\Delta z}\right] \tag{1}$$

$$H_x^{n+1/2}(i,j,k)=H_x^{n-1/2}(i,j,k)-\frac{\Delta t}{m}\times \left[\frac{E_z^n(i,j+1,k)-E_z^n(i,j,k)}{\Delta y}-\frac{E_y^n(i,j,k+1)-E_y^n(i,j,k)}{\Delta z}\right] \tag{2}$$

The other electric field and magnetic filed components can be obtained in a similar way.

1.3 Stability Condition

It is very important to avoid numerical instabilities in the FDTD algorithm, the culture has given the stability condition as following[2]

$$V_{\max}\Delta t=\left[\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}+\frac{1}{\Delta z^2}\right]^{-1/2} \tag{3}$$

where　$V_{\max}$ is the maximal phase velocity in the concerned volume.

1.4 Setting of Absorbing Boundary Conditions and Excitation

The field computation domain must be limited in size because the computer can not store an unlimited amount of data. Several absorbing boundary conditions (ABCs) are developed nowadays. Mur ABCs and superabsorption are used in this paper respectively[3].

For different reflection characterization manifested along whose direction the electromagnetic wave propagated. Now we will discuss which ABCs should be selected for top, side, front and rear surface individually.

In the rear surface (k=G), the first order Mur ABCs are set. Electromagnetic waves are propagated along +z

direction, the electronic field component (E_y=E_z=0) satisfies the one-way wave equation

$$\left(\frac{\partial}{\partial z}-\frac{1}{v}\frac{\partial}{\partial t}\right)E_x=0 \tag{4}$$

its finite difference form is

$$E_x^{n+1}(i,j,k)=E_x^n(i,j,G-1)+\frac{v\Delta t-\Delta z}{v\Delta t+\Delta z}[E_x^{n+1}(i,j,G-1)-E_x^n(i,j,G)] \tag{5}$$

where v is the phase velocity of electromagnetic wave at the boundary surface. The setting of the other surface are similar to that of the rear surface.

In microwave circuit analysis, Gauss impulse is generally selected as an excitation for smoothness in time domain adopting the setting in[4], the E_x component beneath the microstrip transmission line is

$$E_x(t)=\exp\left[-\frac{(t-t_0)^2}{T^2}\right] \tag{6}$$

where $T=40\Delta t$, $t_0=110\Delta t$; the width is $20\Delta z$, its spectrum ranges from 0～14.1 GHz.

1.5 The Approach of Computation Time

Setting a magnetic wall in the antenna axial symmetry plane, so only a half of grids is included, and it could save memory space and computation time. Let $\Delta x=\Delta y$=0.5 mm, Δz=1.5 mm, only the right half of the antenna is concerned, the computation volume are $20\Delta x\times 30\Delta y\times 40\Delta z$, and the patch $15\Delta y\times 18\Delta z$, the microstrip transmission line $2\Delta y\times 20\Delta z$. The thicknesses of the layers of air, silicon and TEFLON are $3\Delta x$, Δx and $4\Delta x$ respectively. Let time step

$$\Delta t=\frac{0.5\Delta x}{c}=\frac{0.5\times 10^{-3}}{2\times 3\times 10^{8}}=0.833\times 10^{-12} \tag{7}$$

For the sake of saving memory space and computation time, we adopt the space step of Δz more 2 times than Δx or Δy.

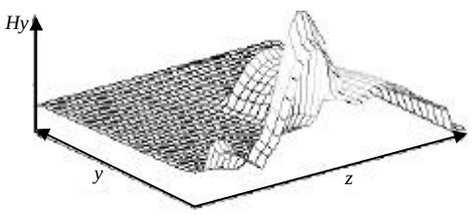

Fig.2 Magnetic field propagation and reflection with source plane several nodesinto the mesh

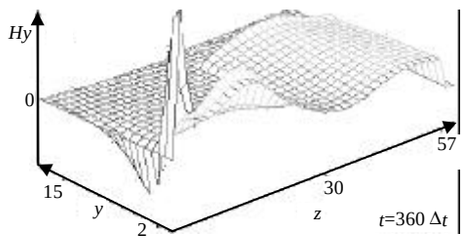

Fig.3 Magnetic field propagation and reflection with source plane several nodes into the mesh

2 Analysis of the Antenna Characterization

The calculated central resonant frequency of the antenna is near 1.9 GHz, and agrees well with the measured data. The fact that the length of the novel antenna patch is only quarter that of a conventional counterpart has proved that it could downsize microstrip antenna to set shorting wall at one edge of a 1/8 wavelength antenna patch. By using stacked structure, the relative bandwidth of the antenna is approximately 12%, while that of a conventional microstrip antenna is only 0.6%～3%.

The computed electric field E_x and H_y at a certain moment are shown in fig.2 and fig.3. It is shown that electromagnetic wave is mainly centralized beneath the microstrip transmission line and patch, and propagates along +z direction. The characteristic parameters such as effective dielectric constant, the characteristic impedance in spectrum domain could be worked out by Fourier transition[5]. In principle the characteristic impedance should be independent of z. But reflect wave exists in the system due to imperfect ABCs, there are fluctuations of the computed characteristic impedances in the z direction. The calculated characteristic impedance $Z_0(w)=47.6\,\Omega$ is

in conformity with the measured result on the whole. The circle wave loss of antenna measured and computed are shown in Fig.4.

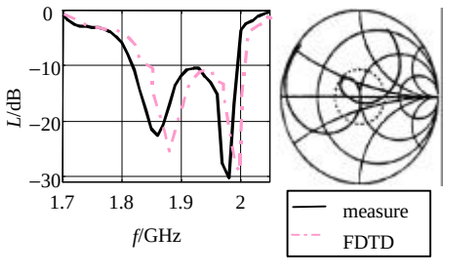

Fig.4　The circle wave loss of antenna

3　Conclusion

A novel MEMS stacked microstrip antenna has been presented in this paper, it performs excellently especially in miniaturization and bandwidth broadening.

FDTD method was used to model the structure of the antenna and a practical economical ABC has been described. Components of electric and magnetic fields in time domain have been computed and then the propagation of the electromagnetic wave was visualized by drawings. By Fourier transition, parameters in spectrum domain could be figured out. The fact that there is a good agreement between the computed values and the measured results have proven that the FDTD associated with Fourier transition is a good instrumentality to analyze microstrip antennas.

参　考　文　献

[1] Yee K S. Numerical solution of initial boundary value problems involving Maxwell' s equations in isotropic media[J]. IEEE AP, 1996, 14(5): 302-307

[2] Taflove A, Brodwin M E. Numerical solution of steady state electromagnetic scattering problem using the time dependent Maxwell' s equations[J]. IEEE Trans. MTT, 1975, 23(8): 623-630

[3] Mur G. Absorbing boundary conditions for the finite difference approximation of the time domain electromagnetic field equations[J]. IEEE Trans. EMC, 1981, 23(4): 1 073-1 077

[4] Zhao A P, Raisanen A V, Cvetkovic S R. A fast and efficient FDTD algorithm for the analysis of planar microstrip discontinuities by using a simple source excitation scheme[J]. IEEE Microwave and Guided Wave Lett, 1995, 5(10): 341-343

[5] Zhang X, Mei K K. Time-domain finite-difference approach to the calculation of frequency dependent characteristics of microstrip discontinuities[J]. IEEE Trans. MTT, 1988, 36(12): 1 775-1 783

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