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Frequency Control of a Resonant Radio Absorber with a Free Space

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Abstract – Numerical calculations of the matching of a resonant radio absorber (RA) have confirmed that the ideal matching of such an RA with free space can be realized using practically any dielectrics with losses at any desired frequency. The conditions are considered that provide the widest matching band of the RA, and it is shown that the ratio of the bandwidth to the RA thickness (bandwidth to thickness ratio) is about 3.7, i.e., more than for the usual single-layer Dallenbach RA (about 3.2).

INTRODUCTION

Among the wide variety of radio absorbers (RAs) for various purposes, single-layer Dallenbach RAs are widely used due to their reliability and ease of implementation. RAs of this type is a dielectric (magnetodielectric) layer with losses, located on a metal screen [1—7]. The frequency dependence of the reflection coefficient on this RA is characterized by several minima at the so-called matching frequencies [4]. The depth of these minima and their location on the frequency scale depends on the electromagnetic properties and layer thickness. By controlling these properties and the layer thickness, it is possible to minimize the reflection coefficients in the operating range of the RA, although it is usually not possible to achieve perfect matching even at the central frequency of this range in this way. In [5], a different way of solving the problem of ideal matching in the middle of the working range of a single-layer RF was proposed using an array of conducting square elements on a dielectric layer with losses, metallized from the opposite side. The effect of radio absorption is due to resonances in the volumes formed by the array elements and the electrically conductive screen. It was shown that by varying the array size and the thickness of the dielectric layer, it is possible to solve the problem of ideal matching of the RA at a given (resonant) frequency for a wide variety of dielectric materials.

The purpose of the article is to determine the factors providing the widest matching band of the resonant RA.

1. WAVEGUIDE MODEL OF THE SLIT BETWEEN ADJACENT ELEMENTS OF THE RESONANT RADIO ABSORBER ARRAY

The design of the resonant RA is a dielectric layer with a loss of thickness *d*, on one side of which there is a array with period P made of metal squares 2a x 2a, and the other side of the layer is metallized (Fig. 1a). When conditions $d \ll 2a$ and $d \ll \lambda$ are met (λ is the wavelength), the field in the volume between the array element and the electrically conductive surface has the form of a TEM-wave capable of resonating, reflecting from the open boundaries of this volume. The radioabsorbing properties of this structure are due to the resonant absorption of power in the dielectric inside the resonators. The power absorption in a separate resonator at the resonance frequency is maximum when the radiation losses (determining the connection with the external space) are equal to the heat losses in the double run TEM-waves in the resonator [6]. In this case, the width of the absorption band is greater the greater the losses. Numerical estimation of radiation losses depending on the width of the gap between adjacent resonators δ (δ = P - 2a) was carried out on a waveguide model.

The calculation model was a rectangular waveguide with cross section A x B (A = 2λ, B = 4λ/75, λ = 75 mm) with transverse slit width δ in one of the wide walls (Fig. 1b). The coefficients were calculated as $|S_{11}|^2$ for reflection and $|S_{12}|^2$ for transmission (by power). The emissivity from slot $|S_{13}|^2$ is determined as

