A New Method to Mitigate Communication Blackout Based on Sandwich Structure

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***Abstract*—It is called communication blackout when the communications between vehicle and ground have been breaking down. The blackout occurs while the plasma frequency of plasma layer is higher than a radio wave frequency. It has greater transmission coefficient in window frequency when the electromagnetic wave propagates in the sandwich structure compared with the media-plasma structure. So a sandwich structure of plasma-media-plasma is proposed to mitigate communication blackout in this paper. The theory of electromagnetic wave propagation in layered-homogeneous media is applied to study the method systematically in the paper. Media thickness and internal plasma thickness which have an effect on propagation coefficients in window frequency are discussed in detail. A horn antenna and sandwich structure are simulated to verify the method.**

Keywords—blackout mitigation; sandwich structure; transmission coefficient; reflection coefficient

I. INTRODUCTION

The high temperature gas around the aircraft will ionize to form a plasma when it is flying in the atmosphere at hypersonic speed. The electromagnetic wave will be reflected and attenuated, which will lead to the interruption of electromagnetic wave propagation, when the electromagnetic wave travels through the plasma. In this case, the communication between the aircraft and the ground will be seriously affected, even lead to the interruption of the communication between aircraft and ground. The phenomenon is called communication blackout. The problem has attracted the attention of many people at home and abroad. Many methods have been proposed to mitigate the communication blackout, such as changing the aircraft aerodynamic shape, spraying electrophilic materials, and the adoption of magnetic window. But these methods have all kinds of limitations. They can't be used effectively[1]-[2].

A sandwich structure of plasma-media-plasma is proposed to mitigate the blackout in this paper. It has greater transmission coefficient When electromagnetic wave propagates in the sandwich structure compared with the media-plasma structure in window frequency[5]-[6]. The method can increase the transmission coefficient by 3~10dB in window frequency. On otherwords it has smaller reflection coefficient in window frequency. The phenomenon can be a good method to mitigate communication blackout of aircraft. Uniform plasma was used to study the method.

II. BASIC THEORIES

A. Plasma electrical parameters

The complex permittivity of plasma generated by the interaction of the hypersonic vehicle and ambient air is frequency dependent and can be represented as follows[3]:

$$\varepsilon = (1-\frac{\omega_p^2}{\omega(\omega - j\nu)})\varepsilon_0 = (1-\frac{\omega_p^2}{\omega^2+\nu^2} + j\frac{\omega_p^2\nu/\omega}{\omega^2+\nu^2})\varepsilon_0 \quad (1)$$

where ε_0 is permittivity of vacuum , ω is the angular frequency of electromagnetic waves , ν is collision frequency and ω_p is plasma frequency given as follows:

$$\omega_p = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}} \approx 56.4\sqrt{n_e} \quad (2)$$

where n_e is electron density, m_e is electron mass, and e is electron charge.

B. Layered-homogeneous media model

A general inhomogeneous profile can be replaced by many fine layers of piecewise constant regions. The rule of thumb is then to segment the layers such that they are much thinner than the wavelength of the wave in the medium. The transmission and reflection coefficients of multlayer media is given in (3) and (4). The multlayer media model is shown in Fig.1[4].

$$\tilde{R}_{i,i+1} = R_{i,i+1} + \frac{T_{i,i+1}\tilde{R}_{i+1,i+2}T_{i+1,i}e^{2ik_{i+1\,z}(d_{i+1}-d_i)}}{1-R_{i+1,i}\tilde{R}_{i+1,i+2}e^{2ik_{i+1\,z}(d_{i+1}-d_i)}} \quad (3)$$

$$\tilde{T}_{1N} = \prod_{j=1}^{N-1} e^{ik_j(d_j-d_{j-1})}\frac{T_{j,j+1}}{1-R_{j+1,j}\tilde{R}_{j+1,j+2}e^{2ik_{j+1\,z}(d_{j+1}-d_j)}} \quad (4)$$

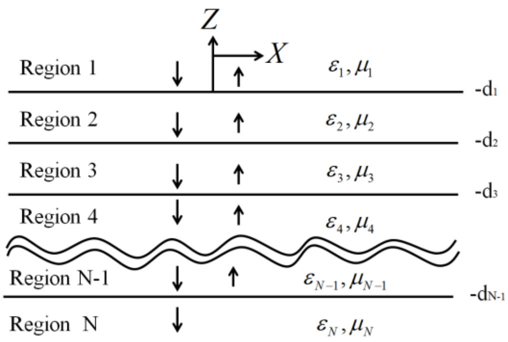


Fig. 1. Reflection and transmission in a multilayered medium

$\tilde{R}_{i,i+1}$ is the generalized reflection coefficient at the interface between i and $i+1$ layer. $\tilde{T}_{1N}$ is the generalized transmission coefficient from $1st$ to $N\text{-}th$ layer.

