Application of Artificial Material in Microwave Absorber

Arun K. Saha
Department of Math, Computer Science & Physics
Albany State University
Albany GA USA
arun.saha@asurams.edu

Walker G. Pendleton
Department of Chemistry & Forensic Science
Albany State University
Albany GA USA
wpendlet@students.asurams.edu

***Abstract*—a microwave absorber is designed with a given absorbing material whose relative permittivity and permeability are known. In this design process, impedance matching between absorber and free space is achieved by circular metal patches of predesigned shape printed periodically on absorbing material. Designed microwave absorber along with predesigned designed metal strip is modeled in 3D electromagnetic simulation software HFSS. Simulated frequency response of reflection coefficient verifies impedance matching and absorption at design frequency.**

Keywords— microwave absorber, free space impedance matching, HFSS, artificial material

I. INTRODUCTION

Microwave absorber is a single or multilayer sheets of dielectric materials stacked one above another and one side covered with metal plane. To design a microwave absorber, design engineer currently depend on material data sheet provided by the companies. To eliminate this dependency, a technique is presented here to gain control on material property artificially by printing predesigned metal patches on the material. Once designers have control on material properties, material with company standard thickness can be used resulting in overall cost effectiveness in design process. Moreover, printing predesigned metal patches does not contribute any weight in the absorber when compared with other absorbers [1-5].

II. MATERIAL & METHOD

A. Theory

According to transmission line theory, the input impedance of a microwave absorber (Fig.1) can be given by (1).

$$Z_{in} = Z_c \tanh\left(\frac{j2\pi f d\sqrt{\varepsilon_r \mu_r}}{c}\right) \qquad (1)$$

Here relative permittivity $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$, relative permeability $\mu_r = \mu_r' - j\mu_r''$, d = absorber thickness, f = frequency at which input impedance is calculated, c = speed of light and intrinsic impedance of absorbing material $Z_c = 120\pi\sqrt{\mu_r/\varepsilon_r}$. For perfect impedance matching, absorber input impedance must be equal to free space impedance $120\pi\ \Omega$ and after some manipulation the following governing equation is obtained assuming dielectric loss tangent $\tan\delta_e = \epsilon_r''/\epsilon_r'$ and magnetic loss tangent $\tan\delta_m = \mu_r''/\mu_r'$.

$$1 - \sqrt{\frac{\mu_r'(1-j\tan\delta_m)}{\varepsilon_r'(1-j\tan\delta_e)}} \times \tanh\left(\frac{j2\pi f d\sqrt{\mu_r'\varepsilon_r'(1-j\tan\delta_m)(1-j\tan\delta_e)}}{c}\right) \qquad (2)$$

After further manipulation, (2) gets the following standard complex form as shown in (3).

$$g + jh = 0 \qquad (3)$$

Inclusion of metal patches in the absorbing material contributes to ε_r' only and dielectric loss tangent $\tan\delta_e$ remains same assuming that metal patches are of very high conductivity. Further assumption is that μ_r' and magnetic loss tangent $\tan\delta_m$ remain unchanged because excitation electric field polarizes along the plane of metal patches. All these assumptions above leave the quantities g and h in (3) as the function of material thickness d and ε_r' only and can be found by solving the following simultaneous equations

$$g(d, \varepsilon_r') = 0 \qquad (4)$$

$$h(d, \varepsilon_r') = 0 \qquad (5)$$

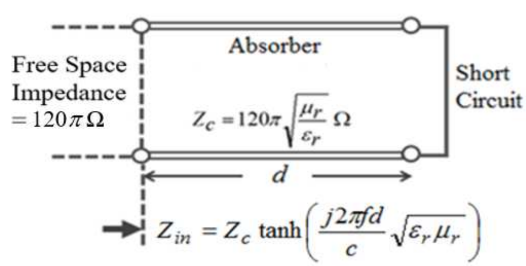

Fig.1. Transmission line model of microwave absorber.

