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The Research of Exciter Frequency Characteristics of a Quad-Band Antenna Based on a Corrugated Horn

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Abstract. The objective of the paper is to study the frequency characteristics of the exciter based on a corrugated horn for a quad-band antenna for satellite communications. The problems of the construction of the corrugated horn as the basis for the radiating system of the quad-band reflector antenna for satellite communications with overlapping of C-, X-, Ku-, and Ka-bands are considered. The conducted analysis of the interrelation of the characteristics of the multiband reflector antenna with the characteristics of the radiating system permits defining a set of the requirements to the parameters of the corrugated horn, which is the base of a radiating system. The corrugated horn, which provides the required characteristics in C-, X-, Ku- and Ka-bands, is developed. The radiation patterns of the corrugated horn within the specified bands and the frequency dependences of the mode converter providing the interface of the horn with a circular feed waveguide are analyzed. The experimental checking proved that within C-, X-, Ku-, and Ka-bands, an average value of the VSWR does not exceed 1.12, and the maximum value makes 1.15 at the frequency.

Keywords: multiband reflector antenna, corrugated horn, performance indicators of the radiating system and feed horn

Introduction

One of the ways to boost the capacity of communication links, volume of the obtained surveillance information at signal intercept in satellite communication links (SCL) is a simultaneous usage of several frequency ranges. Since SCL apply reflector antennas, thus the work in several frequency ranges can be provided by employing either several single-band reflector antennas or one multiband reflector antenna (MBRA) being as good as single-band antennas in regard to radiation characteristics in each of frequency ranges. The last seems to be more preferable, since it allows one to reduce considerably costs when organizing and servicing communication links and data reception.

It is obvious that solving the task of MBRA creation is connected, first of all, with development of original multiband exciters. Hence, the aim of the paper is to examine frequency characteristics of the exciter based on the corrugated horn for the quad-band satellite communication antenna.

The tasks to be solved:

- To establish interrelation of the characteristics of the exciter system with the characteristics of MBRA
- To develop and select the parameters of a corrugated horn to build a radiation system of the quad-band reflector antenna
- To examine experimentally the characteristics of the radiation of the prototype of the developed horn

Interrelation of the characteristics of the exciter system with the characteristics of MBRA

A performance indicator of MBRA can be presented by the following ratio [1]:

$$P_{MBRA} = \prod_{j=1}^{J} \prod_{i=1}^{2} \left(H_{j,i}^{(0)} K_{j,i}^{(1)} K_{j,i}^{(2)} \right)^{m_{j,i}} \qquad (1)$$

where $H_{j,i}^{(0)}$ is the noise Q-factor of MBRA in the j-th frequency range when receiving the signals of the i-th polarization; $K_{j,i}^{(1)}$ is the coefficient taking into account the decrease of the signal-to-noise ratio (SNR) due to depolarization effects in the antenna and waveguide transmission line (AWTL) of the antenna; $K_{j,i}^{(2)}$ is the coefficient considering the decrease of the noise Q-factor due to the errors in beam pointing of the antenna.

A noise Q-factor is determined as follows [2]:

$$H_{j,i}^{(0)} = \frac{4\pi S}{\lambda_j^2} \cdot \eta_{j,i} \qquad (2)$$

where S is the square of the main mirror; $\eta_{j,i}$ is the coefficient of using of the area (CUA) in the j-th frequency range for the signals of the i-th polarization; λ_j is the wavelength of radiation in the j-th frequency range.

The value of CUA$\eta^{(j,i)}$ allowing for the matching of the exciter with the feeder circuit in case MBRA based on [2] can be given as follows:

$$\eta_{j,i} = \eta_1^{(j,i)} \cdot \eta_2^{(j,i)} \cdot \eta_3^{(j,i)} \cdot \eta_4^{(j,i)} \cdot \eta_5^{(j,i)} \cdot \eta_6^{(j,i)} \cdot \eta_7^{(j,i)}. \qquad (3)$$

Private indicators of CUA are determined with the following ratios:

- Aperture coefficient of usage

$$\eta_1^{(j,i)} = 2ctg^2\left(\frac{\theta_0}{2}\right) \cdot \frac{\left| \int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right| + \left| F_H^{(j,i)} \right| \right) \cdot tg(\theta/2) d\theta \right|^2}{\int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot \sin\theta d\theta} \qquad (4)$$

- Coefficient due to the intercept of the share of the energy flow with the primary radiator

$$\eta_2^{(j,i)} = \frac{\int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot \sin\theta d\theta}{\int_0^{\pi} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot \sin\theta d\theta} \qquad (5)$$

