# Visual graphic representation analysis of double layer frequency selective surface-based radar absorbing structure from wideband potential applications

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## Abstract

This paper extends the microwave impedance matching theory into wideband absorbing structure design. A straightforward visual graphic representation analysis is presented. An in-depth analysis is undertaken through double layer lossy frequency selective surface. The study shows that double layer absorber largely enhances the bandwidth than single layer ones.

**Keywords :** Impedance matching Lossy frequency selective surfaces Wideband

## 1. Introduction

In order to get radar absorbers which present thin and wideband characteristics, tremendous efforts have been devoted to improving the performance of radar absorbing materials (RAM) [1–6]. So far, most of the studies have focused on the preparation of materials with new composites and structures, but theory and simulation studies of materials are very rare. Some researchers have advanced theory which is referred to as circuit analog (CA) absorber in [7]. But there is little information available in literature about in-depth analysis and lucid interpretation with specific examples. Therefore, it is important to make detailed analysis using efficient and simple method to design wideband absorbers.

In this paper we present a novel visual graphic representation analysis of wideband absorbing structure based on Smith chart which is convenient for a multianalysis of all the geometric and physical parameter. An absorbing structure comprised of square ring shaped lossy frequency selective surfaces (LFSS) is taken as an example to do the extensive explanation. A broadband absorbing response is obtained through the optimization and calculation. Finally, the simulation verification of the absorbing structure is presented.

## 2. Design Principles of Visual Graphic Representation Analysis

The single layer absorbing panel used in the study consists of one LFSS sheet and one grounded spacer (Fig. 1(a)). The double layer absorbing panel composed of two LFSS sheets, one spacer and one grounded spacer (Fig. 1(c)). The overall thickness of the structure is defined as d. LFSS is an assembly of identical elements arranged in a two-dimensional infinite array. The elements loaded at their centers have been arranged in a rectangular array with inter-element spacing D. A square ring is chosen as the LFSS element, in which r, R, D and $R_S$ are denoted as the inner ring side length, out ring side length, inter-element spacing and surface resistance, respectively (Fig. 1(b)). The equivalent circuit for the absorbing panel is shown in Fig. 1(d). $Z_g$ denotes the input impedance of the ground plane, $Z_a$ denotes the impedance of the LFSS sheet alone and $Z_{in}$ denotes the free-space input impedance of the absorber for normal incidence. Based on this circuit, the equivalent circuit for a LFSS sheet will consists of an RLC series combination. The resistive component is a result of the lossy element material, while the inductance and the capacitance are associated with the elements shape and the gaps between the elements (Fig. 1(a), Fig. 1(b) and Fig.1(c)).

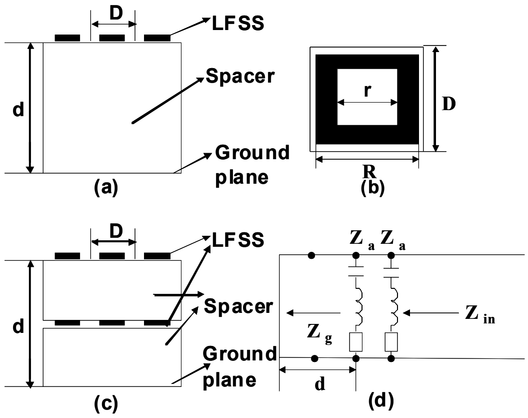



Figure 1: (a) Single layer absorbing panel comprising LFSS (b) Front view of each element in a single LFSS sheet (c) Double layer absorbing panel comprising LFSS (d) Equivalent circuit of absorbing panel.

