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# Reflection Coefficient for Electromagnetic Wave Propagation through the Plasma Generated Nearby the Metal Surface

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**Abstract** We suggest the model to determinate reflection coefficient for electromagnetic wave propagate by using the plasma generated nearby the metal surface. We calculate the coefficient with varying the frequency till 50GHz, incident angle is 30, 60°, and compared with the precedence results[1－6].

**Key words** electromagnetic wave, reflection coefficient.

## Introduction

The great leader Comrade **Kim Il Sung** said as follows.

**"Research work for introducing atomic energy into production should be carried out under a far-reaching programme. Radioisotopes and radiation should be widely applied in various fields, including industry and agriculture."**("**KIM IL SUNG** WORKS" Vol. 15 P. 197)

The problem of conclusion for propagating electromagnetic wave's reflection coefficient by the low-temperature plasma is important task in consideration of the reflection and absorption at the atmosphere plasma.

There are many experimental methods to conclusion of reflection coefficients with the density of plasma. We divided the plasma slab into number of sub plasma slabs and found total reflection coefficient by reflection coefficient in each slabs.

## 1. A Method of Reflection Coefficient Conclusion

To determinate reflection coefficient for electromagnetic wave propagate through the plasma generated nearby the metal surface; we divided the plasma slab into $n$ layers. In each layers, the electron number densities are assumed constant. The external magnetic field is parallel to the $z$-axis, the polarization direction of E is vertical to the $xoy$ plane[4].

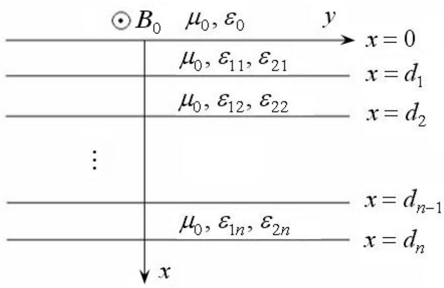


Fig. 1. Divided plasma layer

As shown in Fig. 1, the magnetized plasma slab is divided. The element of the permittivity tensor in the $l^{\text{th}}$ layer are noted as $\varepsilon_{1l}$, $\varepsilon_{2l}$ as Fig. 1.

In the $l^{\text{th}}$ layer, the total magnetic field is the sum of the reflected and incident components[1].

$$H_{lz} = (A_l e^{ik_{lx}x} + B_l e^{-ik_{lx}x}) e^{ik_y y} \tag{1}$$

Substituting of (1) into $\nabla \times \boldsymbol{H}_l = i\omega\varepsilon_0\varepsilon_{rl} \cdot \boldsymbol{E}_l$, we can get the total electric field in $l^{\text{th}}$ layer.

$$E_{lx}=\frac{1}{i\omega\varepsilon_0(\varepsilon_{1l}^2-\varepsilon_{2l}^2)}[(i\varepsilon_{1l}k_y-\varepsilon_{2l}k_{lx})A_l e^{ik_{lx}x}+(i\varepsilon_{1l}k_y+\varepsilon_{2l}k_{lx})B_l e^{-ik_{lx}x}]e^{ik_y y} \tag{2}$$

$$E_{ly}=\frac{1}{i\omega\varepsilon_0(\varepsilon_{1l}^2-\varepsilon_{2l}^2)}[(-\varepsilon_{21}k_y-i\varepsilon_{1l}k_{lx})A_l e^{ik_{lx}x}+(-\varepsilon_{2l}k_y+i\varepsilon_{1l}k_{lx})B_l e^{-ik_{lx}x}]e^{ik_y y} \tag{3}$$

where $k_y$ and $k_{lx}$ have the following relationship: $k_y^2+k_{lx}^2=\omega^2\mu_0\varepsilon_0\left(\varepsilon_{1l}-\frac{\varepsilon_{2l}^2}{\varepsilon_{1l}}\right)$, $k_y=\omega\sqrt{\mu_0\varepsilon_0}\sin\theta$ ($\theta$ incident angle of electromagnetic wave).

At $x=d_l$ to match boundary condition, the following equations are obtained:

$$a_l A_l e^{ik_{lx}d_l}+b_l B_l e^{-ik_{lx}d_l}=a_{l+1}A_{l+1}e^{ik_{(l+1)x}d_l}+b_{l+1}B_{l+1}e^{-ik_{(l+1)x}d_l} \tag{4}$$

$$A_l e^{ik_{lx}d_l}+B_l e^{-ik_{lx}d_l}=A_{l+1}e^{ik_{(l+1)x}d_l}+B_{l+1}e^{-ik_{(l+1)x}d_l} \tag{5}$$

$$a_l=\frac{-\varepsilon_{21}k_y-i\varepsilon_{1l}k_{lx}}{\varepsilon_{1l}^2-\varepsilon_{2l}^2},\ b_l=\frac{-\varepsilon_{21}k_y+i\varepsilon_{1l}k_{lx}}{\varepsilon_{1l}^2-\varepsilon_{2l}^2} \tag{6}$$

solving (4) and (5), we can get

$$A_l e^{ik_{lx}d_l}=\frac{1}{a_l-b_l}[(a_{l+1}-b_l)A_{l+1}e^{ik_{(l+1)x}d_l}+(b_{l+1}-b_l)B_{l+1}e^{-ik_{(l+1)x}d_l}] \tag{7}$$

$$B_l e^{-ik_{lx}d_l}=\frac{1}{a_l-b_l}[(a_l-a_{l+1})A_{l+1}e^{ik_{(l+1)x}d_l}+(a_l-b_{l+1})B_{l+1}e^{-ik_{(l+1)x}d_l}]. \tag{8}$$

