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Multilayer Microstrip Equivalent Antenna Analysis using Finite Difference Time Domain Method

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***Abstract:*-Microstrip equivalent antenna used in radio communication is presented. Finite difference time domain (FDTD) method is used for analyzing microstrip antenna which is based on multilayer multipermittivity dielectric substrate. FDTD method is used for modifying equivalent iterative formula in the condition of cylindrical coordinate system. The mixed substrate which consists two kinds of media (one of them is air) takes the place of original single substrate. The results ofmicrostrip equivalent antenna simulation show that the resonant frequency of equivalent antenna is similar to that of the prototype original antenna. The validity of analysis can be validated by means of antenna resonant frequency formula. The radiation pattern of two antennas show that same radiation pattern and gain. This method can be used to reduce the weight and increase the efficiency of compact antenna, which is significant to the design of missile-borne antenna in military applications.**

Keywords-Microstrip antenna; FDTD; multilayer; military applications.

I. INTRODUCTION

In recent years, antenna has been important module for military antennas [1,7]. Particularly for missile-borne antenna which required to be small in size and light in weight. The microstripantenna [2] has many advantages, such as, small size ,light weight and planar structure. Many work has been doneon its miniaturization [3,4].But few research concentrated on decreasing the weight of antenna and leaving its basic parameters unchanged under the conditions of same size and thickness.

In this work, another model design is proposed. The aims of this work are: a) to conserve the shape of antenna; b) to conservethe of antenna electromagnetic parameters; and c) to decrease the weight of antenna. For this, a substrate with low permittivity and high dielectric permittivity media is taken the place of the original substrate, in which air is used as a lower dielectric permittivity media (high dielectric permittivity media can be any mediaas its dielectric permittivity is higher than original media). The introduction of the air media can effectively decrease the weight of antenna in proposed model. The analysis of equivalent antenna is based on FDTD.

II. EQUIVALENT ANTEENA STRUCTURE AND FDTD ANALYSIS

In1966, K.S. Yee introduced the theory of FDTD [5].FDTD is a novel method which can be used to intuitively and succinctly explain the Maxwell's equations. In this method, the electric field and magnetic field are included in a three-dimensionalModel (Yee cell). This model is used for solving all the problem of electromagnetic field. A circular antenna is easily integrated into a warhead of bomb compared to rectangle antenna. So the formulae in References [6,7]should be amended in the cylindrical coordinatesystem (see Fig. 1).

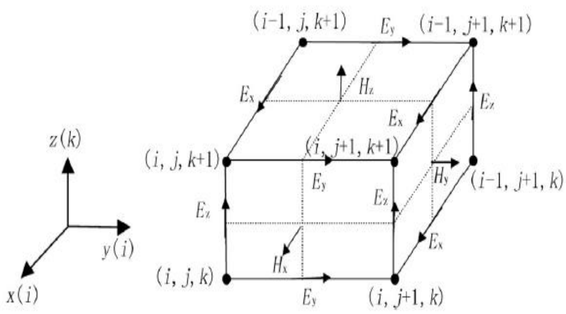

Fig. 1. Yee cell.

$$E_r^{n+1}\left(i+\tfrac{1}{2},j,k\right)=\frac{2\varepsilon-\sigma\Delta t}{2\varepsilon+\sigma\Delta t}E_r^{n}\left(i+\tfrac{1}{2},j,k\right)$$

$$+\frac{2\Delta t}{2\varepsilon+\sigma\Delta t}\times\left[\frac{H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right)-H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j-\frac{1}{2},k\right)}{\left(i+\frac{1}{2}\right)\Delta r\Delta\varphi}-\frac{H_\varphi^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)-H_\varphi^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k-\frac{1}{2}\right)}{\Delta z}\right]\ldots(1)$$

$$H_r^{n+\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)=\frac{2\mu-\sigma\Delta t}{2\mu+\sigma\Delta t}H_r^{n-\frac{1}{2}}\left(i,j+\frac{1}{2},k+\frac{1}{2}\right)-\frac{2\Delta t}{2\mu+\sigma\Delta t}\left[\frac{E_z^n\left(i,j+1,k+\frac{1}{2}\right)-E_z^n\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)}{\Delta r\Delta\varphi}-\frac{E_{\varphi}^n\left(i,j+\frac{1}{2},k+1\right)-E_{\varphi}^n\left(i,j+\frac{1}{2},k\right)}{\Delta z}\right]\ldots(2)$$

Equations(1) and (2) are electric and magnetic fields equation for Yee cell.