Using this approach, the input impedance of the ground plane is given by

$$Z_g = jZ_m \tan(2\pi d\sqrt{\varepsilon_r} / \lambda) \quad (1)$$

where $Z_m$ is the characteristic impedance, $\varepsilon_r$ is the relative permittivity of the ground plane, $\lambda$ is the wavelength of the incidence wave. The input impedance of the free-space LFSS sheet is given by

$$Z_a = -Z_0(1+\Gamma)/2\Gamma \quad (2)$$

where $Z_0$ represents the impedance of free-space, $\Gamma$ is the free-space reflectivity of the LFSS sheet. The free-space input impedance of the absorber for normal incidence is given by

$$Z_{in} = Z_g Z_a / (Z_g + Z_a)\,. \quad (3)$$

The corresponding free-space reflection coefficient of the absorber at normal incidence is given by

$$\rho = (Z_{in} - Z_0)/(Z_{in} + Z_0) \quad (4)$$

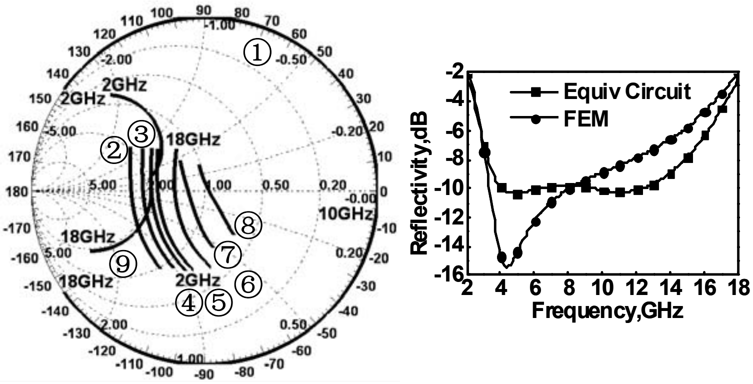
and the reflectivity by

$$\Gamma = 20\log_{10}(\rho)\,. \quad (5)$$

# 3. A Design Example

## 3.1 Single Layer Absorber Design

The admittance of the equivalent circuit is drawn on the Smith chart (Fig. 2(a)).With the purpose of obtaining the largest bandwidth design, an attempt is made in the band of 2 GHz to 18 GHz. The center frequency is 10 GHz. The admittance of the ground plane $Y_g$ which can be equal to short transmission line behaves as an inductor at the lower frequencies in the band of 2 GHz to 10 GHz, and a capacitance at high frequencies in the band of 10 GHz to 18 GHz as indicated by curve ① in Fig. 2(a) at the rim of the Smith chart. The reactive parts of $Y_g$ at 2 GHz and 18 GHz reach to 3.1(normalized admittance). Correspondingly, the admittance of the LFSS sheet $Y_a$ which has an imaginary part come close to the reactive parts of $Y_g$ and a real part approaches free space admittance $Y_0$ should be found to match with $Y_g$. At the center frequency 10 GHz, the distance between the ground plane and the LFSS sheet is approximately $\lambda_0/4$ which is equal to 7.5 mm ($\lambda_0$ is the center wavelength of the incidence wave). It is observed that if the reactive parts of $Y_g$ and $Y_a$ to a large degree cancel each other, the result in a location for the band of 2 GHz to 18 GHz will come very close to the center of the Smith chart and lead to a small reflection. Because a "good" element should be small in terms of wavelength [7], square ring is chosen as an LFSS shape which resonates well before the grating lobes. All the parameters of the square ring shaped LFSS have been analyzed. With the decrease of $R_S$, $Y_a$ is denoted by curves ⑧, ⑦ and ④. With the decrease of D, $Y_a$ is denoted by curves ⑤, ④ and ③. With the increase of the thickness of the square ring, $Y_a$ is denoted by curves ⑥, ④ and ②. Through rigid simulations, it is found that the trend is the same for the real and imaginary part of $Y_a$. Both of the real and imaginary part of $Y_a$ would increase with the change of surface resistance, spacing and the thickness of the square ring. Through optimization, the optimum $Y_a$ matched to $Y_g$ is denoted by curve ④. The LFSS resonate at 8.2 GHz while have a real part of 1.9. The imaginary part of $Y_a$ at 2 GHz and 18 GHz are 0.91 and -0.91, respectively. By one layer match, the sum of $Y_a$ and $Y_g$ is shown by curve ⑨ with the reflectivity shown in Fig. 2(b).