- Coefficient considering inequality of the phase distribution in the aperture

$$\eta_3^{(j,i)} = \frac{\left| \int_0^{\theta_0} \left(F_E^{(j,i)} + F_H^{(j,i)} \right) \cdot tg(\theta/2) d\theta \right|^2}{\left| \int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot tg(\theta/2) d\theta \right|^2} \qquad (6)$$

- Coefficient taking into account the transition of the share of the radiated energy into the cross-polarized component

$$\eta_4^{(j,i)} = \frac{\left| \int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right| + \left| F_H^{(j,i)} \right| \right)^2 \cdot \sin\theta d\theta \right|^2}{\left| \int_0^{\theta_0} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot \sin\theta d\theta \right|^2} \qquad (7)$$

- Coefficient considering the covering of the radiator by the primary radiator

$$\eta_5^{(j,i)} = \frac{\left| \int\limits_{\theta_B}^{\theta_0} \left(\left| F_E^{(j,i)} \right| + \left| F_H^{(j,i)} \right| \right)^2 \cdot \sin\theta d\theta \right|^2}{\left| \int\limits_{0}^{\theta_0} \left(\left| F_E^{(j,i)} \right|^2 + \left| F_H^{(j,i)} \right|^2 \right) \cdot \sin\theta d\theta \right|^2} \qquad (8)$$

- Coefficient taking into account the errors in radiator development

$$\eta_6^{(j,i)} = \exp\left[-\left(\frac{4\pi\varepsilon}{\lambda_j} \right)^2 \right] \qquad (9)$$

where ε is the root-mean-square deviation of the surface of the radiator from the set form.

Moreover, when defining of the amplification factor of MBRA, it is necessary to take into account the matching of the radiator with the antenna external device (AED) determined by VSWR or the reflection index $\Gamma_{j,i}$ in the sectional view of the coupling of the radiator with the AED in the form of the multiplier:

$$\eta_7^{(j,i)} = 1 - \left| \Gamma_{j,i} \right|^2 . \qquad (10)$$

The ratios (1)–(10) define the interrelation of the MBRA efficiency with the parameters of the primary radiator.

The given ratios show that primary radiators of high-effective MBRA used in SCL should have the following characteristics in their ranges:

- Axisymmetric amplitude radiation pattern (RP) in the limits of the working corner sector
- A low level of side lobes out of the working corner sector
- A quasistationary (poorly dependent on frequency) position of the phase center
- A low level of the cross-polarized radiation
- A high level of the matching with the feed waveguide.

Development and selection of the parameters of a corrugated horn to build a radiation system of a quad-band reflector antenna

Varieties of corrugated cone horns with a feed circular waveguide have a broad application as primary radiators of MBRA. The highest efficiency of corrugated cone horns is provided by exciting the hybrid mode HE_{11} having the least critical length of the wave and suppression of the higher modes in the required wave ranges. The last is achieved by the realization of the conditions of exciting of “speed” waves in these ranges [2].

The field of the mode HE_{11} in the aperture of the corrugated horn of the waveguide is determined by the following components:

$$E_x = A_1 J_0\left(\frac{\nu_{11}}{R} \cdot r \right) - A_2 J_2\left(\frac{\nu_{11}}{R} \cdot r \right) \cdot \cos(2\varphi) \cdot \frac{X - Y}{k \cdot R},$$
$$E_y = A_2 J_2\left(\frac{\nu_{11}}{R} \cdot r \right) \cdot \sin(2\varphi) \cdot \frac{X - Y}{k \cdot R}. \qquad (11)$$

where $J_0(\bullet)$, $J_2(\bullet)$ are the Bessel functions of the first class of zero and second orders, respectively; k is the wave number of a free space; A_1, A_2 are the amplitudes of the components determined by the parameters of the horn; X and Y are the normalized impedance and conductivity of the corrugated structure; ν_{11} is the root of the Bessel function of a zero order.

On the sides of the horn at $r = R$, the normalized impedance and conductivity of the corrugated structure can be defined as follows:

$$X = -iZ_0^{-1} E_\varphi / H_z ,$$
$$Y = iZ_0 H_\varphi / E_z . \qquad (12)$$

When the condition $X=Y=0$ is performed, the field of the wave HE_{11} in the aperture of the horn does not depend on the angle φ and $E_y=0$ that defines the lack of the cross-polarized component and axial symmetry of a radiation field. The condition called the condition of the balance of hybrid waves correspond to the specific ratio of lateral components of electric and magnetic fields.

