Characterization of ferrite and silicon carbide based microwave absorber using FSS structures at X-band

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Received 16 September 2003; accepted 7 May 2004

In this paper the experimental result of microwave absorber with a single layer coating of ferrite and silicon carbide (SiC) based paint for X-band is presented. Samples of M-type hexagonal ferrite powder [Ba(MnTi)_{18}Fe_{8.4019}O_{9}] has been developed by dry attrition and sintering process. These developed ferrite powder and SiC powder have been mixed in epoxy resins to form a microwave absorbing paint. This paint was coated on aluminum sheet for absorption studies. The frequency selective surface (FSS) patterns are embedded on the surface of absorber sheet and tested experimentally at X-Band. It was found that SiC based microwave absorbing paint provide wide band absorption characteristics with minimum absorption of 10 dB from 9.5 to 12 GHz for a coating thickness of 1.84 mm.

Keywords: Hexagonal ferrite, Silicon Carbide, Microwave absorber, Frequency selective surface.

PACS No.: 94.106b; 42.68 Ay
IPC Code: 601H22/00

1 Introduction

The radar signal strength, scattered from a target, determines its detectability. This pertains to the radar cross-section (RCS) reduction, which frequently should be reduced. Radar absorbing material (RAM) is a very effective means of RCS reduction in the context of stealth technology.

In order to reduce the radar cross-section of the target, the hexagonal ferrite material is very useful. It was observed that the M-type hexagonal ferrite shows excellent properties of the microwave absorption in the frequency range of 8-18 GHz.

Frequency selective surfaces (FSS) is a two-dimensional periodic array of conducting patches or aperture elements. The frequency filtering property of the FSS comes from its planar periodic structure. The element reflects the incident wave of a specific frequency range according to their shapes, periodicity and the dielectric property of the substrate. When the element size is quite different from the resonant dimensions, the incident wave will travel through an FSS screen as if the screen were essentially transparent.

In the present paper the effects of FSS structure on microwave absorbing characteristics of hexagonal ferrite based microwave absorber have been discussed.

2 Design details of FSS

For an array of thin, continuous, infinitely long, perfectly conducting narrow strips, the shunt impedance is either inductive or capacitive, depending on whether the incident wave is polarized parallel to or perpendicular to the edges of strips, respectively. For an array of period \( p \) and conductor width \( w \) for the electric vector parallel to the conductor, an inductive reactance (normalized to the impedance of free space) is given by

\[
x(w) = \frac{F(p, w, \lambda)}{\lambda} = \frac{p}{\lambda} \cos \theta \left( \ln \csc \frac{\pi w}{2p} + G(p, w, \lambda) \right)
\]

where \( \theta \) is the angle of incidence, \( \lambda \) is the wavelength and
\[
G(p, w, \lambda) = \frac{1}{2} \left[ \frac{(1 - \beta^2)^2[(1 - \beta^2/4)(A_+ + A_-) + 4\beta^2A_+A_-]}{[1 - \beta^2/4 + \beta^4[1 + \beta^2/2 - \beta^4/8]} \times (A_+ + A_-) + 2\beta^6A_+A_-. \right]
\]

where
\[
A_\pm = \frac{1}{\sqrt{1 \pm 2p \sin \theta - \left[ \frac{p \cos \theta}{\lambda} \right]^2}} \quad \text{(2)}
\]
and \( \beta = \sin \frac{\pi w}{2p} \)

Similarly, for the electric vector perpendicular to the conductor, the array has a capacitive susceptance (normalized to the admittance of free space) given by
\[
B(g) = 4F(p, g, \lambda)
\]

where \( g \) is the gap between the conductors using as Eq. (1) with \( w \) replaced by \( g \).

3 FSS comprising periodic array of double square loops

Double square loops array has double resonant frequency. The equivalent circuit for both FSS-1 and FSS-2 are shown in Figs 1 and 2. The basic equations are:

Fig. 1—Structure of double square loop FSS-1

Fig. 2—Structure of circle inside square FSS-2
Normalized loop reactance which is

\[ \frac{X_L}{Z_o} = F(p, s, \lambda) \]  

... (4)

and normalized loop susceptance which is defined as

\[ \frac{B_L}{Y_o} = 4F(p, g, \lambda) \]  

... (5)