B. Material Parameter Estimation

If absorption frequency is chosen 1.5 GHz and a magnetic material MR31 (ε_r' =18.18, $\tan\delta_e$ =0.023, μ_r' =5.2, $\tan\delta_m$ =0.577) available at MAST Technologies Inc., San Diego, CA is considered, then solution of (4) and (5) with Newton-Raphson method gives material thickness d = 3.2 mm and ε_r' = 36.91. But this is obvious that the chance of finding a material with thickness d = 3.2 mm and ε_r' = 36.91 is very rare

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or impossible and here lies the intellectual merit of this research. The magnetic material MR31 has thickness of 1.0mm. Therefore, 3 or 4 sheets of this material can be used. Considering structural symmetry, 4 sheets (4.0mm) are used. Because of thickness difference (4.0mm and 3.2mm), impedance mismatch occurs. Now it is necessary to find out appropriate value of ε_r' for best (but not perfect) impedance matching and this can be found from the plot of magnitude of the quantity $\sqrt{g^2 + h^2}$ of (3) with respect to ε_r' as shown in Fig.2. It is seen from Fig. 2 that best impedance matching occurs at ε_r'= 25.4 for thickness d = 4.0mm.

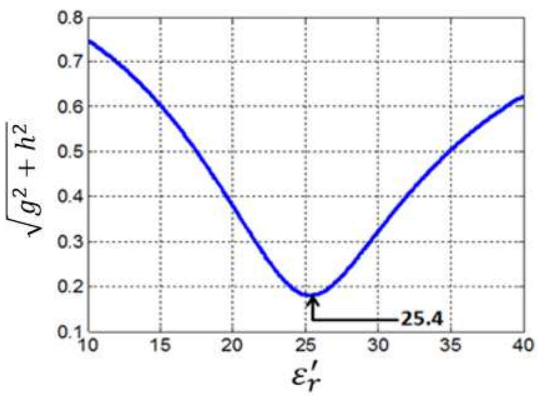
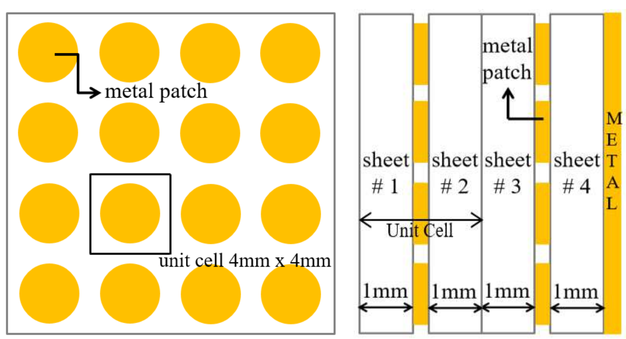


Fig.2. Determination of ε_r' from governing equation.



(*a*) (*b*)

Fig.3. Schematic layout of absorber (*a*) top view (*b*) side view.

C. Material Parameter Realization

The considered material has ε_r' =18.18. Now to enhance this value [6-7] to the desired magnitude of 25.4, circular metal patches are printed periodically on this material as shown in Fig. 3. Periodicity or center to center distance between metal patches is considered 4.0mm as shown in Fig. 3(*a*) and in the direction of thickness periodicity is considered 2.0mm as shown in Fig. 3(*b*). Based on this periodicity, a unit cell (4mm x 4mm x 2mm) in parallel plate waveguide structure is modeled in HFSS as shown in Fig.4. It is assumed that incident electric field is polarized parallel to the plane of metal patch resulting in *no enhancement* in relative permeability $\mu_r = \mu_r' - \mu_r''$. So, for simplicity in calculation, it is suffice to fill the unit cell with material whose relative permittivity is $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ =18.18 – j0.42, Using this unit cell, waveguide reflection/transmission method [8] is used to determine overall effective permittivity ε_r' by knowing reflected power data (S_{11}), transmitted power data (S_{21}), total length of parallel plate wave guide structure (L) and length of unit cell (d). Variation of overall effective permittivity ε_r' with respect to the radius (r) of metal patch is displayed in Fig. 5. Of course, with enhance of ε_r' value, the loss component ε_r'' also increases to maintain dielectric loss tangent ($\tan\delta_e$) almost constant. However, increase in ε_r'' value makes the absorption peak slightly blunt but does not change the chosen absorption frequency 1.5 GHz. Absorption frequency mainly depends on ε_r'.