It can be accepted that $X \approx 0$ in the corrugated field. The condition of the balance for the hybrid mode HE_{11} and minimum level of transformation into the mode EH_{12} greatly contributing into the cross-polarized radiation is achieved at the closest to the zero on the border of the corrugated surface of the conductivity horn. Thus, to fulfill the condition of the balance of hybrid waves, it is necessary to meet $Y \approx 0$. The fulfillment of this condition is achieved at the following parameters of the corrugated structure [2]:

$$t < \lambda/10 , \; 1 - t < \lambda/10$$

Fig. 1 depicts the distribution of the electric field intensity in the aperture of the corrugated horn for the ratio $\xi = A_2(X - Y)/(kA_1R)$ equal to 0, 0.1, and 0.2, respectively.

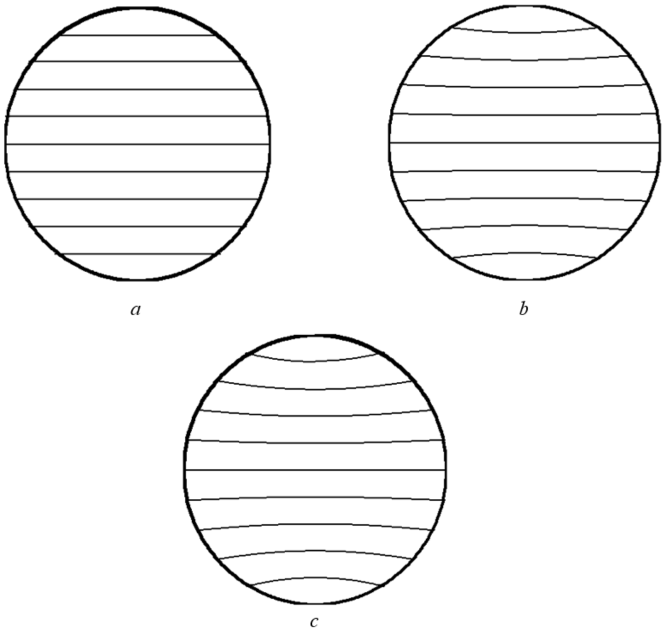


Fig. 1. The lines of electric field intensity in the aperture of the corrugated waveguide:
a) $\xi=0$; *b)* $\xi=0.1$; *c)* $\xi=0.2$.

The conducted research has shown that the best matching for the main and higher modes and for the same level of the power selection, the minimum number of grooves in the structure, stability of the radiation pattern in the frequency band is provided when using the grooves of a trapezoidal cross-section for the horn, and a complicated cross-section for the multimode converter (Fig. 2). Moreover, such selection considering the requirements of tolerances satisfies the requirements of production effectiveness.

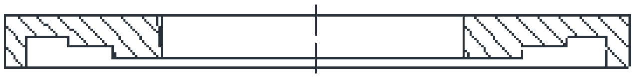


Fig. 2. The form of the groove in the multimode converter

The example of the offered horn feed is designed for the *C, X, Ku,* and *Ka* frequency bands. The size of a circular waveguide, which agrees with the horn, is *0.7C{λ0}* [3, 4]. The exciter for weight saving is made completely from aluminium alloy. The horn has the aperture *3C{λ0}* and length *1.8C{λ0}*. The depth of a groove of the horn is *–0.24C{λ0}* with a constant period. A profile of a transition begins with the diameter *1.4C{λ0}* and ends with the diameter *0.9C{λ0}* on the length *0.8C{λ0}*. The multimode transformer is designed to provide simplicity of engineering implementation in the form of a set of rings of the same thickness with the selections shown in Fig. 2 and has the length *1.5C{λ0}*.