The equivalent inductances and capacitances for double square loop can be calculated as

\[ L_1 = 2L_x L_y \frac{d_1}{p} \ \Rightarrow L_1 = F(p, s_1, \varepsilon) \]

\[ C_1 = 0.75C_x \frac{d_2}{p} \ \Rightarrow C_1 = F(p, s_2, \varepsilon) \]

\[ L_{t2} = L_x \left( \frac{d_2}{p} \right) \ \Rightarrow L_{t2} = F(p, 2s_2, \varepsilon) \]

\[ C_{t2} = (C_x \text{ in series with } C_y) \frac{d_2}{p} \ \Rightarrow C_{t2} = 4F(p, s_2, \varepsilon) \]

\[ \frac{C_2}{C_x} = 4F(p, g_2, \varepsilon) \]

where \( d_1 \) is the side of inner square, \( d_1 \) the side of outer square, \( g_1 \) the gap between inner and outer square, \( g_1 \) the gap between outer square, \( s_1 \) the width of outer square, and \( s_2 \) the width inner of square.

The variable \( p \) is the sum of \( d_1 \) and \( g_1 \). Table 1 shows the dimension of FSS-1 and FSS-2 structures.

### 4 Preparation of ferrite powder and characterization

A sample of M-type barium hexagonal ferrite powder \([\text{Ba}_{1.6} \text{Fe}_{8.4} \text{O}_{19}]\) has developed by dry attrition and sintering method. The starting materials are \( \text{BaCO}_3, \text{MnCO}_3, \text{TiO}_2 \), and \( \text{Fe}_2\text{O}_3 \), all in the pure form. Sintering was carried out at 1150°C for 8 h. The average particle size of developed ferrite powder was measured by scanning electron microscope and it was found that the average particle size lies in the range of 5 micron. Two samples of paints have been developed by mixing ferrite powder and SiC powder, 60% by weight into epoxy resin (Mat Sole). The developed ferrite paint and SiC paint are coated on the conducting aluminum sheet of size (94.5x74) mm to study the absorption characteristics at X-band.

Two fabricated frequency selective surfaces are embedded on different samples of ferrite and SiC based absorber sheets and their absorption characteristics have been measured by ATD Method\textsuperscript{6,7}. The block diagram of the experimental setup for measurement of microwave absorption is shown in Fig. 3.

### 5 Result and discussion

The microwave absorption characteristics for ferrite and SiC based absorber are shown in Figs 4-6.

Figure 4 shows the absorption characteristics of single layer coating of SiC based and ferrite based microwave absorber with coating thickness of \( t = 0.84 \) mm. From Fig. 4 it is observed that it gives narrow band characteristics. The peak value of microwave absorption
absorption of 10.2 dB is obtained at 9.2 GHz in SiC based absorber and in case of ferrite based absorber two peaks are obtained at 8.6 GHz and 10 GHz with peak value of absorption of 6.8 dB and 5.1 dB, respectively.

Figure 5 represents the effect of two layers on absorption properties of ferrite based absorber. A layer of coating thickness of 1 mm is coated on single layer ferrite based paint of coating thickness of 0.84 mm. From Fig. 5 it is noticed that the overall absorption characteristics improved as compared to the single layer coating of ferrite. It gives wide band characteristics of absorption with minimum absorption of 10.2 dB from 10.2GHz to 12 GHz.

Figure 6 shows the effect of frequency selective surface namely FSS-1 and FSS-2 on single layer SiC based microwave absorber. It is observed that SiC absorber provides broadband absorption characteristics with minimum absorption of 13 dB at coating thickness of 1.84 mm for the frequency range 9.6-12 GHz. Further, by embedding FSS-1 structures on the absorber the overall absorption increases in the frequency range of 10.8-12 GHz. It provides broadband absorption characteristics with minimum absorption of 18 dB in this range. For FSS-2 structure, the absorption characteristics are improved at 10.6 GHz. It also provides broadband characteristics with minimum absorption of 13.3 dB in the range 10-12 GHz.

6 Conclusions
In this paper the experimental results of different structure of FSS on the performance of microwave absorbers have been presented. It is concluded that SiC gives excellent absorption properties as compared to ferrites. Two layer structure comprising SiC-Ferrite combination provides broadband characteristics with minimum absorption of 10 dB in the frequency range 10.2-12 GHz. The FSS-2 provides maximum absorption as compared to FSS-1. Such types of microwave absorbing paints are very useful for reduction of the radar cross-section of different targets.

References