III. SIMULATION AND RESULTS

Electromagnetic simulation is applied to investigate the relationship between propagation coefficients and plasma parameters in sandwich structure.

A. Simulation model

Simulation model is shown in Fig.2. All the layers are infinite in horizontal direction. The plane wave is used to investigate the reflection and transmission coefficients of the structure. The propagation direction of plane waves is perpendicular to the plasma surface.

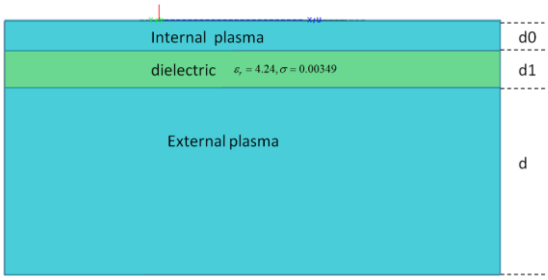
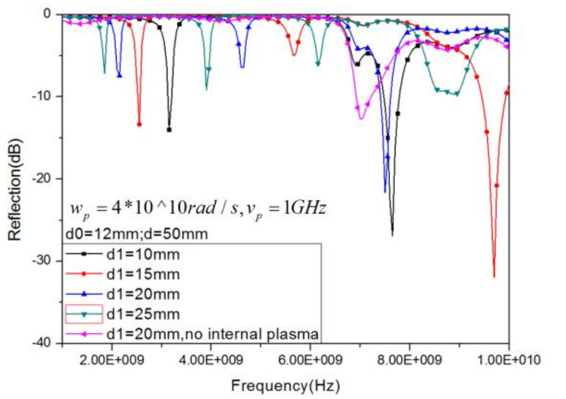


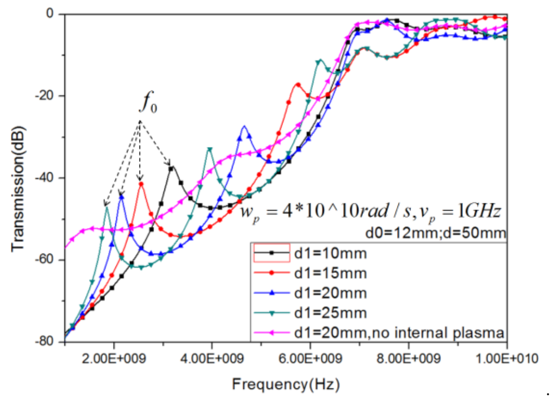
Fig. 2. The simulation sandwich model structure

B. The relationship between propagation coefficients and dielectric thickness

Dielectric thickness d_1 has great influence on window frequency(f_0) in Fig.3. The window frequency increases as the thickness of dielectric decreases. The transmission coefficient of sandwich structure is about 10dB bigger than media-plasma structure in window frequency by comparing curve “d1=20mm” with curve “d1=20mm,no internal plasma” when the thickness of dielectric is 20mm.



(a)

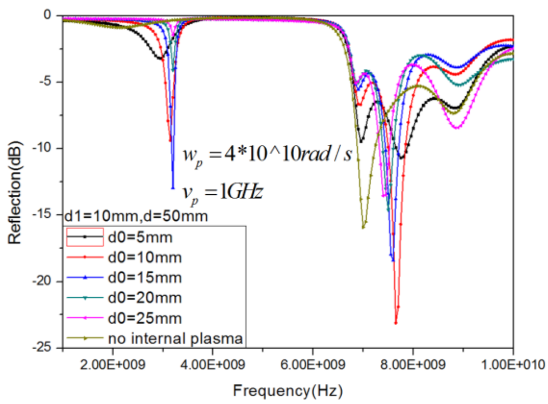


(b)