$$|S_{13}|^2 = 1 - |S_{11}|^2 - |S_{12}|^2. \qquad (1)$$

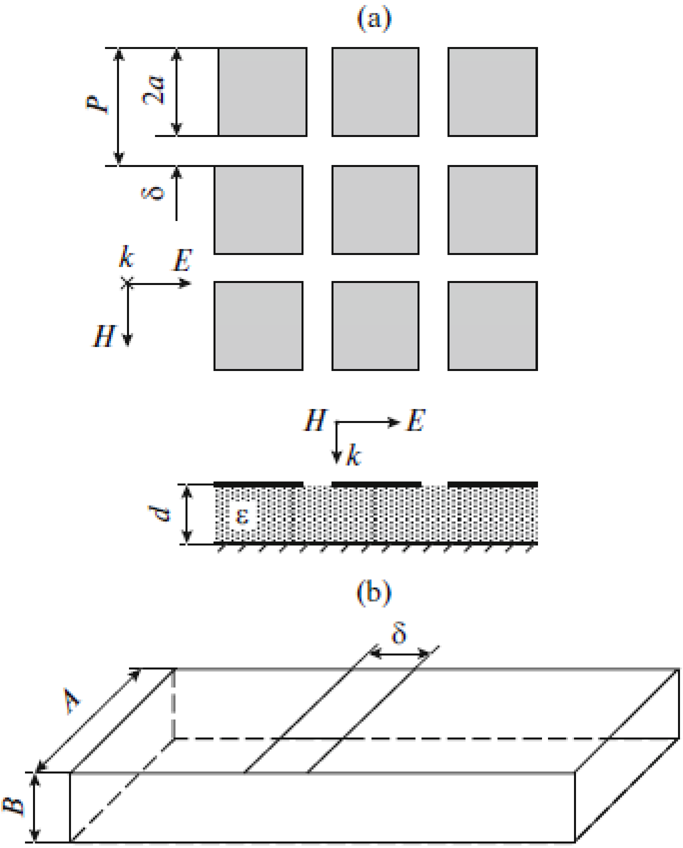

Fig. 1. Resonant radio absorber: (a) diagram, (b) waveguide model of the slot between the array elements.

Figure 2 shows the dependences of these coefficients on slot width 5 for two values of the dielectric constant of the medium inside waveguide, ε = 1 and 4. As follows from Figs. 2a and 2b, with an increase in the slot width, coefficients $|S_{11}|^2$ and $|S_{13}|^2$ increase monotonically, and the coefficient $|S_{12}|^2$ decreases monotonically.

Thus, with an increase in the width of the slots between the elements of the RA array, the absorption bandwidth of an individual resonator should increase (due to an increase in radiation into the external space), but the number of resonators per unit area of the RA decreases, which, on the contrary, should decrease the absorption band of the RA. The result of the action of these two factors is the existence of a certain optimal slit width at which the widest absorption band of the RA is provided.

2. DEPENDENCE OF THE ABSORPTION BANDAGE ON THE WIDTH OF THE SLOTS BETWEEN THE ELEMENTS OF THE RADIO ABSORBER ARRAY

The purpose of the numerical calculation of the dependence of the absorption band of the RA on the width of slits δ is an estimate of the optimal value of this width.

