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# A study on the behaviour of M-type barium hexagonal ferrite based microwave absorbing paints

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**Abstract.** **This paper deals with development of single- and double-layer microwave absorbing paints using Mn-substituted barium hexagonal ferrite. The comparative studies of both theoretical and experimental results at Ku band have been reported. It has been found that the single layer absorbing paint exhibits peak absorption of 12·3 dB at 17·4 GHz for a thickness of 1·12 mm. Double layer absorbing paint with each layer of different composition of ferrite gives a broad band characteristics, but at the cost of lowered absorption.**

**Keywords.** **Hexagonal ferrite; radar cross-section; microwave absorbing paint.**

## 1. Introduction

Electromagnetic interference (EMI)—a specific kind of environmental pollution is drawing more attention recently, due to the explosive growth in the utilization of electric and electronic devices in industrial, commercial and military applications. Serious electromagnetic compatibility (EMC) have become apparent. This has led to the search for more effective electromagnetic wave absorbing materials in the microwave range. Spinel type ferrite has been used as a thin electromagnetic wave absorber in the MHz frequency range, for application such as TV ghost suppression. However, this material does not work well in the GHz range because of decrease in magnetic loss, $\mu_r''$ (Naito and Suetake 1971). It was observed that the hexagonal ferrite with planar magnetic anisotropy are of interest for use as microwave absorber in the GHz range.

Ferrites are a class of magnetic materials that can absorb microwave energy by lossy interaction of the magnetic field of the electromagnetic wave with the magnetization of the ferrite material (Jha and Banthia 1989). The hexagonal ferrite finds potential application in the development of microwave absorbers due to the significant value of permeability (> 1) in GHz range, planar anisotropic behaviour and high magnetization (Naito and Suetake 1971; Amin and James 1981).

When a coating of ferrite paint is applied on a target its radar cross-section reduces and its detection by radar becomes difficult. Therefore, such type of microwave absorbing paints are used in camouflaging military aircraft and missiles against radar detection. The main advantages of paint is that, it can be applied over any target of complex geometry in order to reduce its radar cross-section (Aiyer *et al* 1989; Gupta *et al* 1993).

In this paper, the development and characterization of single and double layer microwave absorbing paints using Mn-substituted barium hexagonal ferrite have been reported, and the results are given in figures 4–8.

## 2. Theory of microwave absorption

Figure 1 shows an infinitely conducting plane coated with a microwave absorbing paint of thickness, $t$, whose complex permittivity and permeability are $\varepsilon$ and $\mu$, respectively.

It is assumed that a TEM wave propagating along Z-direction with its electric field '$E$' parallel to X-axis and magnetic field '$H$' parallel to Y-axis is incident normally on the absorbing plate as shown in figure 1, in which region 1 is free space, region 2 is absorbing paint and region 3 is metal surface.

The incident wave gives rise to a series of waves travelling in both positive as well as negative Z-direction within the absorbing paint coating.

The electric fields in different regions can be written as

$$\overline{E_0} = a_0 e^{-jk_0 z} + b_0 e^{jk_0 z}, \quad (1)$$

$$\overline{E_1} = a_1 e^{-jk_1 z} + b_1 e^{jk_1 z}, \quad (2)$$

where, $\overline{E_0}, \overline{E_1}$ are the electric field in free space and absorbing paint, respectively, $a_0$, $b_0$ are the amplitudes of the incident and reflected waves, respectively in free space, $a_1$, $b_1$ are the amplitudes of the incident and

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reflected waves, respectively in microwave absorbing paint and $k_0$, $k_1$ are the wave number in free space and microwave absorbing paint, respectively.