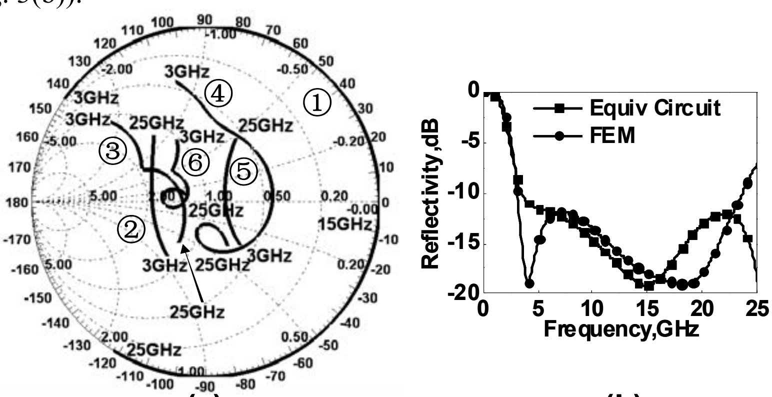



(a) (b)

Figure 2: (a) Smith chart plots of the single layer absorber with various parameters. Parameters of the square ring shaped LFSS are: Curve ② r=4.5 mm, R=10.5 mm, $R_S$ =70 ohm/sq, D=11 mm; Curve ③ r=5 mm, R=10 mm, $R_S$ =70 ohm/sq, D=10.5 mm; Curve ④ r=5 mm, R=10 mm, $R_S$ =70 ohm/sq, D=11 mm; Curve ⑤ r=5 mm, R=10 mm, $R_S$ =70 ohm/sq, D=11.5 mm; Curve ⑥ r=5.5 mm, R=9.5 mm, $R_S$ =70 ohm/sq, D=11 mm; Curve ⑦ r=5 mm, R=10 mm, $R_S$ =116.83 ohm/sq, D=11 mm; Curve ⑧ r=5 mm, R=10 mm, $R_S$ =162.5 ohm/sq, D =11 mm (b) Reflectivity of the singer layer absorber.

## 3.2 Double Layer Absorber Design

To enlarge the bandwidth, the double layer structure is designed (Fig. 1(c)). The thickness of each air spacer is 5 mm which leads the overall thickness to 10 mm. Through optimization, $Y_a$ of the first and second LFSS layer are denoted by curves ② and ⑤ (Fig. 3(a)). After matching with the first LFSS layer, the sum of curve ① and curve ② is shown by curve ③ located on the left of the Smith chart which is far from the center. Obviously, it is difficult to have ideal result in the low and high frequencies by curve ③. Traveling through 5 mm of air layer, the admittance changes to the right of the Smith chart by curve ④. After matching with the second LFSS layer by curve ⑤, curve ⑥ moves toward the center which has significantly reduced the reflectivity in the wideband frequencies (Fig. 3(b)).




(a) (b)

Figure 3: (a) Smith chart plots of the double layer absorber. Parameters of the square ring shaped LFSS are: Curve ② r=5 mm, R=10 mm, Rs=70 ohm/sq, D=11 mm; Curve ⑤ r=6.25 mm, R=8.75 mm, Rs=70 ohm/sq, D=11 mm (b) Reflectivity of the double layer absorber.

### 3.3 **Reflectivity Calculation**

To demonstrate the advantages of the proposed method, the reflectivity of the single and double layer absorber is obtained by finite element analysis and also by visual graphic representation analysis method (Fig. 2(b) and Fig. 3(b)). The computation result agrees with that get from the equivalent circuit model to a great extent. The double layer absorbing structure allows obtaining remarkable performance (-8 dB in the band from 2.9 GHz to 24.6 GHz) with an overall thickness of 10 mm. The bandwidth is nearly three times enhanced than single layer. This performance is superior to Salisbury screen, optimized Jaumann screen and the available commercially non-magnetic multilayer structures (see for instance [8]) with the same thickness.

## 4. Conclusions

In this paper a deep-depth analysis and research are presented on the reflectivity of wideband absorbing structure comprised of LFSS sheet. The results demonstrate that the use of Smith chart avoids the narrowband absorbing performance limitations in the traditional optimizer and greatly improves the efficiency of the design. The results also prove that double layer absorber has greatly enhanced the bandwidth than single ones. The design with a reflection less than 8 dB over a bandwidth exceeding 8:1 and thickness less than $\lambda/10$ at the lowest frequency is obtained. These research results provide an effective theory instruction for the design of radar absorbing structures.

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