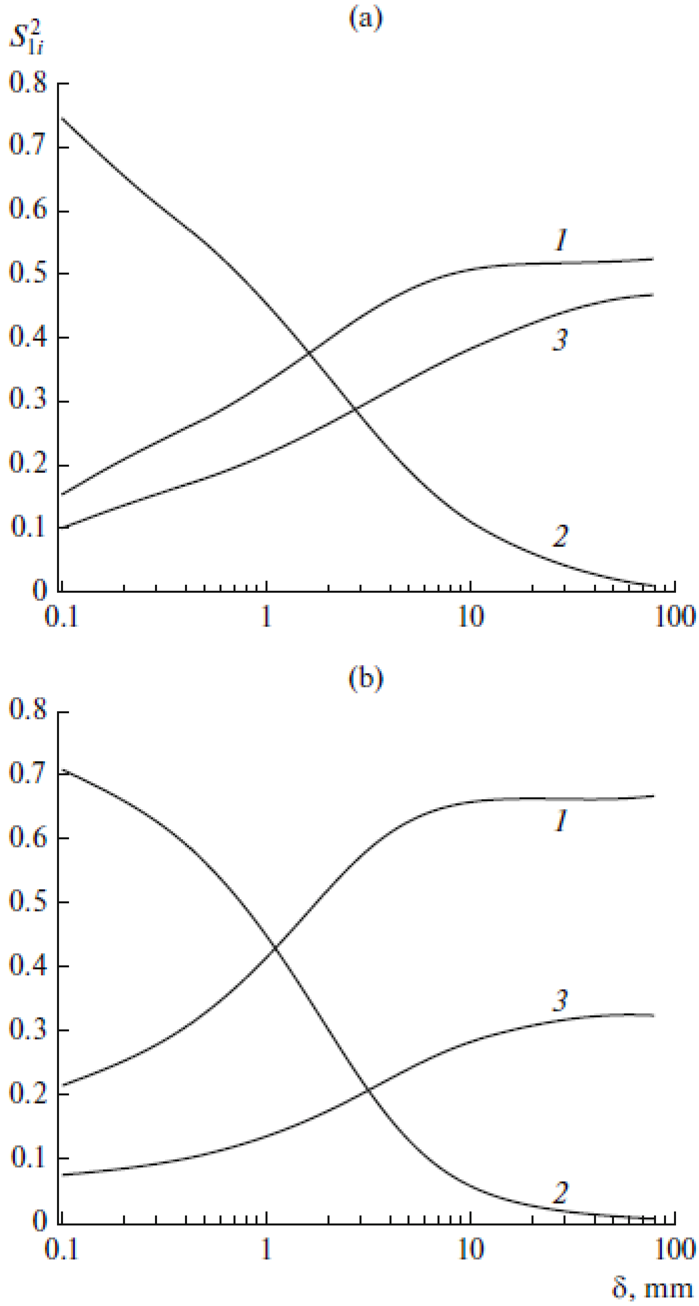

Fig. 2. Reflection coefficients dependence S_{11}^2 (1), passing S_{12}^2 (2), and radiation S_{13}^2 (3) from slot width δ at ε = 1 (a) and 4 (b).

For this, the frequency dependences of the reflection coefficient on the RA were calculated in a wide range of δ. Structures with the following characteristics were taken as calculation models:

Case I. ε = 1 – jε'', 2a = 26 mm, d = 4 mm,

δ = 1; 2; 4; 6; 8; 12; and 16 mm.

Case II. ε = 4 – jε'', 2a = 26 mm, d = 4 mm,

δ= 1; 2; 3; 4; 6; 10 and 14 mm.

The value of ε'' was selected so that at the resonant frequencies there was a complete match for the RA with free space (the reflection coefficient is less than -40 dB).

Figure 3 shows the frequency dependences of the reflection coefficient on the RA for cases I and II, and Table 1 shows the characteristics corresponding to these dependences.

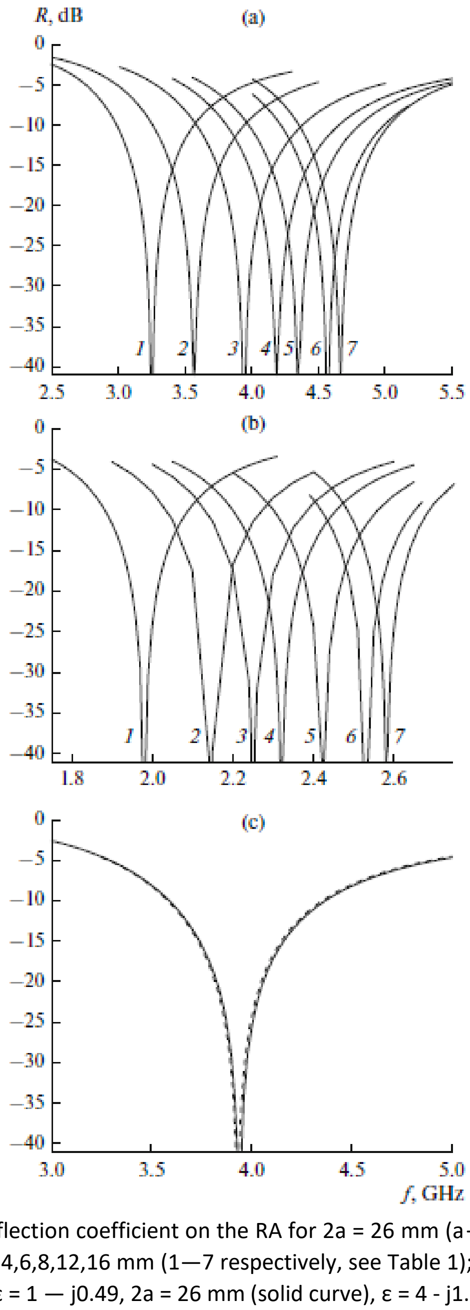

Fig. 3. Frequency dependences of the reflection coefficient on the RA for 2a = 26 mm (a—c) and 12.7 mm (c), *d* =4 mm and different ε and δ: (a) ε = 1 — jε'', δ = 1,2,4,6,8,12,16 mm (1—7 respectively, see Table 1); (b) ε = 4 — jε'', δ = 1,2,3,4,6,10,14 mm (1—7 respectively, see Table 1); (c) ε = 1 — j0.49, 2a = 26 mm (solid curve), ε = 4 - j1.36, 2a = 12.7 mm (dashed curve).

