Investigation into EM properties of Low-Frequency cut-off Screens for RCS reduction of air-intakes

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Abstract- Low RCS airborne platforms must be effective both against low-frequency early warning and surveillance radars, as well as high frequency tracking and kill systems. The frontal RCS is often dominated by the RCS of the air-intake cavity and engine front face. While suitable shaping of the intake and the application of RAM is a preferred solution, the effectiveness of RAM coatings is limited to higher frequencies, generally 6 GHz and above.

For reducing the RCS at lower frequencies, the use of a mesh screen to block the EM propagation into the duct, while allowing adequate airflow for the engine, is investigated. This method allows a conformal screen to act like a shaped PEC surface, thus presenting a low RCS. This solution may be suitable for subsonic air-vehicles.

This paper investigates the EM properties of simple mesh screens which may be used for the purpose. A computational and experimental study over 100MHz-6 GHz frequency range, of a simple mesh screen over a short rectangular cavity, is presented. The effects of variables such as cell size and spacing, screen depth, etc. are studied and conclusions drawn. The attendant fluid dynamics and pressure loss to the engine are not in the scope of this paper.

Keywords- Cavity, Mesh, Screen, RCS, Frequency Selective

I. INTRODUCTION

Air-intake cavities are one of the more prominent contributors to aircraft RCS in the frontal sector. While, the serpentine shaped duct design is preferred for attenuating the EM energy through application of the RAM, but the realization of broadband RAM (0.1-18 GHz) with reasonable weight and thickness constraints is a big challenge. It appears more feasible to achieve RCS reduction through RAM application over 6 to 18 GHz. For lower frequencies (less than 6 GHz), the use of cut-off screens has been employed for reducing duct RCS. An appropriately designed Radar screen, applied over the entrance to the air-intake, can be used to block the penetration of EM energy inside the duct, for wavelengths below the cut-off wavelength of the screen.

Out of the various design parameters, it has been found through computational studies that the screen cell size determines the minimum frequency that can penetrate through the screen, so this method becomes inappropriate for higher frequencies (above 6 GHz) as the cell size becomes smaller.

In this paper, various computational studies have been performed in order to investigate the high-pass filter characteristics of simple mesh type radar screens. The effects of variables such as cell size and spacing, screen depth, etc. on the EM characteristics of the screen have been studied. A standard rectangular cavity with a slanted aperture face was designed as a test object to emulate the general radar screen application scenario. The analysis of radar screens was performed from the RCS point of view, using a broadband (0.2- 20 GHz) frequency sweep for a fixed angle of incidence. FDTD & MoM based EM solvers were used for the computations.

This paper does not go into any considerations other than the Electromagnetic properties of such screens.

2. PRINCIPLE OF THE RADAR SCREEN

Frequency Selective Surfaces (FSS) are periodic structures, which are designed to generate a filter type transmission response. They may be designed to achieve filter response of low-pass, high-pass, band-pass or band-stop type. For obtaining high frequency transmission characteristics, a slot type FSS is required. A simple mesh screen is, in essence, a slot type FSS.

Fig.1 Typical radar Screen Fig.2 Flat Plate

Fig.1 shows a representative radar screen of dimensions (length x width x depth): 300mm x 300mm x 3 mm and cell size (length x width): 20.66 mm x 20.66 mm. Also, the wall width between adjacent cells is 4 mm.

Fig.2 shows a flat plate of same dimensions as the radar screen. The material used for computations in both cases is PEC.
Fig. 3 Comparison of computed broadband (0.2 GHz - 20 GHz) RCS response of flat plate and radar screen using FDTD based solver at normal incidence (green- flat plate, red- radar screen)

The computed results for RCS over 0.2 - 20 GHz for the flat plate (green color) and radar screen (red color) using FDTD based solver, for normal incidence (perpendicular to the radar screen plane) are as shown in Fig. 3 for the horizontal polarization case. It is observed that the radar screen behaves as a flat plate in the lower frequency range, up to about 4 GHz, and thereafter starts permitting the incident EM radiation through the screen, in effect, acting as a high-pass filter.