Two medium exist in Yee grid (the permittivity's are ε_{r1}; ε_{r2}).From Ampere circuital theorem, we have,

$$\oint H^{*}\,dl=\iint\varepsilon\frac{\partial E}{\partial t}ds+Eds\ldots(3)$$

Assuming that the magnetic conductivities of two dielectric media are the same. It can be known from the boundary condition of electromagnetic field that the normal component of magnetic field on the Interface between the two media is continuous, in cylindrical coordinate system [8]; Equation (3) could be rewritten as

$$\oint \mathrm{H}^{*}\mathrm{dl}=\mathrm{H}_{\mathrm{r}}^{\mathrm{n}+0.5}(\mathrm{i},\mathrm{j}+0.5,\mathrm{k})\mathrm{r}\Delta-\mathrm{H}_{\varphi}^{\mathrm{n}+0.5}(\mathrm{i},\mathrm{j}+0.5,\mathrm{k})\Delta\mathrm{r}-\mathrm{H}_{\mathrm{r}}^{\mathrm{n}+0.5}(\mathrm{i},\mathrm{j}-0.5,\mathrm{k})\mathrm{r}\Delta\theta+\mathrm{H}_{\varphi}^{\mathrm{n}+0.5}(\mathrm{i},\mathrm{j}+0.5,\mathrm{k})\Delta\ldots(4)$$

In FDTD iteration,

$$E_r^{n+\frac{1}{2}}(i,j,k)=\frac{1}{2}[E_r^{n+1}(i,j,k)+E_r^{n}(i,j,k)]\ldots(5)$$

The right hand side equation (5) can be extended to

$$\iint\varepsilon\frac{\partial E}{\partial t}ds=\sum_{i=1}^{m}\sum_{j=1}^{n}\iint_{ij}\varepsilon_{ij}\frac{\partial E}{\partial t}ds_{ij}=\frac{E_r^{n+1}(i,j,k)-E_{r(i,j,k)}^{n}}{\Delta t}\times[\varepsilon_{11}r_1\Delta_{r1}\Delta_{\theta1}+\varepsilon_{12}r_1\Delta_{r1}\Delta_{\theta2\ldots\ldots}+\varepsilon_{mn}r_m\Delta_{rm}\Delta_{\theta n}]\ldots(6)$$

$$\iint\sigma Eds=\sum_{i=1}^{m}\sum_{j=1}^{n}\iint_{ij}\sigma_{ij}Eds_{ij}=\frac{E_r^{n+1}(i,j,k)-E_{r(i,j,k)}^{n}}{2}\times\sigma_{11}r_{11}\Delta_{r1}\Delta_{\theta1}+[\sigma_{12}r_1\Delta_{r1}\Delta_{\theta2}\ldots+\sigma_{mn}r_m\Delta_{rm}\Delta_{rn}\Delta_{\theta n}]\ldots(7)$$

Substituting equations (4), (6) and (7) into Eq. (3), we have,

$$E_r^{n+1}\left(i+\frac{1}{2},j,k\right)=\frac{2\varepsilon_{eff}-\sigma_{eff}\Delta t}{2\varepsilon_{eff}+\sigma_{eff}\Delta t}E_r^{n}\left(i+\frac{1}{2},j,k\right)+\frac{2\Delta t}{2\varepsilon_{eff}+\sigma_{eff}\Delta t}\left[\frac{H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j+\frac{1}{2},k\right)-H_z^{n+\frac{1}{2}}\left(i+\frac{1}{2},j-\frac{1}{2},k\right)}{\left(i+\frac{1}{2}\right)\Delta r\Delta\varphi}-\frac{H_{\varphi}^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k+\frac{1}{2}\right)-H_{\varphi}^{n+\frac{1}{2}}\left(i+\frac{1}{2},j,k-\frac{1}{2}\right)}{\Delta z}\right])\ldots(8)$$

After the simplification, the equivalent permittivity can be obtained

$$\varepsilon_{eff}=\frac{\varepsilon_{11}r_1\Delta_{r1}\Delta_{\varphi1+}\varepsilon_{12}r_1\Delta_{r1}\Delta_{\varphi2}\ldots+\varepsilon_{mn}r_m\Delta_{rm}\Delta_{\varphi n}}{rdrd\varphi}\ldots(9)$$

Through the analysis mentioned above, the structure of antenna substrate can be designed, as shown in Fig. 2.

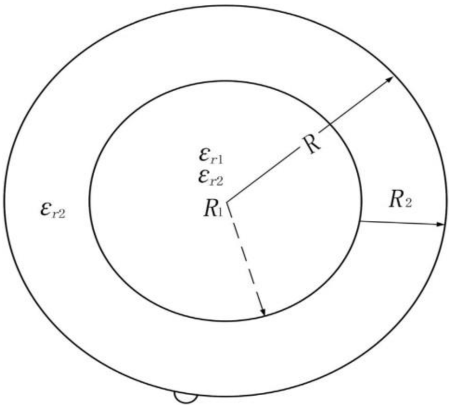

Fig. 2. Structure of substrate.