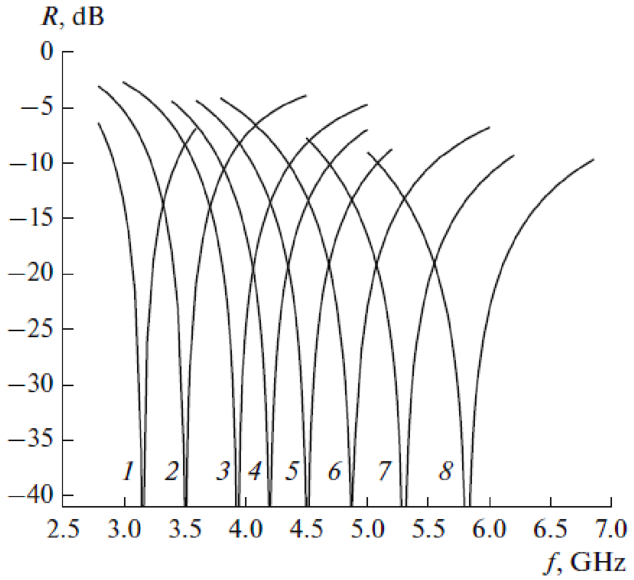

Fig. 4. Frequency dependences of the reflection coefficient on the RA for ε = 1 - jε”, δ = 4 mm, *d* = 4 mm, and 2a = 34,30,26,24,22,20,18,16 mm (1—8, respectively, see Table 2).

From Table 1 it follows that the maximum values of absorption bands $\Delta f/f_r$ = 20% in case I and $\Delta f/f_r$ = 11.6% in case II are achieved at values δ = 4 and 3 mm, respectively (see Figs. 3a and 3b, curves 3), i.e., at values equal to or close to thickness *d* of the dielectric layer. The significantly smaller absorption band in case II is associated with a lower resonance frequency. Therefore, a correct comparison of both cases was carried out at the same resonance frequencies. To this end, for the case when ε' = 4, *d* = 4 mm, and δ = 3 mm the frequency dependence of the reflection coefficient on the RA was calculated for element size 2a = 12.7 mm of an array at which the resonant frequency coincides with resonant frequency *f* = 3.94 GHz (see Fig. 3a, curve 3). Figure 3c demonstrates that the calculated frequency dependences (dashed and solid curves) practically coincide and are identical to curve 3 in Fig. 3a. Thus, the absorption band width in both cases is the same and equal to 20%, which confirms the efficiency of using materials with a fairly wide range of values ε'. In this case, tuning to the required frequency is realized by changing size 2a of array elements with constant (close to optimal) width of 8 of gaps between elements. Figure 4 shows the frequency dependences of the reflection coefficient on the RA with parameters *d* = 4 mm, δ = 4 mm, ε= 1 - jε”, and different sizes 2a. Table 2 shows their characteristics.

Figure 4 and Table 2 show that with an increase in resonant frequency f_r the absorption bandwidth increases monotonically $\Delta f/f_r$% reaching 31% at 2a = 16 mm, which is explained by the increase in communication with the external space of the resonators formed by the elements of the array and the electrically conductive screen. At the same time, quantity $\Delta\lambda/d$ remains practically unchanged.