To ratio of (7) to (8) can be expressed as:

$$\frac{A_l}{B_l}=\frac{a_{l+1}-b_l}{a_l-a_{l+1}}e^{-i2k_{lx}d_l}+\frac{\dfrac{b_{l+1}-b_l}{a_l-a_{l+1}}-\dfrac{(a_{l+1}-b_l)(a_l-b_{l+1})}{(a_l-a_{l+1})^2}}{\dfrac{a_l-b_{l+1}}{a_l-a_{l+1}}e^{-i2k_{(l+1)x}d_l}+\dfrac{A_{l+1}}{B_{l+1}}}e^{-i2(k_{(l+1)x}+k_{lx})d_l} \tag{9}$$

Now, we can see that $A_l/B_l$ has the recursive relation with $A_{l+1}/B_{l+1}$. Besides, for the region $n$+1. which is metal, we have $A_{n+1}/B_{n+1}=0$, $a_l=0$, $b_l=0$. For region $l$= 0, which is free space, we have $a_0=-ik_{0x}$, $b_0=ik_{0x}$.

Total reflection coefficient is as follows.

$$R=\frac{|E_R|^2}{|E_I|^2}=\sum_{l=i}^{n}\left(\frac{A_l}{B_l}\right)^2 \tag{10}$$

In this paper, we have made a algorithm to solve this problem that is same as Fig. 2.

We set the parameters, plasma maximum density $N_e=10^{-12}\text{cm}^3$, collision frequency $\nu=10\text{GHz}$ and then calculated reflection coefficient changing the frequency and incident angle of electromagnetic wave.

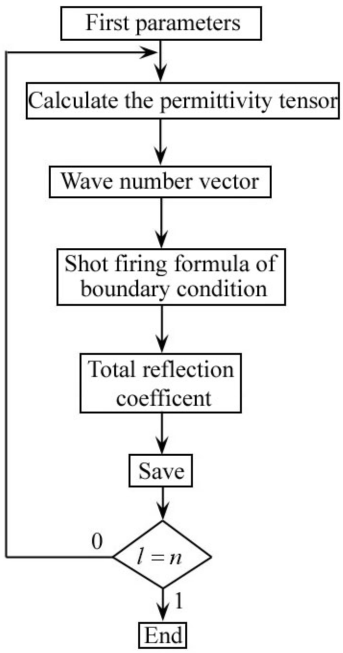


Fig. 2. Simulation algorithm

## 2. Simulation Results and Analysis

To check the above model, we calculate the reflection coefficient of a 10cm plasma slab excited by a vertical incident plane wave and compare with the result in [6].

As the frequency changes, the reflection coefficient is shown in Fig. 3.

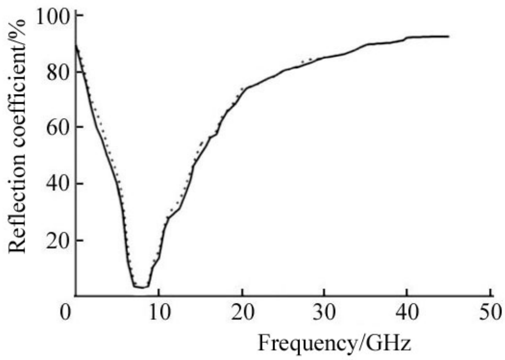


Fig. 3. Results of reflection coefficient with increase frequency
Full line－simulation line, dotted line— experimental line[6]

And then compared results when incident angles are 30, 60°[6].

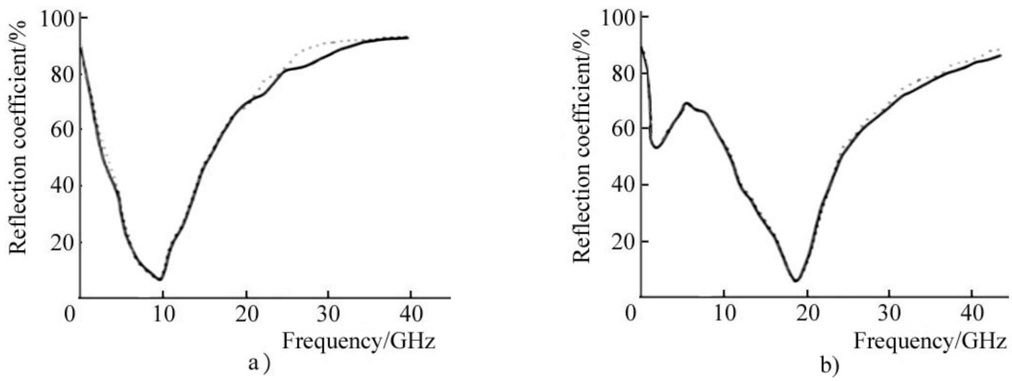


Fig. 4. Results of reflection coefficient with increase frequency
a) 30°, b) 60°, Full line－simulation line, dotted line— experimental line

In Fig. 3, 4, we can see the simulation results are well identical with the precedence experimental results.

## Conclusion

In this paper, we suggest the model to calculate the reflection coefficient when electromagnetic wave through the plasma nearby the metal surface.

We calculate the coefficient with vary the frequency till 50GHz, incident angle is 90° and then 30, 60°. Thus our model is corrected by experimental results.

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