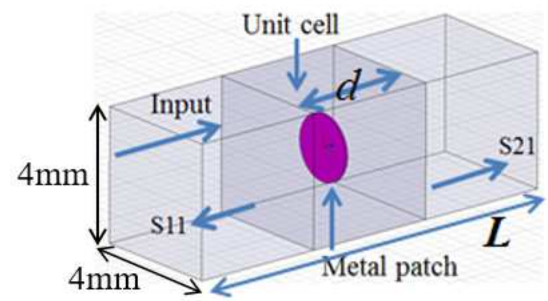


Fig.4. Unit cell to determine overall effective permittivity.

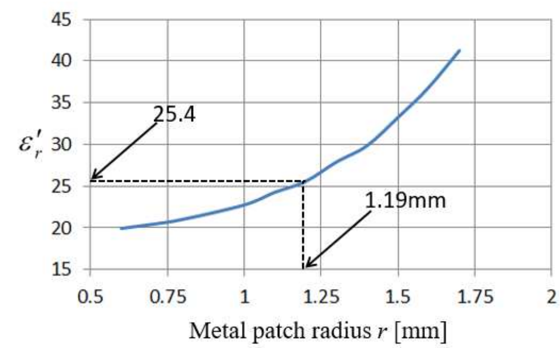


Fig.5. Variation of overall effective permittivity with respect to the radius of metal patch.

From Fig.5, it is seen that for metal patch radius = 1.19mm, overall effective permittivity (ε_r') becomes 25.4 which is the required value for best impedance matching as shown in Fig. 2.

III. RESULT

Now, all information is available to design the absorber. The required information to fabricate the absorber include 1mm thick magnetic material with relative permittivity $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ =18.18 – j0.42, relative permeability $\mu_r = \mu_r' - \mu_r''$ = 5.2 – j3.0, metal patch radius r = 1.19mm, periodicity of metal patches = 4.0mm in planer direction, 2.0mm in thickness direction and 4 sheets of such material are stacked one above another as shown in Fig. 3(*b*). The designed absorber is modeled in HFSS as shown in Fig. 6.

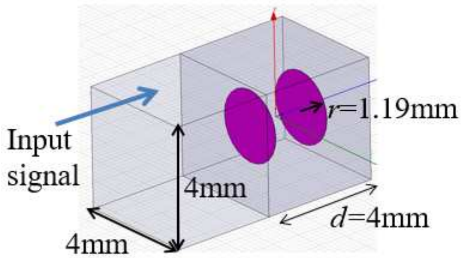


Fig. 6. HFSS model of the designed absorber.

Simulated frequency response of the reflection coefficient is displayed in Fig. 7. Simulation result shows that best absorption (S_{11} = -26 dB) occurs at 1.48 GHz which is in excellent agreement with the design value of 1.50 GHz.

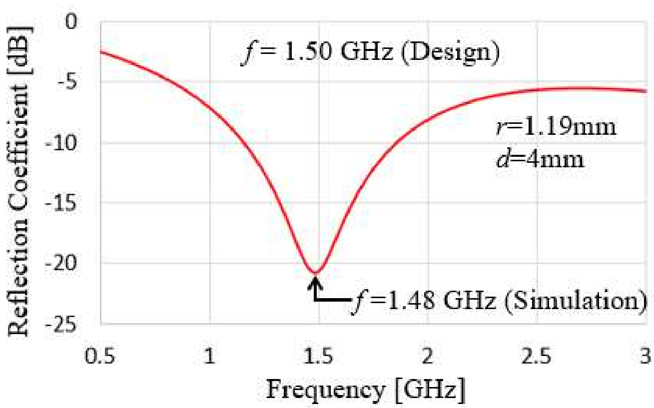


Fig.7. Frequency response of the designed absorber.

IV. CONCLUSION

Artificial material technique is successfully applied to design a microwave absorber. The merit of this technique is that any given material can be transformed into a microwave absorber just by printing predesigned metal patches with appropriate periodicity. However, the upper limit of the desired absorption frequency cannot be higher than the absorption frequency of a single layer. This is because the absorption frequency of an absorber is determined by the quarter wave resonance phenomenon and when metal patches are embedded, overall effective permittivity is increased resulting in decrease in absorption frequency. Adopting the proposed technique, designers can avoid the procurement of custom-fabricated material resulting in huge cost savings.

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