Optimized Design of Broadband Radar Absorbent Material

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Abstract - Radar absorbent material (RAM) is widely used such as interference prevention between devices using radio waves and the wall of anechoic chamber. They have excellent characteristics depending on the applications, such as broadband characteristics, oblique incidence characteristics and both polarization characteristics. In recent years, various optimization methods have been used in RAM design studies. In this paper, we study the optimized design of two flat layers RAM with broadband characteristics by using Non-dominated sorting genetic algorithm-II (NSGA-II). The index of radio wave absorption amount is 20 dB corresponding to the absorption rate of 99 %, and the objective of this study is to obtain broadband characteristics satisfying the index. As a result, it is confirmed that broadband characteristics with relative bandwidth of 158 % can be obtained from 1.78 GHz with respect to 20 dB. In addition, two flat layers RAM with the maximum relative bandwidth is possible to be designed for the required minimum frequency at 1.78 GHz or higher by using the proposed optimized design method.

Index Terms — Radar Absorbent Material, Broadband, NSGA-II, Optimization.

1. Introduction

Various kinds of radar absorbent material (RAM) are widely used such as interference prevention between devices using radio waves and the wall of anechoic chamber. They have excellent characteristics depending on the application, such as broadband characteristics, oblique incidence characteristics and both polarization characteristics. On the other hand, there are disadvantages such as structural restrictions, frequency limitation and the need of fabrication accuracy [1]. Therefore, it is important to design RAM of which shape is not restricted for use, and how much the above-described required performance is satisfied.

In this paper, we use two flat layers RAM having the flat plate structure in order to overcome structural restrictions and widen application for use. Moreover, we use dielectric material, since it can be used in a high frequency region where the complex relative magnetic permeability decreases and it is also lightweight compared with the magnetic material such as ferrite [2]. The determination of the electrical material constant of each layer is the most important with respect to the received frequency and the incident angle, because they affect the performance of RAM, that is, the values of the complex relative permittivity and the thickness. In order to solve such a problem, many researchers applied optimization methods to calculate them [3], [4]. We also investigate the optimized electric material constant by applying Genetic Algorithm (GA). Since GA is usually a single-objective optimization, we use NSGA-II (Non-dominated sorting genetic algorithm-II) [5], which is one of the Multi-Objective GA (MOGA). The index of wave absorbing amount \((W_a)\) is 20 dB corresponding to the absorption rate of 99 %. We optimize the electrical material constant so as to satisfy broadband characteristics of 20 dB or more at normal incidence.

2. RAM Configuration

Fig. 1 shows configuration of two flat layers RAM. Flat layers RAM has a structure that RAM is installed on a metal plate, and it is possible to reduce its energy by controlling the amplitude and the phase of the reflected wave. \(W_a\) is determined by the values of the electric material constant of RAM. In addition, dielectric RAM has a permeability of \(1 + j\theta\), so the values of complex permittivity and thickness of each layer are design variables.

In this study, the index of \(W_a\) is set to 20 dB as described above, and broadband characteristics are investigated to satisfy this index. Moreover, because the complex permittivity depends on the received frequency, it is necessary to consider the frequency dispersion of the real part and the imaginary part of permittivity. Thus, we use the following formulas using those values at 1 GHz and the decay coefficients \(a\) and \(\beta\) [6].

\[
\varepsilon_r(f) = \frac{\varepsilon_r(1\text{ GHz})}{f^a}. \tag{1}
\]
3. Optimization Method

The calculated frequency range is specified from 0.1 to 15.0 GHz. In order to satisfy the broadband characteristics, we aim for the expansion of frequency bandwidth. The objective function is set so that frequencies at which \( Wa \) is 20 dB or more are continuously obtained and the number \( N \) of the frequencies is maximized. In addition, it is important to lower the minimum frequency \( f_{\text{min}} \), that is, the first frequency at which \( Wa \) is 20 dB or more. This leads to further broadband characteristics.

Therefore, the objective functions are defined as the following two equations, and we maximize them by NSGA-II.

\[
F = N. \tag{3}
\]

\[
G = - f_{\text{min}}. \tag{4}
\]

4. Optimization Results

There are 10 design variables in total, and their ranges are shown below. The real part of permittivity of each layer at 1 GHz is from 1 to 20, the imaginary part of permittivity is from 0 to 20, the values of decay coefficients are from 0 to 1, and the thickness of each layer is from 1 mm to 20 mm.

Fig. 2 shows the optimized results of two objective functions. The horizontal axis shows the relative bandwidth at which \( Wa \) is 20 dB or more, and the vertical axis indicates the minimum frequency.

Point A satisfies broadband characteristics best. Moreover, it also satisfies lowering the minimum frequency. It can be confirmed that the proposed two flat layers RAM has relative bandwidth of 158 % and the minimum frequency of 1.78 GHz with respect to \( Wa \) of 20 dB. Moreover, in the distribution of the optimized results in Fig. 2, the points having the maximum relative bandwidth for each minimum frequency appear on a straight line at the right end.

The frequency located at the right end of the optimization results in Fig. 2 is \( f \) [GHz], and the relative bandwidth that \( Wa \) is 20 dB or more is defined as \( BW \) [%]. The line can be approximated by the straight line expressed as in (5).

\[
f = -7.46 \times \frac{BW}{100} + 13.5847. \tag{5}
\]

The numbers of frequencies up to the upper limit frequency of 15.0 GHz are determined with respect to each minimum frequency. The reason why the broadband characteristics can be obtained is considered that the maximum numbers of frequencies are taken. Therefore, the maximum value of the relative bandwidth with respect to each minimum frequency appears as the straight line. This result shows that two flat layers RAM with the maximum relative bandwidth is possible to be made for the required minimum frequency at 1.78 GHz or higher.

From the above, the proposed two flat layers RAM satisfies broadband characteristics including the low frequency band by optimizing the two objective functions simultaneously. By considering frequency dispersion of the complex permittivity, it is possible to obtain \( Wa \) of 20 dB in a wider frequency range.

5. Conclusion

In this paper, we investigate the optimized electric material constant of two flat layers RAM with broadband characteristics by NSGA-II. As a result, it was possible to achieve broadband characteristics, that is, the relative bandwidth of 158 % from 1.78 GHz for the index of radio wave absorption amount 20 dB. In addition, two flat layers RAM with the maximum relative bandwidth is possible to be designed for the required minimum frequency at 1.78 GHz or higher along the approximate straight line. Moreover, since the minimum frequency is designed to be low in this proposed method, we can design the necessary RAM even if the required frequency band is low. As a future work, we will study other characteristics required for RAM such as oblique incidence characteristics by applying this optimized design method.

References