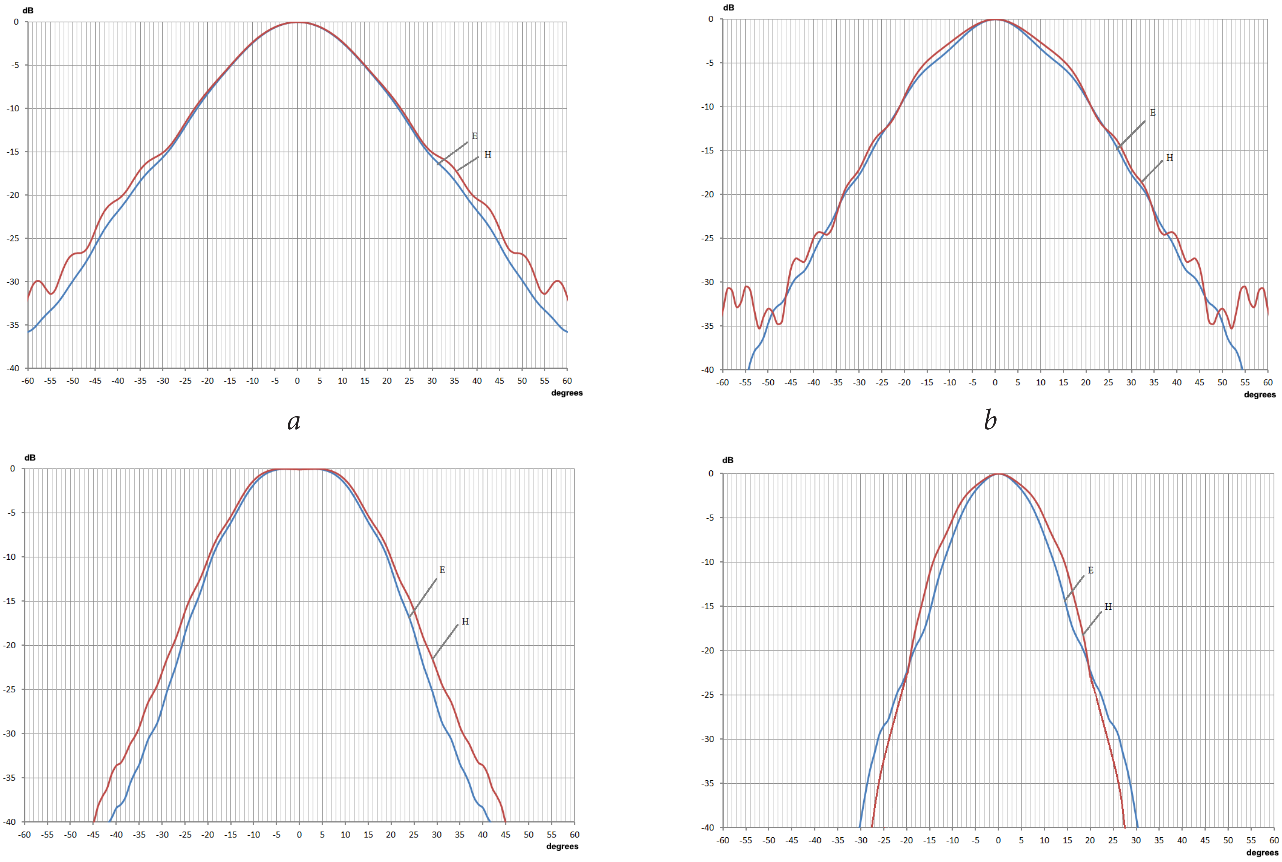
To use as a part of a high-effective MBRA designed based on the dual-reflector scheme, the exciter ensuring the best CUA according to (2)–(9) is expediently to make from the described corrugated horn, the multimode transformer of which creates the required out-phasing of the filed in the exciter. This allows one to provide a negligible change of the width of the radiation pattern with the change in the frequency.

An experimental study of the characteristics of the radiation of the prototype of the developed horn

Experimental radiation patterns of the corrugated horn in the *E*- and *H*-planes are given in Fig. 3. The width of radiation pattern at the level –15 dB on the lower and upper frequencies of the working ranges are 58° in the *E*-plane and 60° in the *H*-plane, respectively. The given level of radiation is achieved by the highest effectiveness of the reflector system [1,4]. In *X*-, *Ku*-, and *Ka*- bands, on can observe a monotonous decrease in the width of radiation pattern, which makes 54° in both planes for *X*-band, 47° in the *E*-plane, 48° in the *H*-plane for the *Ku*-band, 34° in the *E*-plane, and 35° in the *H*-plane for the *Ka*-band. Such measurement of the width of radiation pattern ensures maximum effectiveness of the multiband exciter system according to the indicator (3). In addition to this, formed radiation patterns have almost the same width in *E*- and *H*-planes and a low level of side radiation that determines a high axial symmetry of radiation pattern and high cross-polarized radiation.