The electric field components are constant in any XY-plane and satisfy the Helmholtz wave equation (Gupta *et al* 1993)

$$(\nabla^2 + \bar{K}^2)\psi = 0, \tag{3}$$

where $\bar{K}$ is the complex wave number and $\psi = E_x$ a wave function for normal incidence. The reflection coefficient, $R_0$, at the front surface of microwave absorbing paint is given by (Kim *et al* 1993; Meshram *et al* 2000)

$$R_0 = (Z_m - 1)/(Z_m + 1), \tag{4}$$

where $Z_m$ is the normalized input impedance with respect to the free space, and is given by

$$Z_m = [\mu_r/\varepsilon_r]^{0.5} \tan h(jkt), \tag{5}$$

where $\mu_r = \mu_r' - j\mu_r''$ and $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ are the complex relative permeability and permittivity, respectively of the absorber. The absorption coefficient can be computed from the relation

$$A = -20 \log_{10}|R_0|. \tag{6}$$

## 2.1 *Theory of two-layer microwave absorbing paint*

The geometry of a two-layer microwave absorbing paint coated on metal surface is as shown in figure 2. $\varepsilon_1$, $\mu_1$ are the permittivity and permeability of first layer, respectively. $\varepsilon_2$, $\mu_2$ are the permittivity and permeability of second layer, respectively. $t_1$, $t_2$ are the thickness of first layer and second layer, respectively.

Impedance of second layer is given by (Kim *et al* 1993)

$$Z_{in(2)} = \sqrt{\frac{\mu_{r2}}{\varepsilon_{r2}}} \tan h(jk_2t_2). \tag{7}$$

Now using impedance transformation, resultant impedance of two-layer is given as (Kim *et al* 1993)

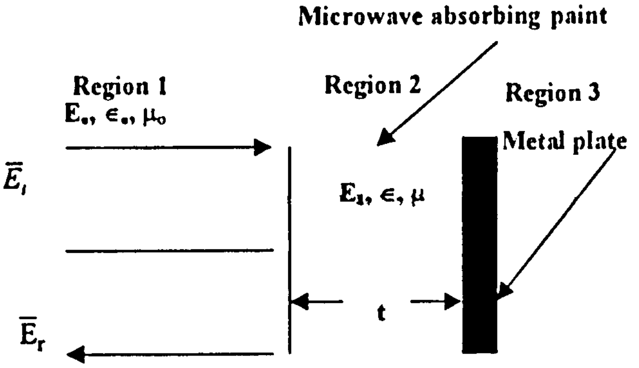


**Figure 1.** Single layer microwave absorbing paint.

$$Z_{in(1)} = Z_1 \frac{Z_{in(2)} + Z_1 \tan h(jk_1t_1)}{Z_1 + Z_{in(2)} \tan h(jk_1t_1)}, \tag{8}$$

where,

$$Z_1 = \sqrt{\frac{\mu_{r1}}{\varepsilon_{r1}}},$$

and

$$R_0' = \frac{Z_{in(1)} - 1}{Z_{in(1)} + 1}. \tag{9}$$

Hence the overall absorption coefficient for the two-layer paint is given as

$$A = -20 \log_{10}|R_0'|. \tag{10}$$

# 3. Fabrication

## 3.1 *Preparation of ferrite powder*

Manganese-substituted barium hexagonal ferrites with composition $[Ba(CoTi)_\delta Fe_{(11.9-\delta)}Mn_{0.1}O_{19}]$ and $[Ba(CoTi)_\delta Fe_{(11.9-\delta)}Mn_{0.15}O_{19}]$ for $\delta = 1.6$ were prepared by dry attrition and sintering procedure. First of all pure constituents in the form of oxides or carbonates are dried in oven at 110°C to remove any moisture present in the powder. Then these materials are charged in an attritor for 4 to 5 h to obtain homogeneous mixture of different constituents with fine grade particles (< 20 μm). The powder is obtained and sintered at 1150°C for 4 to 5 h. The sintered product which is spongy mass is crushed mechanically and then again charged in the attritor to obtain powder with very fine particles.

## 3.2 *Fabrication of microwave absorbing paint*

Microwave absorbing paint has been fabricated by mixing ferrite powder in a binder, 60% part of ferrite powder, 40% part of epoxy resin and methyl ethyl ketone as thinner required were taken by weight. Epoxy resin is kept in oven at 100°C for 30 min. Then 60% ferrite powder was mixed by pastel and mortar for 30 min to get homogeneous dispersion.

