DESIGN OF A SINGLE LAYER BROADBAND MICROWAVE ABSORBER USING COBALT-SUBSTITUTED BARIUM HEXAGONAL FERRITE

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ABSTRACT: A microwave absorber is generally used to reduce the reflection from the large scale structures such as aircraft, ships, tanks etc. In order to design a good absorbing system, it is very important to not only determine the characteristics of the parameters of the absorbing medium, but also to estimate & minimize the effects of the angle of incidence and polarization of the incident wave. In this communication we present a theoretical and practical design of a single layer microwave absorber which exhibits broad band characteristics for both normal and oblique incidence. A single layer absorber was designed, fabricated and tested at normal as well as at oblique incidence. It is found that the theoretical & practical results agree very closely.

1. INTRODUCTION

It is often desirable to prevent or minimize the electromagnetic reflections from the surfaces of some objects such as air crafts, ships, tanks etc. This can either be achieved by constructing the object with small cross section [1,2] or by coating the object with a thin layer

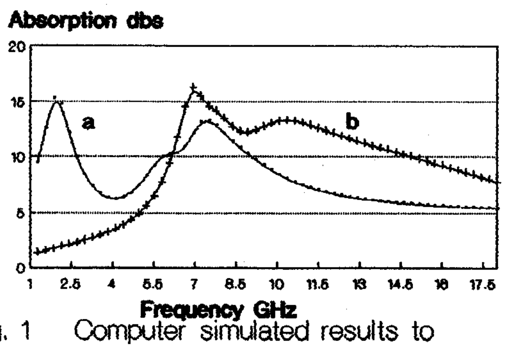

Fig. 1 Computer simulated results to show the increment in the bandwidth of a single layer absorber.

of absorbing material. This may serve as an absorbing, interference or dispersion layer.

Thin sheet Absorbers are made by dispersing a lossy material (eg. graphite ferrite, etc) in a binder (eg. rubber, PVC etc) and are generally a quarter wavelength thick, known as resonant Absorbers. The peak absorption obtained depends on the thickness d (resonant absorption), as well as on the properties of the lossy material (material absorption) used. The resonant absorption & material absorption are independent of each other. If these two types of absorptions effects are combined together the bandwidth of absorption is considerably increased, both at normal and at oblique incidence of the electromagnetic wave.

This communication deals with theoretical as well as the practical design of a single layer absorber which gives more than 10 dB absorption in a desired band. Experimentally 8 db absorption has been obtained both at normal and oblique incidence.

2. THEORY

Co-substituted Barium Hexagonal Ferrite (Co-BHF), have been reported [3] to give significant values of μ_r, the relative complex permeability at microwave frequencies. They provide the additional

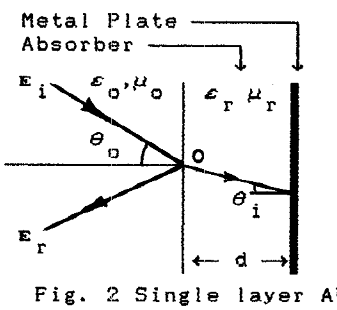

Fig. 2 Single layer Absorber oblique incidence

advantage of controlling the Ferromagnetic resonance (f_r) at any desired frequency between 2 to 46 GHz. It is found that Co-BHF with $\mu_r \simeq 5$ gives excellent absorption at resonance. The computer simulated results for the single layer absorber made by dispersing Co-BHF in rubber at normal incidence for a thickness of 7.5mm & an f_r of 7.5 GHz.[4] is plotted as curve 'a' in Fig.1. The first peak is due to the quarter wavelength effect the second is due to the f_r of Co-BHF. For the same f_r of 7.5GHz. and a quarter wavelength thickness (at 7.5GHz) of 1.51mm the simulated results are plotted as curve 'b' in Fig.1. If minimum 10 dB absorption is taken as a criterion for bandwidth considerations then the large increment in the bandwidth can be observed as shown in curve 'b' of Fig.1.