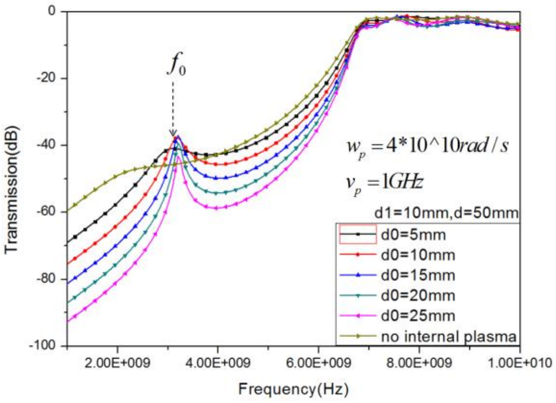
Fig. 3. (a).The relationship between reflection coefficient and dielectric thickness; (b).The relationship between transmission coefficient and dielectric thickness

C. The relationship between propagation coefficients and internal plasma thickness

Fig.4 depicts the effect of varying thickness d_0 of internal plasma slab. The bandwith of window frequency becomes narrower when the thickness of internal plasma is added. The curve “no internal plasma” is obtained from the media-plasma structure. It has lower transmission cofficient in window frequency compared with other curves.



(a)



(b)

Fig. 4. (a).The relationship between reflection coefficient and internal plasma thickness; (b).The relationship between transmission coefficient and internal plasma thickness

D. Horn antenna feeding model and simulation results

In Fig.5, a horn is used to replace the plane wave and acts as a source to illuminate the sandwich structure. The horn antenna can work at 6.25GHz. Fig.6 shows the antenna gain in this case is about 4dB bigger than covered only by plasma sheath in its direction.

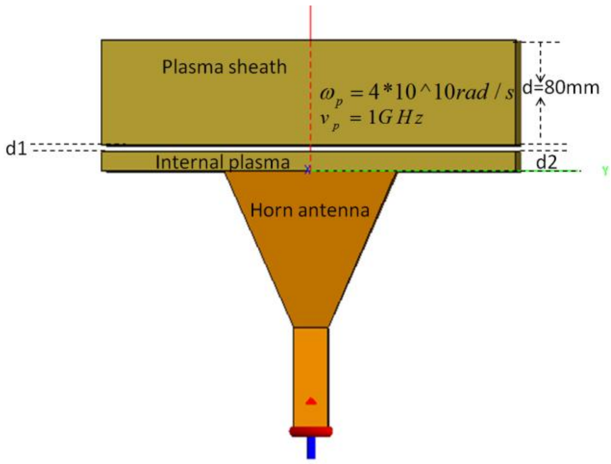
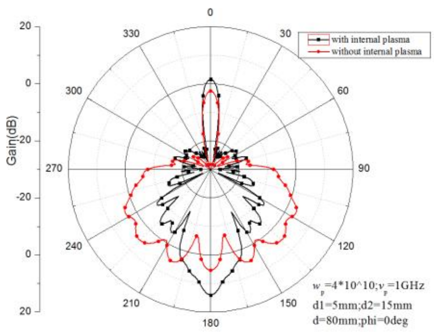
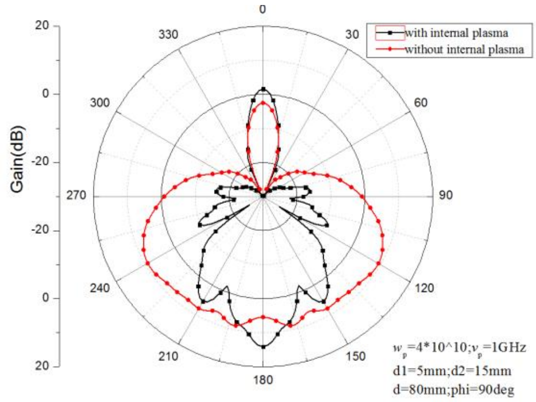


Fig. 5. The simulation model of horn antenna covered by sandwich structure



(a)



(b)

Fig. 6. The patterns of horn antenna. (a).*phi*=0deg; (b).*phi*=90deg

IV. CONCLUSION

This paper proposes a method to mitigate communication blackout. The method makes the most use of the structure that plasma sheath is on the outside of the antenna window. Sandwich can be formed when an internal plasma is produced inside the antenna window. The internal plasma parameters can be controled artificially. Sandwich structure can mitigate the blackout which was proved by simulation. The application of sandwich structure can improve transmission coefficient about 10dB in infinite plane model, and more than 4dB higher in a real horn antenna model. Two reasons have been analyzed to explain the difference, the sandwich structure of the horn antenna model is finite in horizontal direction, and the propagation of waves is not all perpendicular to the plasma layers. Some paremeters such as plasma frequency and collision frequency of plasma will be discussed in future work.

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