II. SCREEN PARAMETERIZATION STUDIES

II. (a) Effect of cell size variation on cut-off frequency: Fig. 4 shows the radar screen used for cell size variation studies. While the wall thickness between adjacent cells is kept fixed at 4 mm and cell depth is fixed at 4 mm, variations are made in square-shaped cell dimensions. Cell sizes of 12.44 mm, 20.66 mm, 33 mm and 45.32 mm are compared.

II. (b) Effect of cell depth variation on cut-off frequency: Similarly, the broadband RCS studies were performed for analysis of effect of variation of RCS as a function of cell depth. Here, the wall thickness between adjacent cells is kept fixed as 4 mm and the cell size is fixed as 30 mm x 30 mm. The cell depth is varied for different test cases as 1 mm, 10 mm, 20 mm, 30 mm, 40 mm and 50 mm.

II. (c) Effect of cell size variation on cut-off frequency: Similarly, the broadband RCS studies were performed for analysis of effect of variation of RCS as a function of cell depth. Here, the wall thickness between adjacent cells is kept fixed as 4 mm and the cell size is fixed as 30 mm x 30 mm. The cell depth is varied for different test cases as 1 mm, 10 mm, 20 mm, 30 mm, 40 mm and 50 mm.

Fig. 4 Radar screen with appropriate cell parameters

Fig. 5 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of radar screen using FDTD based solver at normal incidence with variation in cell size.

Fig. 5 shows the broadband (0.2-20 GHz) RCS results of the radar screen using FDTD based solver for variation in cell size (red- flat plate, brown- cell size 12.44 mm, navy blue- cell size 20.66 mm, blue- cell size 33 mm, magenta- cell size 45.32 mm at normal incidence for horizontal polarization. It is observed through the results that the screen cut-off frequency of the screen is essentially decided by the cell size and decreases proportionally with the increase in cell size.

Fig. 6 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of radar screen using FDTD based solver at normal incidence with variation in cell depth.

Fig. 6 shows the comparison of broadband (0.2 - 20 GHz) RCS computation results with variation in cell depth. The RCS plots are represented as navy blue- cell depth 1 mm, brown- cell depth 10 mm, blue- cell depth 20 mm.
mm, red- cell depth 30 mm, orange- cell depth 40 mm and magenta- cell depth 50 mm. The additional green colored RCS plot is for flat plate RCS response for same dimensions. All the computations have been performed for normal incidence (perpendicular to radar screen plane) and for Horizontal polarization case.

It is observed that if the screen cell size is $\lambda/2$ (for $\lambda$ cut-off wavelength), if the cell depth is reduced below $\lambda/2$, then the screen performance degrades (cut-off frequency is reduced and hence, becomes more transmitting for lower frequencies) and if the cell depth is increased, then the screen performance achieves its required cut-off frequency, until it becomes invariant with further increase in cell depth.

II. (c) Effect of wall thickness variation on cut-off frequency: Further, the broadband RCS studies were performed with variation in cell wall thickness between adjacent cells. The cell size dimensions were kept fixed as 30 mm x 30 mm and the cell depth is also 30 mm. The wall thickness was varied as 3 mm, 4 mm and 5 mm, respectively.

Fig. 7 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of radar screen using FDTD based solver at normal incidence with variation in cell wall thickness

Fig. 7 shows the comparison of broadband (0.2 GHz - 20 GHz) RCS computation results with variation in cell wall thickness. In the RCS plot, the cell wall thickness is varied as 3 mm -pink color, 4 mm -blue color, 5 mm -red color and reference flat plate response represented by green color, at normal incidence (perpendicular to radar screen plane) for Horizontal polarization case. It is observed that the radar screen cut-off frequency is very slightly variant with cell wall thickness variation. After cut-off frequency, the RCS response of screen with higher wall thickness is closer to the flat plate response (i.e. more reflective). The wall thickness would typically involve a trade-off between sufficient strength and aerodynamic performance.

Hence, it can be generalized that if the screen cell size is $\lambda$ then the screen cut-off wavelength becomes $2\lambda$.

III. APPLICATION OF RADAR SCREEN ON A SIMPLE CAVITY TYPE STRUCTURE

III. (a) Standard Rectangular Cavity with slanted opening: Fig. 8 shows a standard Rectangular cavity with slanted opening designed for the purpose of analysis of various radar screen broadband RCS response. The rectangular cavity dimensions are height x width x depth (of lower portion): 196 mm x 196 mm x 496 mm. The depth of cavity upper portion is 300 mm. The slanted opening of the rectangular cavity is angled 45 deg upwards.