Consider an infinitely conducting plane coated with a uniform layer of material (Absorber) of thickness d, whose complex relative permittivity & complex relative permeability are given by ε_r & μ_r respectively. Let a uniform plane wave travelling in the +ve Z direction be incident on the surface of the absorber at an angle of θ_o as shown in the Fig.2. If the interface point 'o' is chosen as the origin of a coordinate axis system, then the incident & reflected field (E_i & E_r) in different layers can be written as

$$E_{ii} = b_{ii}\exp[j\{\omega t - k_i(x\sin\theta_i + z\sin\theta_i)\}] \quad .(1)$$

$$E_{ir} = b_{ii}\exp[j\{\omega t - k_i(x\sin\theta_i - z\sin\theta_i)\}] \quad .(2)$$

where a_i & b_i are the amplitudes of the incident & reflected fields, ω the angular frequency, k the complex wave number & θ is the incident angle. Then the reflection coefficient R_{jo}, at the front surface of the absorber is given by

$$R_{jo} = (Z_{jm} - 1)/(Z_{jm} + 1) \quad . (3)$$

where j stands for the type of polarization of the incident wave Thus, if the incident electric field is polarized perpendicular to the plane of incidence, the impedance parameter Z_{jm}, is given by

$$Z_{nm} = \frac{\mu_r}{N}\frac{\cos\theta_i}{\cos\theta_o}\tanh(kd\cos\theta_i) . (4a)$$

where $\sin\theta_o = N\sin\theta_i$ and $N = \sqrt{\varepsilon_r \mu_r}$

further, if the incident field is polarized parallel to the plane of incidence, the impedance parameter Z_{pm} is given by

$$Z_{pm} = \frac{\mu_r}{N}\frac{\cos\theta_o}{\cos\theta_i}\tanh(kd\cos\theta_i) . (4b)$$

in order to remove the dependence on polarization we impose an extra condition that $|N| >> 1$. That is the wave inside the absorber is travelling in a direction normal to the surface. Thus, for normal incidence, $Z_{pm} = Z_{nm} = Z_m$ and is given by

$$Z_m = \sqrt{\mu_r/\varepsilon_r}\tanh(kd) \quad .(4c)$$

The frequency dispersion characteristics of μ_r for Co-BHF [4], can be represented as

$$\mu'_r = \frac{4.0}{\sqrt{1+(f-f_r)^2}}\cosh\frac{2(f-f_r)}{f+f_r/2} \quad .(5a)$$

$$\mu''_r = \mu'_r(f-1.0) \quad .(5b)$$

The maximum available value of $\varepsilon_r = 10-j1$ for the Co-BHF was assumed. The values of permittivity & permeability will be diluted by the addition of rubber as the binder and can be computed. The thickness of the Absorber will then be given as

$$d = \lambda/[4\ \mathrm{real}(\sqrt{\varepsilon\mu})] \quad . (6)$$

where λ_o is the free space wave length at f_r, ε & μ are the equivalent permittivity and permeability of the ferrite rubber composite material. The absorption can then be computed from the relation, $P = -20\log_{10}|R_{jo}|$

3. Design and Fabrication of the Absorber

The design specifications were minimum 10dB absorption over 12-18 GHz. (Ku-band). The design was made by using the flexible tolerance [13] method, a miltivariable constraint optimization subroutine. The optimization subroutine was used because the bandwidth requirement was itself nonunique, in the sense that beyond a given level the absorption could fluctuate in an unspecified manner. The optimization subroutine was run several times with different numerical weights & the optimized values of 12.8 GHz.

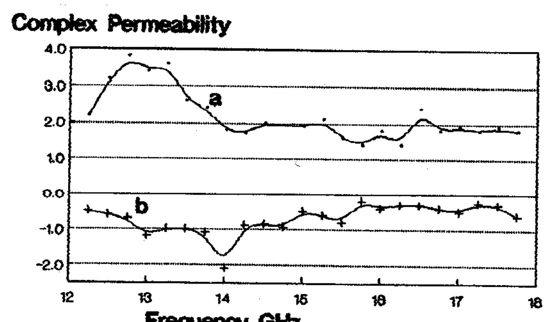

Fig. 3 Experimentally determined values for μ_r. Curves a & b corrosponds to real and imaginary parts of μ_r

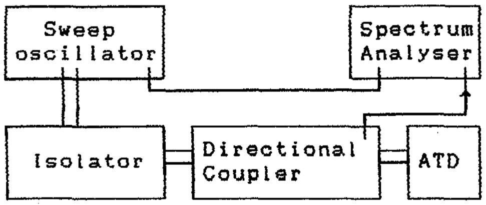

Fig. 4 Experimental set up to measure absorption of the absorber using the ATD.

for f_r and a 45%:55% ferrite:rubber ratio was selected. The computer simulated absorption characteristics for the selected parameters is shown as curve 'a' in Fig.5. The f_r of Co-BHF can be varied by varying δ, the amount of cobalt substituted. The variation of f_r with δ can be represented [3,4] by the following empirical relation

$$\delta = 1.09 - 0.023 f_r \qquad .(7)$$

thus δ for any required f_r in GHz. between 3.9 & 46 GHz can be determined. The conventional ceramic procedure was employed in the preparation of the Co-BHF & the particle size was controlled to ≤15 microns by employing a sub-sieve technique [5]. The frequency dispersion characteristics of permeability for the