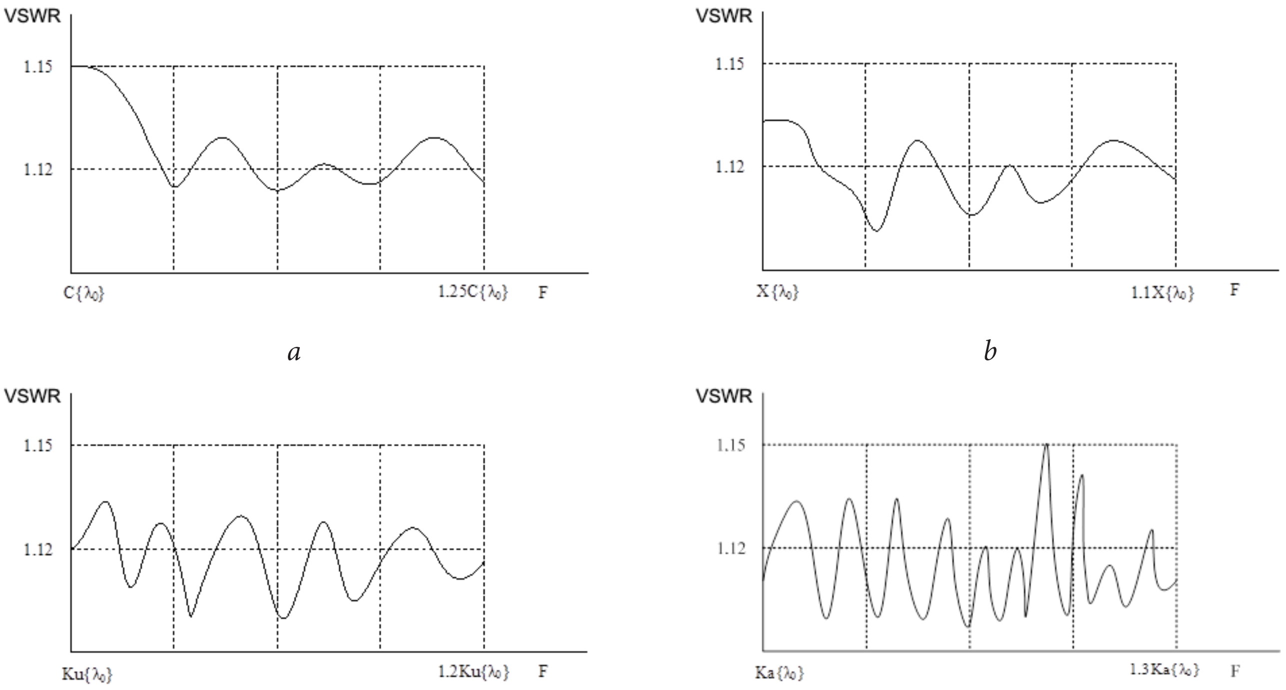
The measured VSWR of the horn exciter in the frequency bands of *C, X, Ku,* and *Ka* is given in Fig. 4. The mean value of VSWR in the frequency band does not exceed 1.12 at the maximum value 1.15 in the frequency of *C{λ0}*.

Thus, using the considered quad-band horn permits one to achieve the highest axial symmetry of radiation pattern in the limits of the working sector of angles, low level of side lobes, high level of matching with the feed waveguide, and high coefficient of a polarizing cross coupling of orthogonal linear polarizations of the exciter that provides a high efficiency of MBRA in general.



a *b* *c* *d*

Fig. 3. Radiation patterns of the corrugated horn: a) *C*-band, b) *X*-band, c) *Ku*-band, d) *Ka*-band



a *b* *c* *d*

Fig. 4. Frequency dependences of VSWR of the quad-band corrugated horn: a) *C*-band, b) *X*-band, c) *Ku*-band, d) *Ka*-band

Conclusions

1. The conducted research has allowed one to establish the interrelation of characteristics of the exciter system with the characteristics of MBRA and to prove the requirements imposed to the exciter system. It is shown that the corrugated horn, when the condition of the balance of the hybrid mode and minimum level of transformation into the mode is fulfilled, to the full extent meets the requirements to the exciter system of MBRA.

2. The quad-band corrugated horn with matching to the circle waveguide containing the original multimode converter of types of waves adjoining through the radial transition to a corrugated horn is developed. Based on the mathematical simulation, the parameters of a corrugated horn and mode converter are chosen.

3. Experimental check has shown that in the bandwidth of C-, X-, Ku-, and Ka-bands, an average value of VSWR does not exceed 1.12, and the maximum value is 1.15 at the frequency. Radiation patterns of the exciter have a high axial symmetry.

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