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A NOVEL WIRE GRID EMBEDDED C-SANDWICH RADOME STRUCTURE FOR BROADBAND AIRBORNE APPLICATIONS

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ABSTRACT: *The application of symmetric wire grid structures for the broadbanding of C-sandwich radome panel, with core thickness optimized for power transmission, is presented. The performance parameters of wire grid embedded C-sandwich wall are evaluated based on equivalent transmission line method. The superior broadband EM performance of wire compensated C-sandwich wall is established based on a comparative study with the conventional structure at normal incidence and at a high incidence angle often encountered in streamlined airborne radomes.*

1. INTRODUCTION

Enhancement of electromagnetic (EM) performance parameters of airborne radomes over broadband is a major requisite for modern airborne radar systems. Various techniques for broadbanding of multilayered radomes have been reported in the literature [2,4&5]. Techniques based on metallic structures embedded in the radome panels also have been widely reported for improving the EM performance of radomes [1,3&6].

Since multilayered wall configurations (like A-sandwich, C-sandwich etc.) have high strength to weight ratio, they are generally preferred to monolithic half-wave wall for the design of large streamlined radomes. Among the multilayered wall configurations, C-sandwich shows superior power transmission characteristics as compared to A-sandwich over a range of incidence angles.

In the present work, a C-sandwich wall configuration with core thickness optimized for power transmission over 8-12 GHz is selected for the enhancement of EM performance parameters using wire grids. The presence of metallic structures in the skin or core layers may improve one performance parameter while the other parameters may degrade considerably. Hence the design parameters of the wire grids are optimized in such a way that the EM performance of the wire compensated C-sandwich wall has been improved significantly at the normal incidence and at a high incidence angle.

2. EM DESIGN ASPECTS OF WIRE GRIDS EMBEDDED C-SANDWICH RADOME PANEL

The C-sandwich wall configuration consists of two skin layers and a middle layer (glass composite: typical values as relative permittivity, $\varepsilon_r = 4.0$; electric loss tangent, $\tan \delta_e = 0.015$) with identical foam core ($\varepsilon_r = 1.15$; $\tan \delta_e = 0.002$) in between the middle layer and each skin layer. The inner and outer skin thicknesses of the C-sandwich are kept constant at 0.9 mm, while the thickness of the middle layer is 1.8 mm. The core thickness of C-sandwich configuration optimized for maximum power transmission over the frequency range 8-12 GHz is 5.44 mm.

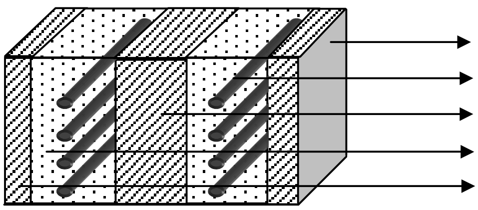

Fig. 1 Schematic of wire grid embedded C-sandwich radome panel

The wire grid, which consists of planar array of thin parallel wires of circular cross section, is embedded symmetrically in the mid-plane of each core as shown in the schematic (Fig. 1). The material properties of the wire grid are assumed to be uniform in the direction of the wires. Besides the polarization of the incident wave, the influence of such a grid depends on the pitch and diameter of the wires. The effect of the wire grid is maximum when the electric field of the incident wave is polarized in the direction of the wires.

In order to get broadband EM performance, the inductive susceptance of the wire grid should match with the capacitive susceptance of the dielectric medium. This necessitates the optimization of the design parameters of wire grids. The optimum dimensions of the wire grid are determined at the center frequency (10 GHz) of the selected frequency range 8-12 GHz. For normal incidence, the optimum wire grid dimensions are D = 1.5 mm and P = 56.6 mm. The optimum wire grid dimensions for perpendicular polarization at the angle of incidence 60° are D = 0.1 mm and P = 8 mm. The modified C-sandwich structure can be considered as two wire compensated A-sandwiches placed back-to-back.

3. EM PERFORMANCE ANALYSIS OF WIRE GRIDS EMBEDDED C-SANDWICH RADOME PANEL

The electromagnetic performance parameters power transmission, power reflection and insertion phase delay of the C-sandwich configuration with wire grids are computed based on the equivalent transmission line method [1]. The entire wall configuration is considered as an equivalent transmission line with different sections corresponding to skin, core and wire grids. The change in the characteristic impedance of the free space and C-sandwich configuration represents a discontinuity in the line, which is a major source of reflection of the wave passing through the structure.

As compared to free space, the dielectric layers of C-sandwich wall can be considered as low impedance lines connected end-to-end. A matrix consisting of A_i, B_i, C_i, and D_i parameters represents i^{th} dielectric layer. Hence the whole configuration can be represented by a single matrix obtained by the multiplication of matrices corresponding to individual layers.