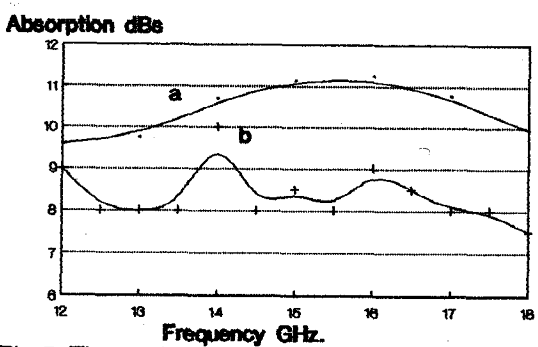

Fig.5 Theoretical & experimental results for the designed Absorber Sheet.

prepared ferrite was determined, by the conventional "open ckt-short-ckt" method [6]. The dispersion so obtained is plotted in Fig.3

The ferrite-rubber in the required ratio of 45%:55% was mixed & fabricated into a sheet of dimension 300X300X1.8mm.

4. Measurement Of Reflection Loss Or Absorption.

1.For normal incidence : The Absorber Testing Device ATD, [7] was employed to obtain the absorption characteristics of the absorber. The experimental set up is shown in Fig.4. A reference power level is noted without the absorber, and the reflected power with the absorber was measured. The difference in the two will give the power absorbed by the absorber. The measured absorption is plotted as curve 'b' in Fig.5.

2.For oblique incidence : A free space bistatic measurement setup operating in the frequency range of 8-18 GHz. as shown in Fig.6 was employed to measure $|R_{no}|$ & $|R_{po}|$. The absorption characteristics obtained for a particular angle of incidence is plotted as curve 'b' in Fig.7. The absorption as a function of the incident angle is shown in Fig.8

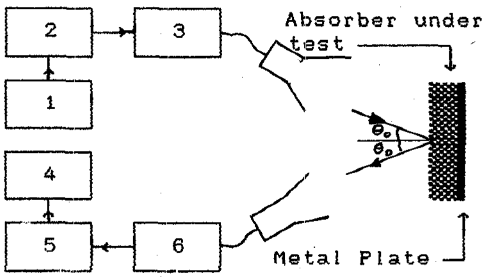

Fig. 6 Bistatic measurement setup for obliquely incident wave. 1.Microwave source, 2.and 5.Coaxial to waveguide adopters, 3.& 6.Tuners

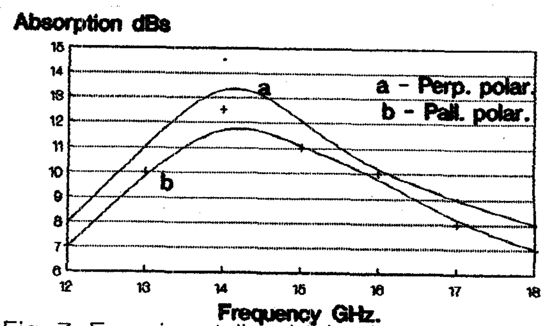

Fig. 7. Experimentally obtained Absorption Charateristics at 30 degrees incident angle

5. Results & Discussions :

The theoretical analysis and design of a single layer Absorber with broad band characteristics are given. An absorber to give a minimum 10dB over 12-18 GHz.has been designed and fabricated.The

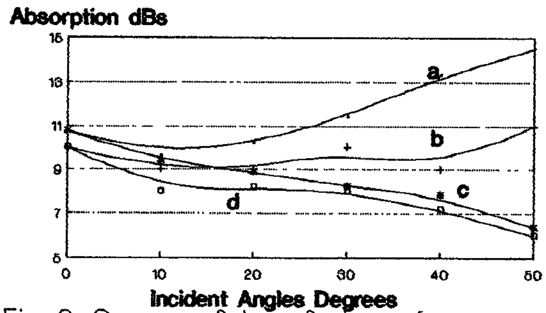

Fig. 8. Curves a & b, c & d, are for normal & parallel polarizations, a & c theoretical, b & d experimental curves

experimentally obtained absorption follow the same pattern and agree closely with the theoretical results. As can be observed from the Fig.7 & 8 a minimum of 8 dB absorption has been achieved over the desired frequency band. The reduction in the absorption obtained can be due to the practical limitation of the fabrication process. The above design procedure can also be used for other frequency bands. The design approach is being extended to multilayer absorbers to obtain a higher peak absorption and larger bandwidths.

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