III. DISCUSSION OF SIMULATION

Through the above analysis, FR4 substrate is chosen for original substrate. The basic parameters of antenna are ε_r= 4:4, R =14 mm, h =2 mm, r= 12 mm. Equation (10) shows the relationship between two medium.Fig.3 shows the prototype antenna design. Table 1 lists the parameters of equivalent antennas.

$$\varepsilon_{r1}R_1^2+\varepsilon_{r2}R_2^2=\varepsilon_rR^2$$

$$R_{1+}R_{2=}\mathrm{R}\qquad\ldots(10)$$

	ε_{r1}	ε_{r2}	R_1	R_2
A	12.8	1	8.56	6.42
B	9.7	1	9.8	5.0

TABLE 1: PARAMETERS OF EQUIVALENT ANTENNAS

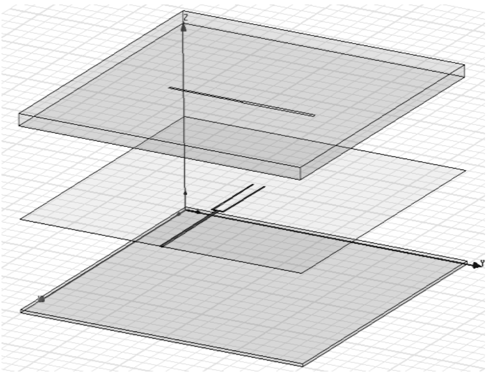

Fig .3.Prototype antenna design

Fig. 4 shows that the resonant frequency of original antenna is 3.2 GHz, and the resonant frequencies of the equivalent antennas A and B are also remain unchanged. It can be concluded from the resonant frequency formula that the permittivity is the only factor which has effect on resonant frequency when the radius of radiation patch and the working mode remain the same. So two media can be treated as a singlemedium which has a same permittivity as that of original medium. The results prove the accuracy of FDTD analysis. Because the position of feed point was not changed in simulation, the S11 parameters of the equivalent antenna deteriorated compared to the original antenna. So the equivalent antenna is not exactly equal to the original antenna.

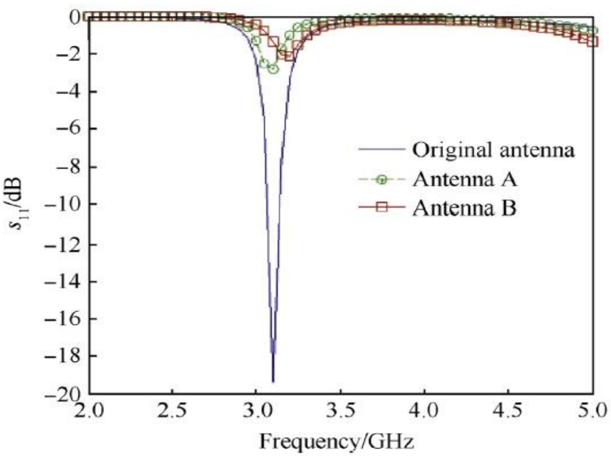

Fig. 4.Resonant frequencies of three antennas.

The parameters can be improved by changing the position of feed point. Fig. 5 shows the S11 parameters after changing the position of feed point.

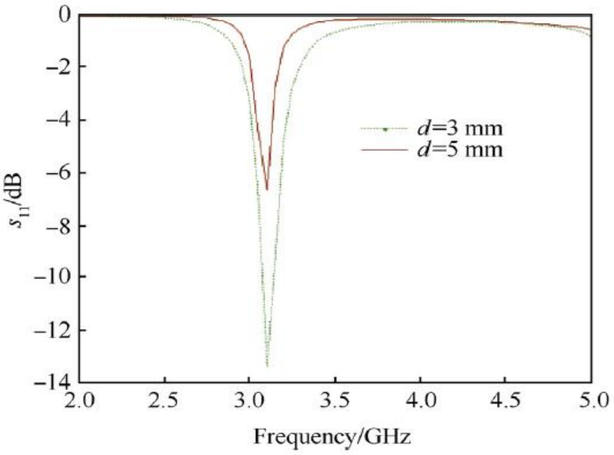

Fig. 5.S11 with different feed feint.

Fig. 6 and 7 show the radiation patterns of equivalent antenna and original antenna. It can be seen from Fig. 6 and 7 that the direction and co polarization of equivalent antenna are similar to those of the original one. This shows that the equivalent antenna can replace the original antenna.

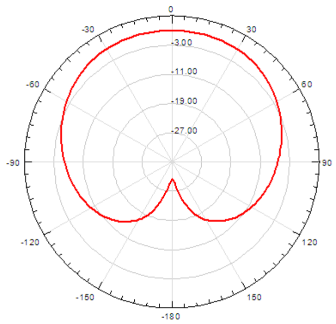

Fig. 6. Original radiation pattern.

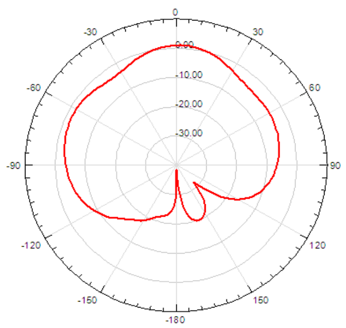

Fig. 7.Equivalent radiation pattern.

IV. CONCLUSION

A method for decreasing the weight of antenna was proposed in the paper. By means of analysis based on FDTD, air medium and a higher permittivity medium are introduced to take the place of original substrate. The simulation results show that resonant frequency, radiation pattern and gain of equivalent antenna did not change. The air media can be used to reduce the weight of antenna.

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