Role of Dielectric Loss in Microwave Absorber Design

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***Abstract*—a theoretical analysis is conducted to understand the role of dielectric loss component in the design process of a microwave absorber. The analysis starts with the determination of input impedance of the absorber and equating this to free space impedance in order to develop the impedance matching equation. The result of analysis showed that absorbing material must have some amount of loss component for impedance matching at a certain frequency and for perfect impedance matching a specific value of loss factor is required along with specific value of dielectric constant and material thickness.**

***Keywords*— microwave absorber, free space impedance matching, dielectric loss factor**

I. Introduction

Microwave absorber is a single or multilayer sheets of dielectric materials stacked one above another with one side covered with a metal plane. The input impedance of a microwave absorber, which depends on three parameters such as dielectric constant, loss component and thickness, is a complex quantity whereas free space impedance is real number. As a result, to determine a specific material parameter by solving the impedance matching equation is not straight forward and exact solution of one parameter may not be found for perfect impedance matching because of the constraints to other two parameters of the material. Therefore, best impedance matching suffices if perfect matching is not achievable.

II. Material & Method

A. Theory

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

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

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 $\tan\delta_m = \mu_r''/\mu_r'$.

$$1 - \sqrt{\frac{\mu_r'(1-j\tan\delta_m)}{\varepsilon_r'(1-j\tan\delta_e)}} \times \tanh\left(\frac{j2\pi f d\sqrt{\mu_r'\varepsilon_r'(1-j\tan\delta_m)(1-j\tan\delta_e)}}{c}\right) = 0 \tag{2}$$

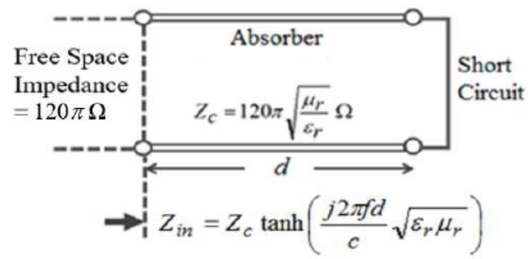

Fig. 1. Transmission line model of microwave absorber.

B. Analysis

Case of lossless nonmagnetic dielectric material

In this case, $\mu_r' = 1$, dielectric loss tangent $\tan\delta_e = \epsilon_r''/\epsilon_r' = 0$, magnetic loss tangent $\tan\delta_m = \mu_r''/\mu_r' = 0$, and (2) takes the following form as shown in (3). In (3), the left hand side is a complex quantity consists of a non-zero real and a non-zero imaginary component and can never be equal to zero and as a result, no solution exists.

$$1 - j\sqrt{\frac{1}{\varepsilon_r'}} \times \tan\left(\frac{2\pi f d\sqrt{\varepsilon_r'}}{c}\right) = 0 \tag{3}$$

Case of lossy nonmagnetic dielectric material

In this case, $\mu_r' = 1$, magnetic loss tangent $\tan\delta_m = \mu_r''/\mu_r' = 0$, and (2) takes the following form as shown in (4). With further manipulation (4) takes the form of (5), (6) and then (7) as below

$$1 - \sqrt{\frac{1}{\varepsilon_r'(1-j\tan\delta_e)}} \tanh\left(\frac{j2\pi f d\sqrt{\varepsilon_r'(1-j\tan\delta_e)}}{c}\right) = 0 \tag{4}$$

$$1 - (p + jb) = 0 \tag{5}$$

$$(1 - p) + jb = 0 \tag{6}$$

$$a + jb = 0 \tag{7}$$

Now, the left hand side of (7) is a complex quantity in which the real and imaginary component can be zero or close to zero

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simultaneously to make a solution possible. A numerical example is provided below to explain the solution process and the role of loss component in impedance matching and absorber design.

III. NUMERICAL RESULT

Let's design a microwave absorber with absorption frequency (*f*) 10.3 GHz and the material that was chosen had thickness d=2.0 mm, $\varepsilon_r' = 9.0$, but considered as a variable, $\varepsilon_r'' = 4.5$, $\tan\delta_e = \epsilon_r''/\epsilon_r' = 0.50$, μ_r'=1.0, $\mu_r'' = 0$, $\tan\delta_m = \mu_r''/\mu_r' = 0$, and speed of light is c=3.0x10^8 m/s. Plugging all these parameters into (4), the magnitude of the quantity $\sqrt{a^2+b^2}$ was plotted against ε_r' as shown in Fig. 2. From this plot, it was seen that best impedance matching occurred at $\varepsilon_r' = 13.2$ for absorption frequency of 10.3 GHz. Now, to enhance the value of ε_r' from 9.0 to 13.2 periodic insertion of metal strips into the material was necessary [1]. Inserted metal strips were considered to have very high conductivity and did not contribute to the overall loss factor $\tan\delta$. 3D electromagnetic simulation software HFSS was used to extract material parameters ε_r' and ε_r'' as shown in Fig. 3. Reflection/transmission method was adopted in the extraction process [2]. The simulation result showed that with the enhancement of ε_r', the loss component ε_r''also increased from 4.5 to 6.81 (Fig. 3) to keep dielectric loss tangent $\tan\delta = \varepsilon_r''/\varepsilon_r'$ almost constant.