Let Z_0 be the characteristic impedance of free space. The characteristic impedances of the skin, core and wire grid are represented by Z_s, Z_c, and Z_G respectively. Let Φ be the electrical length corresponding to each layer, which is a function of the complex permittivity (ε^*) of dielectric layer, the angle of incidence (θ) and the thickness of the dielectric layer (d). The electrical length corresponding to each dielectric layer is represented by

$$\Phi = \frac{2\pi d\sqrt{\varepsilon^* - \sin^2\theta}}{\lambda} \tag{1}$$

The matrix representing each layer of C-sandwich wall are as follows:

The outer skin:

$$\begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} = \begin{bmatrix} \cos\Phi_1 & j\frac{Z_s}{Z_o}\sin\Phi_1 \\ j\frac{Z_o}{Z_s}\sin\Phi_1 & \cos\Phi_1 \end{bmatrix} \tag{2}$$

In the modified wall configuration, the wire grid is located at the mid-plane of each core. Hence each core can be considered to be made up of two identical sections with wire grid in between them. Then each section of the outer core is represented by

$$\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} = \begin{bmatrix} \cos\Phi_2 & j\frac{Z_c}{Z_o}\sin\Phi_2 \\ j\frac{Z_o}{Z_c}\sin\Phi_2 & \cos\Phi_2 \end{bmatrix} \tag{3}$$

Let A_{WG}, B_{WG}, C_{WG} and D_{WG} be the elements of the matrix representing wire grid.

$$\begin{bmatrix} A_{WG} & B_{WG} \\ C_{WG} & D_{WG} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ jB_G & 1 \end{bmatrix} \tag{4}$$

Here B_G represents the shunt susceptance of the wire grid [1]. For perpendicular polarization,

$$B_G = \frac{-1}{\left(\frac{P}{\lambda}\right)\sqrt{\varepsilon_c - \sin^2\theta}\left[\log_e\left(\frac{P}{\pi D}\right) + 0.6\left(\frac{P}{\lambda}\right)^2\left(\varepsilon_c + 2\sin^2\theta\right)\right]} \tag{5}$$

Here ε_c is the dielectric constant of the core. P and D are the pitch of the wire grid and wire diameter respectively. λ is the wavelength in the medium.

The middle layer:

$$\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix} = \begin{bmatrix} \cos\Phi_3 & j\frac{Z_s}{Z_o}\sin\Phi_3 \\ j\frac{Z_o}{Z_s}\sin\Phi_3 & \cos\Phi_3 \end{bmatrix} \tag{6}$$

Similar to the outer core, each identical section of the inner core is represented by

$$\begin{bmatrix} A_4 & B_4 \\ C_4 & D_4 \end{bmatrix} = \begin{bmatrix} \cos\Phi_4 & j\frac{Z_c}{Z_o}\sin\Phi_4 \\ j\frac{Z_o}{Z_c}\sin\Phi_4 & \cos\Phi_4 \end{bmatrix} \tag{7}$$

The inner skin:

$$\begin{bmatrix} A_5 & B_5 \\ C_5 & D_5 \end{bmatrix} = \begin{bmatrix} \cos\Phi_5 & j\frac{Z_s}{Z_o}\sin\Phi_5 \\ j\frac{Z_o}{Z_s}\sin\Phi_5 & \cos\Phi_5 \end{bmatrix} \tag{9}$$

The entire C-sandwich configuration with wire grids is represented by

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ jB_G & 1 \end{bmatrix}\begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}\begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix}\begin{bmatrix} A_4 & B_4 \\ C_4 & D_4 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ jB_G & 1 \end{bmatrix}\begin{bmatrix} A_4 & B_4 \\ C_4 & D_4 \end{bmatrix}\begin{bmatrix} A_5 & B_5 \\ C_5 & D_5 \end{bmatrix} \tag{10}$$

Using equation (10), the *A, B, C* and *D* parameters of the final matrix are computed. The power transmission coefficient is given by

$$P_{tr} = \left[\frac{4}{(A+B+C+D)^2}\right] \tag{11}$$

The power reflection coefficient is given by

$$P_{rf} = \left[\frac{A+B-C-D}{A+B+C+D}\right]^2 \tag{12}$$

4. NUMERICAL RESULTS AND DISCUSSION

The power transmission, power reflection and insertion phase delay (IPD) characteristics of the wire grid embedded C-sandwich (with optimum core thickness) are computed for perpendicular polarization at normal incidence and at 60°. A comparative study of EM performance of wire compensated C-sandwich with that of C-sandwich alone is carried out. The EM performance parameters are evaluated for both configurations. Figures 2 and 3 show the power transmission characteristics of the modified C-sandwich configuration with wire grids over the frequency range 8-12 GHz. It is observed that the power transmission characteristic of C-sandwich alone at normal incidence shows sharp fall around 12 GHz. With the inclusion of the wire grids, the transmission efficiency of the C-sandwich radome panel is improved considerably (around 95%) throughout the frequency range. Even though the power transmission efficiency of C-sandwich wall alone at 60° excels the wire grid embedded wall over a small range 8.7-10.2 GHz, the overall performance of wire compensated C-sandwich is better than that of C-sandwich wall alone (Fig. 3).