Table 2. Characteristics of the frequency dependences of the reflection coefficient on the RA for the case ε = 1 - je”, δ = 4 mm, *d* = 4 mm

Curve number	δ, mm	ε"	f_r, GHz	$\Delta f/f_r$,%
ε = 1 – *j*ε" (see Fig. 3a)				
1	1	0.47	3.25	17.8
2	2	0.50	3.565	19.3
3	4	0.49	3.94	20.0
4	6	0.47	4.18	19.85
5	8	0.42	4.34	19.1
6	12	0.36	4.565	17.1
7	16	0.30	4.66	14.4
ε = 4 – *j*ε" (see Fig. 3b)				
1	1	0.73	1.98	10.6
2	2	0.76	2.148	11.2
3	3	0.77	2.25	11.6
4	4	0.76	2.32	11.2
5	6	0.72	2.425	10.7
6	10	0.60	2.53	9.1
7	14	0.51	2.58	8.1

δ is slot width, f_r is resonant frequency, $\Delta f/f_r$, % is absorption bandwidth at the reflection level of—10 dB, ε" is optimal values

Table 2. Characteristics of the frequency dependences of the reflection coefficient on the RA for the case e = 1 - jε”, δ = 4 mm, *d* = 4 mm

Curve number (see Fig. 4)	2*a*, mm	ε"	f_r, GHz	$\Delta f/f_r$,%
1	34	0.38	3.16	16.1
2	30	0.42	3.515	17.9
3	26	0.49	3.94	20.0
4	24	0.53	4.20	21.4
5	22	0.56	4.51	23.1
6	20	0.60	4.87	24.4
7	18	0.67	5.30	26.8
8	16	0.73	5.81	31.0

Attitude Δλ/*d* for all curves is 3.7.

3. CALCULATION OF SAMPLES OF A RADIO ABSORBER WITH REAL MATERIALS

Composites of two types are considered as dielectrics with losses for resonant RA.

Type I—a layered structure of alternating layers of polystyrene foam with a thickness of 6 mm and carbon-containing paper. The thickness of the layer of carbon-containing paper in different samples was different and amounted to 0.07, 0.14, and 0.21 mm. The complex dielectric constant of the paper, measured at 4 GHz, is ε= 20 - *j*15, and the calculated values of the dielectric constant of composites ecomp are approximately equal: 1.2 - *j*0.25, 1.4 - *j*0.5, and 1.6 - *j*0.75, respectively.

Type II—polyurethane elastomer filled with carbon black with a concentration of 2, 4, and 6 vol %. Dielectric constants of composites ecomp measured at 6 GHz are 5 - *j*1, 6.4 - *j*1.6, and 9 - *j*2.7 respectively.

Table 3. Characteristics of the frequency dependences of the reflection coefficient on the RA for composites of type I and II

Curve number	$2a$, mm	δ, mm	d, mm	ε'	ε"	f_r, GHz	$\Delta f/f_r$,%	$\Delta\lambda/d$
Type I composite (see Fig. 5a)								
1	27	2	2.05	1.2	0.25	4.01	12.5	3.71
2	23.5	4	3.45	1.4	0.5	4.01	16	3.7
3	20.1	4	4.4	1.6	0.75	4.01	19.8	3.72
Type II composite (see Fig. 5b)								
1	8.5	1.2	1.7	5	1	6	12.5	3.65
2	6.9	2	2.15	6.4	1.6	6	6	3.7
3	4.7	2	2.6	9	2.7	6	19.8	3.78

Figure 5 shows the calculated frequency dependences of the reflection coefficient on the RA based on type I and II composites, and Table 3 show their characteristics. When calculating the characteristics of the RA, the resonance frequencies were set at f_r = 4 and 6 GHz in the case of type I and II, respectively. From the calculation results given in Table 3, it follows that with an increase in the imaginary part of the dielectric constant of the material, the band of operating frequencies increases $\Delta f/f_r$ and RA thickness d but attitude Δλ/d remains practically unchanged and approximately equal to 3.7. For comparison, let us point out that for a conventional singlelayer Dallen-bach RA based on a dielectric material without frequency dispersion of the permittivity, this ratio in the hypothetical case of ideal matching of the RA with free space is 3.2 [7—9].

The calculation results also show that the perfect matching of the resonant RA with free space can be realized for any dielectric with losses at any given frequency.