The freshly prepared paint was immediately applied on the surface of aluminium sheet of specified surface

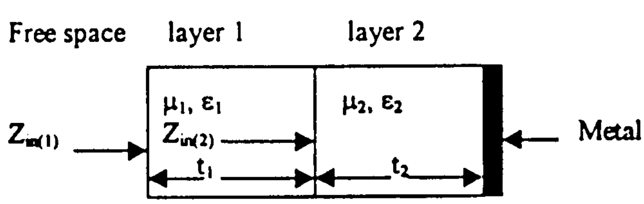


**Figure 2.** Two-layer microwave absorbing paint.

dimension (85 mm × 54·5 mm) required for Ku band microwave absorption studies. The thick film was allowed to cure overnight in air. A large number of such coatings with different ferrite contents and of varying thicknesses were formed for the absorption studies.

## 4. Microwave absorption measurement

The experimental setup for measuring microwave absorption is shown in figure 3. A reference power level is noted without the absorber in the ATD (Meshram *et al* 2000), and the reflected power with the absorber in the ATD is measured. The difference in two readings gives the power absorbed by the absorber.

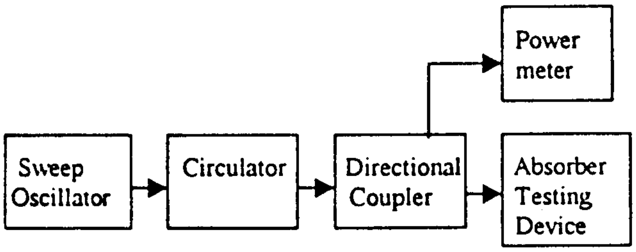


**Figure 3.** Experimental setup for measuring absorption of microwave absorbing paint using ATD.

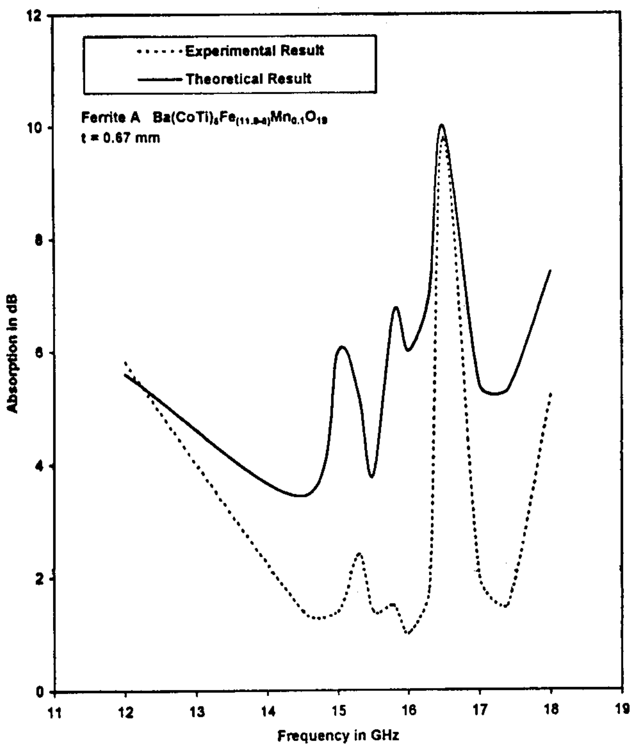


**Figure 4.** Absorption curve for single layer microwave absorbing paint (MAP).

## 5. Results and discussion

The experimental and theoretical absorption characteristics for the single layer microwave absorbing paints are shown in figures 4–8.

Figure 4 shows the absorption curve for single layer microwave absorbing paint obtained by using ferrite "A" [$Ba(CoTi)_\delta Fe_{(11\cdot 9-\delta)}Mn_{0\cdot 1}O_{19}$] for thickness of $t$ = 0·67 mm. It is observed that the nature of theoretical and experimental results are same.

Figure 5 shows the absorption curve for single layer microwave absorbing paint obtained by using ferrite "B" [$Ba(CoTi)_\delta Fe_{(11\cdot 9-\delta)}Mn_{0\cdot 15}O_{19}$] for thickness of $t$ = 0·62 mm. It is observed that in case of ferrite (B) four peaks of absorption are obtained at 14·5, 15·8, 16·3 and 17·4 GHz with absorption of 4 dB, 5·2 dB, 6·0 dB and 5 dB respectively.

