Special aspects of backscattering amplitude characteristics measurement of small and ultrasmall RCS objects in K_a-band

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Abstract. A bench for special aspects of backscattering amplitude characteristics measurement of small and ultrasmall RCS objects in K_a-band is presented. The RCS of quadcopter Syma X12 are defined for ± 2 GHz band from different radiation directions for both vertical and horizontal polarization.

1 Introduction

The heady development of small size pilotless vehicles causes to state the tasks for detection devices [1-3]. The viable detecting solution seems impossible without original data to be formed, and to be objective for small UAV RCS. The understated RCS data could lead to a increased complexity and price of a detection device, but at the same time the overstated data won't solve the problem effectively [4, 5]. In this case the process of getting this objective RCS data for pilotless vehicles is quite current. The most difficult in the problem is that small RCS value, of about 0.001...0.5 cm², causes a great impact upon the measuring methods choise and upon the shape of the measuring benches for backscattering characteristics of the objects with such a small RCS value.

This paper aims to RCS measurement for quadcopter Syma X12 (fig.1) in K_a-band both in vertical and horizontal polarizations.

Fig. 1. A quadcopter Syma X12.

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The following problems has been solved : the measuring bench for small and ultrasmall objects RCS in K_a -band has been developed and set up, the RCS measurement method is developed, the RCS measurements have been made for the suggested quadcopter.

The quadcopter Syma X12 is in fig. 1 with its overall size sans rotor of 45x45x21 mm, the rotor length is 33.5 mm, with the rotors reaches the maximal size of 87 mm.

2 The backscattering amplitude characteristics measuring bench

The RCS measurement is made with the use of backscattering characteristics measuring bench inside the anechoic chamber which has constructed with the principals discribed in paper [6]. The measurement bench is based on a vector network analyzer and measures the input reflection coefficient $S_{11}(f)$ in 8 GHz band and then procecces in the time domain [7] with exception of outside reflections.

Fig. 2 shows the schematics of backscattering characteristics measuring bench for small and ultrasmall objects RCS in K_a -band.

Fig. 2. The schematics of backscattering characteristics measuring bench for small and ultrasmall objects RCS in K_a -band.

The following notations are introduced as: 1 – research object; 2 – rotary mechanism; 3 – rotary control unit; 4 – vector network analyzer; 5 – PC; 6 – uninterruptable power supply unit; 7 – radar-absorbing material; 8 – total station Leica TCR 802 power; 9 – anechoic chamber. The table 1 contains the main characteristics of the measurement bench.

Table 1. Measuring bench characteristics.

Characteristic	Value
Bandwidth, GHz	8
Polarization	linear
Distance between objects, m	2
Number of measured points per band	801
IF bandwidth, GHz	1
Time window width, ns	2,5
Transmitted power, dBm	0
Measured parameter	S11

There is the research object suspended from the ceiling of the anechoic chamber with polyamide string in the horn antenna far-field. The quadcopter is fixed in the space with tensed string from the four angles of the rotary part. Such a location helps to revolve the research object about its vertical axis, not counting on the other furniture but the fishing-line inside the workspace. The place of the small pilotless vehicles and spherical reference reflectors is checked by the total station while being mounted inside the measurement bench workspace. The fig. 3 shows the quadcopter Syma X12 fixed with the string for RCS measurements from different radiation directions.

Fig. 3. The quadcopter Syma X12 placed in the backscattering characteristics measuring bench for small and ultrasmall objects RCS in K_a -band : a – horizontal state, b – vertical state, c – main radiation directions.

During the processes of tuning and chechout of the measurement bench the following features of small and ultrasmall object RCS measurement are experimentally proved. The research object should be hanged far enough from other reflectors, even for radio transparent materials or covered with radar-absorbing material of a high quality; the diameter of the used dielectric string should be minimum.

For example the RCS value for the anechoic chamber wall with radar-absorbing material and reflection coefficient minus 50 dB, the reflection square 1 m^2 in 30 GHz frequency is given by (1) [8, 9] and equals to 1.26 m^2 .

$$\sigma_w = 4\pi \frac{S^2}{\lambda^2} - |\Gamma_{\text{abs}}| \quad (1)$$

Where σ_w is the RCS, m^2 ; S is the plane reflector area, m^2 ; λ is the wavelength in free space, m; $|\Gamma_{\text{abs}}|$ is the reflection coefficient of the radio-absorbing material.

According to [10] RCS of the string is

$$\sigma_s = k \cdot L^2 \quad (2)$$

Where σ_s is the string RCS, m^2 ; k is the coefficient depends on d/λ and polarization.

The diameter of a radiated area is 300 mm for mainlobe beamwidth 9° at the distance of 2 m. If the string diameter is 0.2 mm then $k \approx 0.00025$ for any polarization in 30 GHz. The maximum RCS for five parts of the string with the length of a workspace half-diameter (150 mm) is $1.4 \cdot 10^{-4} \text{ m}^2$, in case of reflection signals in-phase sum. This is by order less then sensitivity requirements of 0.001 m^2 .