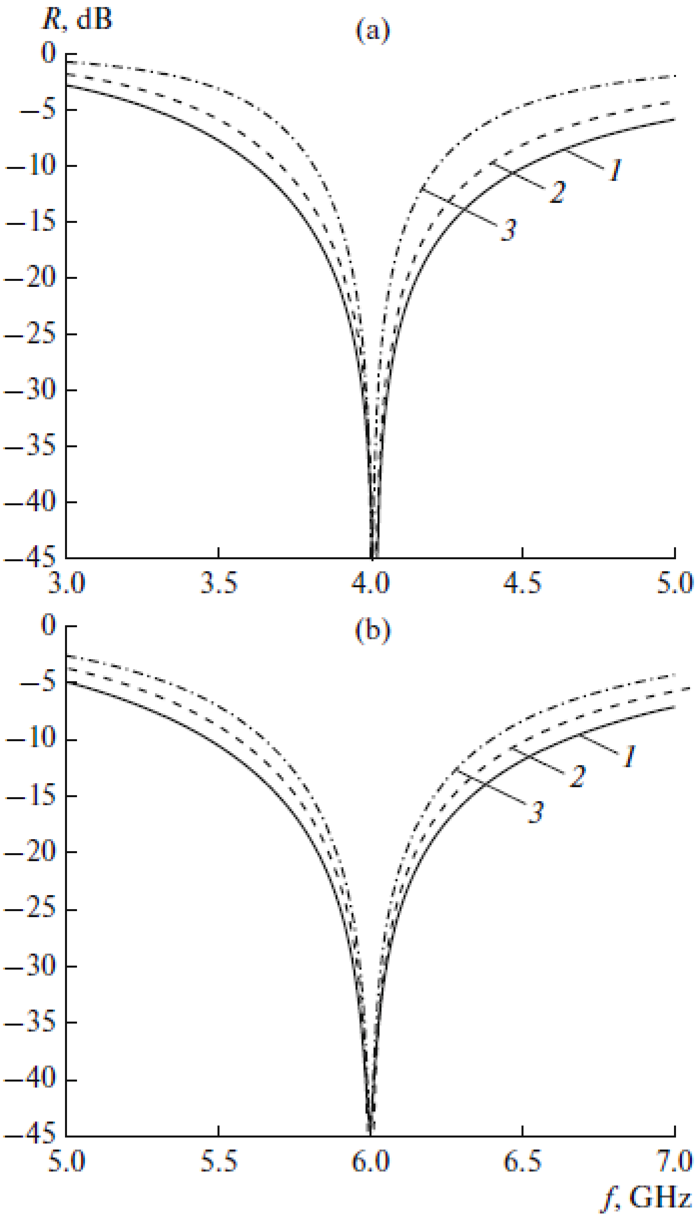

Fig. 5. Frequency dependences of the reflection coefficient on the RA based on composites of type I and II: (a) ε = 1.2 - *j*0.25 (1), ε = 1.4 - *j*0.5 (2), ε = 1.6 - *j*0.75 (3) (see Table 3), (b) ε = 5 - *j*1 (1), ε= 6.4 - *j*1.6 (2), ε= 9 - *j*2.7 (3) (see Table 3).

CONCLUSIONS

Numerical calculations have shown that the largest value of the absorption band width at a given resonant frequency of the resonant RA is provided at a certain ratio of slit width δ between adjacent array elements to thickness *d* of a layer of material between the array and the screen, which is relatively weakly dependent on dielectric constant ε. When ε = 1 this ratio is equal to unity, and with an increase to ε = 4, decreases to 3/4.

Calculations performed for various composites in a wide range of values of £ and ε" confirmed the ability to provide the reflection coefficient from the RA of less than -40 dB at a given frequency only by controlling the dimensions of the RF structure without changing the characteristics of the dielectric. In this case, it was shown that the level of the reflection coefficient of — 10 dB, the absorption bandwidth ratio Δδ to the thickness of the dielectric layer d is about 3.7, which is more than the analogous ratio for the classical Dallenbach quarter-wave RA equal to 3.2. These calculations showed that the ideal matching of the resonant RA with free space can be achieved for almost any dielectric with absorption at any given frequency.

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