Fig. 8 Standard Rectangular Cavity with slanted opening

Fig. 9 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of standard rectangular cavity and flat plate using FDTD based solver at normal incidence

Fig. 9 shows the comparison of broadband (0.2 GHz - 20 GHz) RCS response of standard rectangular cavity with slanted opening (red color) and flat plate (blue color) using FDTD solver at normal incidence (perpendicular to the cavity back-plate) for Horizontal polarization. As observed, the RCS of standard rectangular cavity which also has a flat back-plate is comparable to the flat plate response over the whole frequency band.

III. (b) Rectangular Cavity with slanted opening blocked by a flat plate: Fig. 10 shows the model of
same Rectangular cavity with its slanted opening blocked by flat plate.

Fig. 10 Standard Rectangular Cavity with slanted opening blocked by flat plate

Fig. 11 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of standard rectangular cavity with slanted opening blocked and unblocked by a flat plate using FDTD based solver at normal incidence

Fig. 11 shows the comparison of broadband (0.2 - 20 GHz) RCS response of standard rectangular cavity with slanted opening blocked (green color) and unblocked (red color) by a flat plate at normal incidence (perpendicular to the cavity back-plate) for Horizontal polarization case. As observed, there is drastic reduction in RCS levels as the incident EM radiation is scattered by the cavity blocking plate in the upward direction. So, if a radar screen with a suitable cut-off frequency is applied instead of this cavity blocking plate, then similar reduction in RCS levels can be achieved below the cut-off frequency, as the radar screen typically behaves as a flat plate in this frequency range.

III. (c) Rectangular Cavity with slanted opening covered with Radar screen:

Fig. 12 Standard Rectangular Cavity with slanted opening blocked by Radar screen

Fig. 12 shows the same standard rectangular cavity structure covered with radar screen. The screen fully covers the slanted opening and the cell depth of screen is 10 mm. The screen cell size is 8 mm x 8 mm.

Fig. 13 Comparison of computed broadband (0.2 GHz-20 GHz) RCS response of standard rectangular cavity blocked and unblocked by a flat plate, blocked by a radar screen using FDTD/ MoM based solver at normal incidence

Fig. 13 shows the comparative analysis of broadband RCS response of standard rectangular cavity with opening unblocked (red color), with opening blocked (green color), with opening covered with radar screen (magenta color) using FDTD based solver. Similar computation was performed with opening covered with radar screen using MoM based solver also as shown using black color. The broadband computations are performed for normal incidence (perpendicular to the cavity back-plate) for Horizontal polarization case. As observed through these RCS plots, at lower frequencies the radar screen RCS response matches closely with the flat plate RCS response and as the frequency is increased, the response deviates towards the cavity RCS response without radar screen.

In the earlier cases (Section II), there was no backing behind the radar screen, so, the fall in RCS beyond a certain deviation from the ideal response was considered for the derivation of cut-off frequency. In this case (Section III), there is flat plate backing behind the radar screen. So, the cut-off frequency will be seen by the rising RCS levels beyond a certain frequency as the radar screen tends to change its frequency response to become
more transparent to the incident EM radiation with increase in frequency.

IV. CONCLUSIONS
Design of a radar screen with appropriate dimensions and required aerodynamic performance can be one of the solutions for low frequency RCS management of air-intake cavities, especially for low speed airborne vehicles. The cut-off frequency of radar screen is dependent mainly on the cell size. The cell depth is also one of the crucial factors. If the cell depth is less than cell size, then the screen becomes more transparent for lower frequencies, which is undesirable. The cell depth has to be at least greater than cell size dimensions for lesser transparency at lower frequencies. The wall thickness between adjacent cells is seen to show lesser variation on RCS response, which can be exploited in adjusting for the trade-off between radar screen strength and its aerodynamic performance. It has been observed through our computation studies, that a radar screen designed appropriately for the proposed cut-off frequency has to be essentially applied conformal to the target surface, so as to emulate cavity less surface for lower frequencies of the incident EM radiation.

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