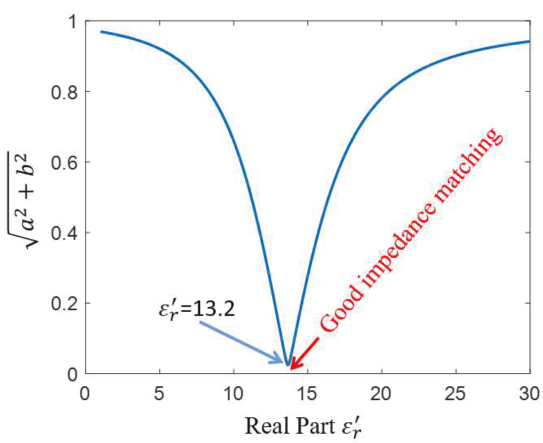

Fig. 2. Determination of ε_r' from governing equation.

As expected, the increase in ε_r'' value from 4.5 to 6.81 *should not affect the operational frequency or absorption frequency.* This could be attributed to the facts that dielectric loss tangent $\tan\delta$ remained almost constant and presence of ε_r' in the numerator and denominator of the major term in (4) canceled out the effect of enhancement in the value of ε_r'. As a result, absorption frequency (*f*) remained unchanged which was verified in Fig. 4 by plotting the quantity $\sqrt{a^2+b^2}$in (7) with respect to the frequency (*f*).

However, the increase in ε_r'' value slightly affected the impedance matching at the desired absorption frequency 10.3 GHz. This little impedance mismatch was displayed in Fig. 4, where it was seen that best absorption occurred at 10.3 GHz but the absorption point was somewhat far from frequency axis showing poor impedance matching. This was due to the fact that according to (4), perfect impedance matching at a certain frequency (*f*) occurred for particular values of $d, \varepsilon_r', \varepsilon_r'', \tan\delta$. Inserted metal strips although did not change $\tan\delta$, but ε_r' and ε_r'' changed significantly (Fig. 3) to cause impedance mismatch.

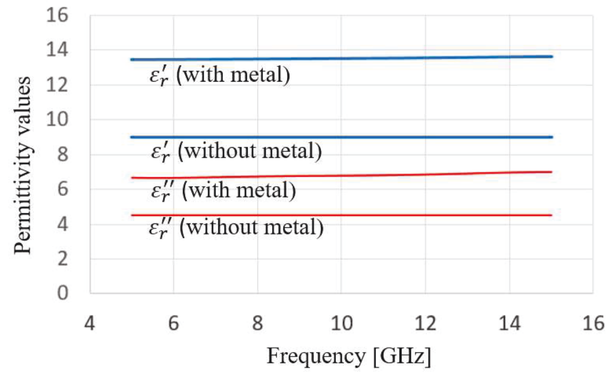

Fig. 3. $\varepsilon_r'$and ε_r'' values with and without metal strips

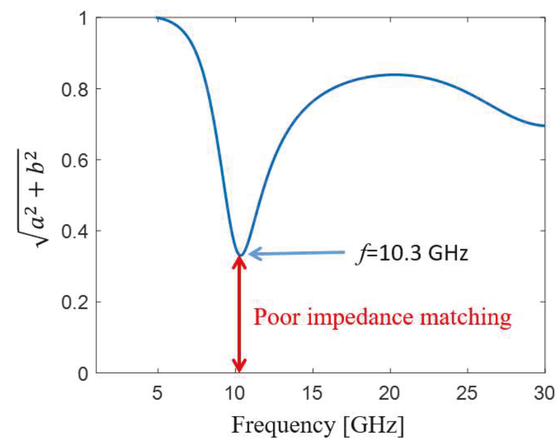

Fig. 4. Demonstration of absorption frequency and corresponding impedance matching

IV. CONCLUSION

The theoretical analysis conducted here supports the fact that a microwave absorber can never be fabricated with a lossless dielectric material as incident signal gets fully reflected because of impedance mismatch. With a lossy dielectric material, reasonably good impedance matching can be obtained although practically perfect matching might be a case of very rare instance because of the constraints in available material parameters.

ACKNOWLEDGMENT

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