3 The methods of backscattering amplitude characteristics masurement

The backscattering amplitude characteristics measurement has the following procedure. The vector network analyzer measures the input reflection coefficient S_{11} and then transform into the time domain with signal rejection out of the object location area.

Equation (2) gives the complex envelope $\Gamma(f)$ of reflective wave from the research object.

$$\Gamma(f) = F\{G(t) \cdot F[S_{11}(f) \cdot W(f)]^{-1}\} \quad (2)$$

Where $F\{\}$ is fast Fourier transform (FFT); $F\{\}^{-1}$ is inverse FFT (IFFT); $W(f)$ is special weight window [11]; $G(t)$ is time data window. The Kaiser window with $\beta = 10$ was chosen in this paper and that matches the sidelobe level in time domain of minus 74.2 dB.

At first the research object position in the time domain is searched. The location of the object response in the time domain is estimated by the distance from the object and fider electromagnetic length.

Afterwards, the measurement bench is graduated when the received signal level from the reference reflectors is measured in a current band. The RCS references of the laboratory are shown in fig. 4.

Fig. 4. The reference reflectors in the RCS measurement laboratory.

Metall balls 50 and 100 mm in diameter are used. After the calculated and experimental references RCS difference being compared with not more then 0.5 dB error, the bench is calibrated for the next object RCS measurements.

4 The experimental RCS determination for the quadcopter Syma

After measurement bench graduation and checkout within the reference reflectors the quadcopter Syma X12 is placed in a work space of the laboratory bench. The quadcopter RCS from the different directions in a horizontal polarization is measured. After the horn was revolved about the axis on 90° for the polarization to change, the set of measurements continues.

The figures 5 and 6 show the time domain plots for the reflection coefficient both with and without the quadcopter Syma X12 in horizontal polarization.

Fig. 5. The time domain plot for the reflection signal in laboratory bench with the quadcopter Syma X12, horizontal polarization.

Fig. 6. The time domain plot for the reflection signal in laboratory bench without the research object, horizontal polarization.

The « 1 » area for both time domain plots shown in fig. 5-6 contains the reflection from the antenna and microwave fider elements: microwave cable, coaxial adapter, coaxial-waveguide adapter. The use of the Kaiser window with $\beta = 10$ makes to possible to reduce these reflections into the «3» area to not more than minus 100 dB level.

The « 2 » area of the time domain plots contains the anechoic chamber elements reflections, the distance to them is less than the distance to the research object. Also in case of a small reflection value the thermal noise can be seen. Particularly their level used to depend on IF filter band of a VNA receiver. The IF filter band decrease lets the thermal noise power to be reduced. At the same time the measurement duration is increasing.

The « 3 » area of fig. 5 contains the response of the quadcopter Syma X12 but in fig. 6 this response is absent. The time gate width is equal to 2.5 ns, it corresponds to the « 3 » area size. In the « 4 » area the both plots contain the particular response caused by wave reflection from the anechoic chamber wall with radar-absorbing material.

The measured quadcopter Syma X12 RCS in K_a -band at horizontal and vertical polarizations from the different directions to the pilotless vehicles (fig. 3c) are shown accordingly in figures 7 and 8.

Fig. 7. The RCS of quadcopter Syma X12 in K_a -band at the horizontal polarization.

Рис. 8. The RCS of quadcopter Syma X12 in K_a -band at the vertical polarization.

The measured quadcopter Syma X12 RCS is not more than 0.02 m^2 and in average is 0.0032 m^2 for one-side band of 2 GHz from the different radiation directions at the horizontal polarization. The RCS of the quadcopter from the different radiation directions is not more than 0.03 m^2 and in average is 0.0052 m^2 at the vertical polarization. The averaging was processed in one-side band of 2 GHz and for the all seven radiation directions.

The «6» direction gives the maximum value of the quadcopter RCS for both considered polarizations. The most probable directions to the flying quadcopter from the radar are «1»-«5». Their RCS are not more than 0.006 m^2 for horizontal polarization and not more than 0.014 m^2 for vertical polarization.

4 Conclusion

The RCS characteristics measurement bench of small and ultrasmall objects in K_a -band was developed. In case of the small pilotless vehicle RCS values the following features of their backscattering characteristics are concluded in K_a -band: the object should be hanged far enough from other reflectors, even for radio transparent materials or covered with radar-absorbing material of a high quality. The string diameter shouldn't be more than 0.2 mm.

The measured quadcopter Syma X12 RCS is not more than 0.02 m^2 and in average is 0.0032 m^2 for one-side band of 2 GHz from the different radiation directions of UAV at the horizontal polarization. The RCS of the quadcopter from the different radiation directions is not more than 0.03 m^2 and in average is 0.0052 m^2 at the vertical polarization.

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