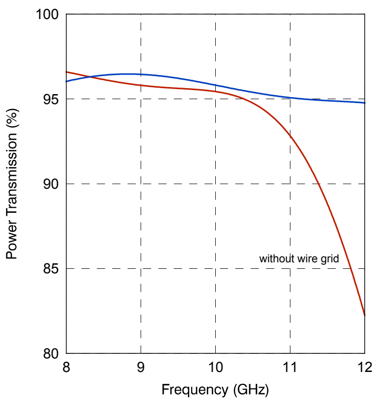

Fig. 2 *Power transmission* characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at normal incidence

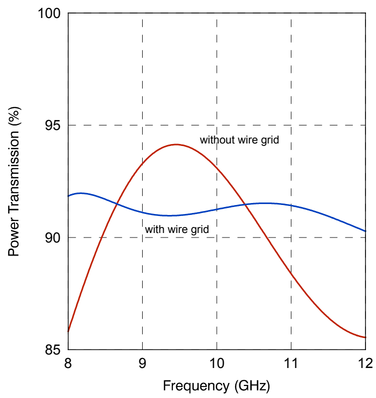

Fig. 3 *Power transmission* characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at 60°

The power reflection characteristic of the wire compensated C-sandwich wall is much better than that of C-sandwich alone at normal incidence as well as at 60° (Figs. 4 and 5). It is observed that the power reflection characteristic of C-sandwich alone at normal incidence is high around 12 GHz. The low power reflection characteristics of the wire grid embedded C-sandwich wall offers minimal side lobe level degradations for antenna pattern.

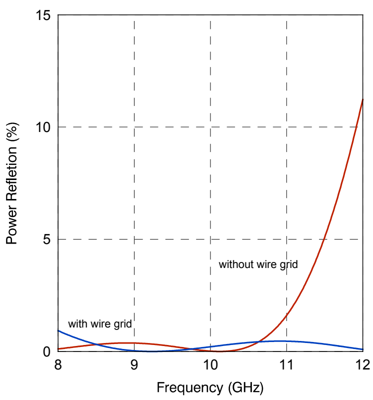

Fig. 4 *Power reflection* characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at normal incidence

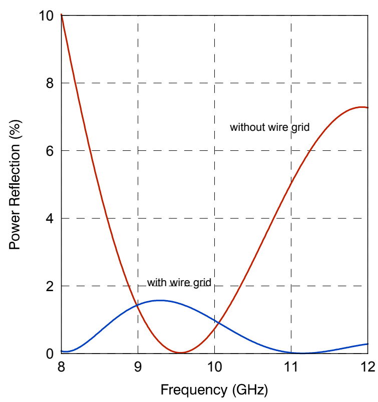

Fig. 5 *Power reflection* characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at 60°

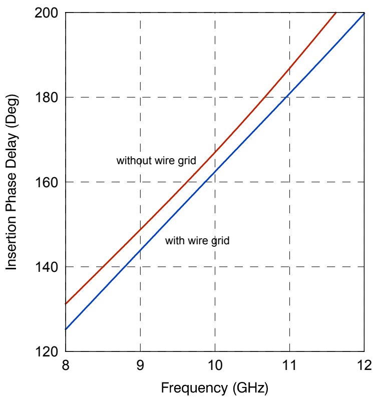

Fig. 6 *Insertion phase delay* (IPD) characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at normal incidence

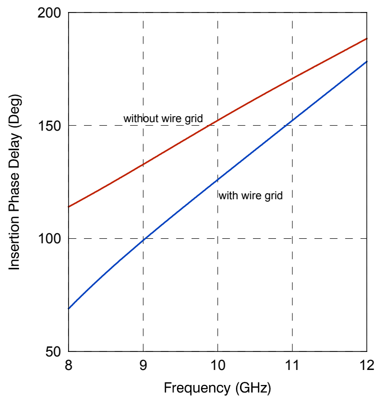

Fig. 7 *Insertion phase delay* (IPD) characteristics of *wire-compensated* C-sandwich and C-sandwich *alone* at 60°

The IPD characteristics (Figs. 6 and 7) of modified configuration are better than that of C-sandwich alone at both incidence angles. At high incidence angle (60°), the IPD characteristics of the modified structure are far superior to that of C-sandwich alone. These results indicate that the wire compensated C-sandwich wall may offer better boresight error (BSE) characteristics as compared to C-sandwich alone.

5. CONCLUSIONS

The EM performance analysis of C-sandwich radome with symmetric wire grids has been carried out. The analysis of the results indicates that the C-sandwich with wire grids show high power transmission, low power reflection and better IPD characteristics over broadband at normal incidence and at a high incidence angle. The superior EM performance of wire compensated C-sandwich wall for the wide range of incidence angles makes it suitable for the design of large streamlined airborne radomes. The wire grids embedded in the cores of C-sandwich radome panel not only enhances the EM performance, but also improves the structural rigidity of the wall configuration which is desirable for aerospace applications.

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