Figure 6 shows the effect of two layers on microwave absorption characteristics. It may be noted that the two-layer absorber provides much higher absorption than the single layer ones in the frequency range of 14·5–17·4 GHz. The minimum absorption being 6 dB for overall layer thickness of 1·54 mm which is significantly higher than minimum values of absorption obtained with all single layer absorbers. Therefore it can be inferred that two-layer absorber provide broad band absorption characteristics from 13–18 GHz with minimum absorption of 6 dB.

Figure 7 shows the effect of two-layer on microwave absorption. When another layer of ferrite 'A' of thickness 0·89 mm is coated on ferrite 'B' of thickness 1·12 mm

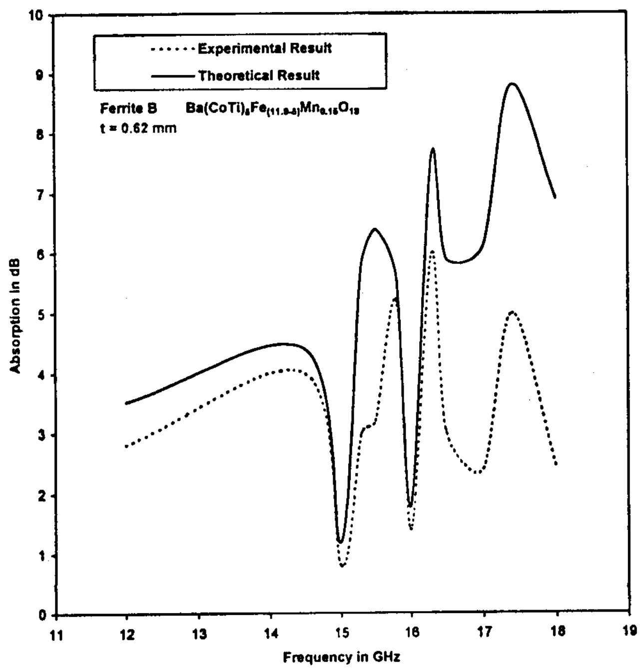


**Figure 5.** Absorption curve for single layer microwave absorbing paint (MAP).

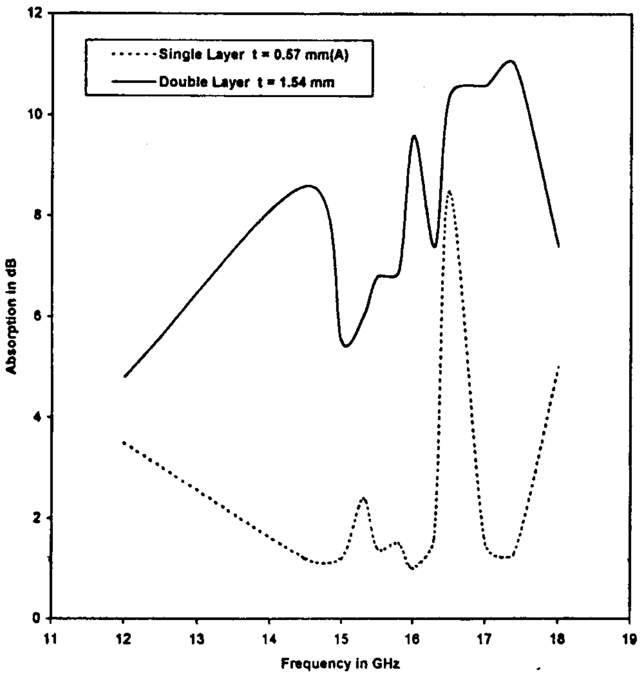


**Figure 6.** Effect of double layer on microwave absorbing paint (MAP).

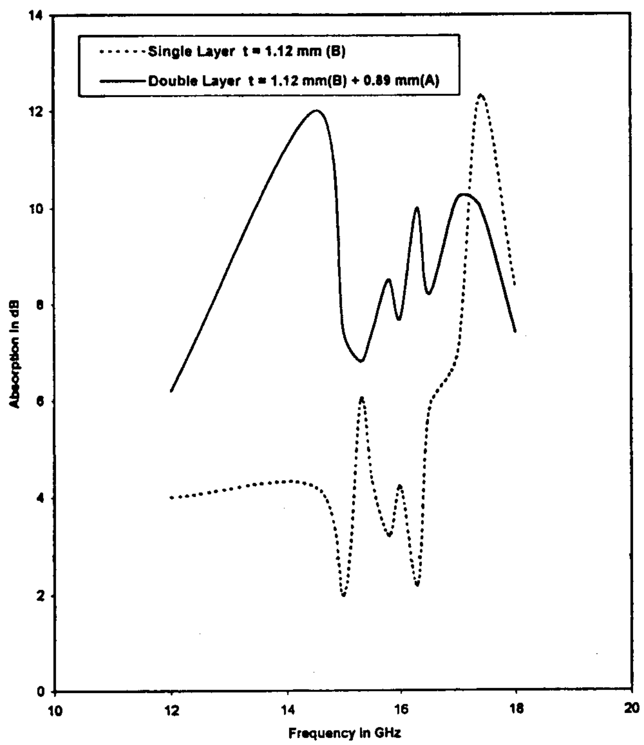


**Figure 7.** Effect of double layer on microwave absorption.

then two-layer absorber formed. Two-layer microwave absorber provides broad band characteristics from 13–18 GHz with a minimum absorption of 7 dB for total thickness of 2·01 mm.

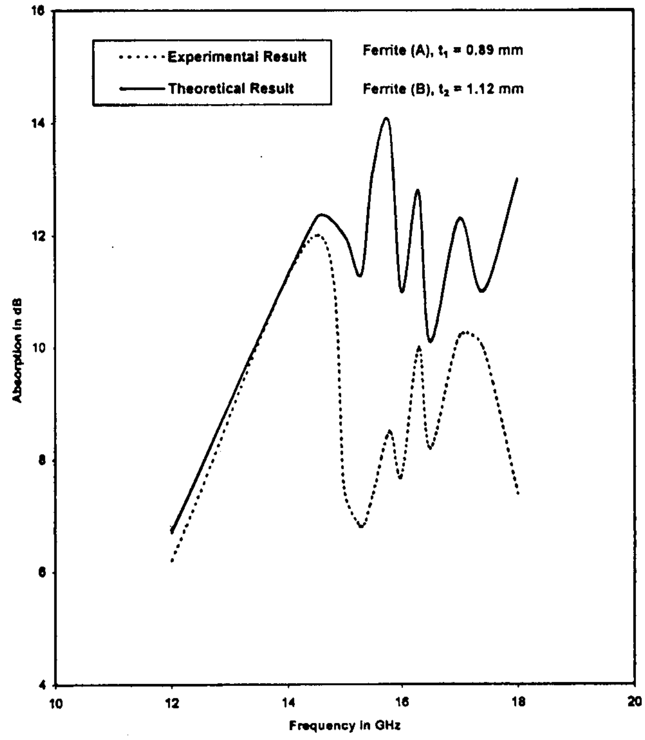


**Figure 8.** Absorption curve for double layer microwave absorbing paint.

Figure 8 shows the theoretical and experimental result of two-layer microwave absorbing paint. From the figures it is observed that two-layer absorber provides broad band absorption characteristics between frequency range of 12 and 18 GHz with a minimum absorption of 6 dB. However, the nature of curves for experimental and theoretical results are same.

## 6. Conclusions

Microwave absorbing paints have been developed using Mn-substituted barium hexagonal ferrite for different concentrations of Mn at Ku band. The variation in experimental and theoretical results are due to practical constraint in the preparation of ferrite and the measurements. However, the nature of curves as shown in figures 4–8 at different frequencies for theoretical and experimental values is in good agreement. In the present investigation no attempt has been made to control the shape, size and distribution of ferrite particles. These were prepared by crushing and milling of fired product. It is expected that particles so produced are angular in shape with wide range of size distribution. This is the likely cause of variation in absorption characteristics while comparing theoretical and experimental values. Further it is observed that the two-layer microwave absorber provides broad band characteristics. Such type of microwave absorbing paint can be used for coating on the exterior surface of military aircraft to reduce radar cross-section.

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