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Simulation modeling of functional adaptive interference nulling for multibeam hybrid reflector antenna systems*

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Abstract. This paper considers the simulation of adaptive nulling mechanism patterns in hybrid reflector antenna systems with a 19-element feed element, in which the radiation pattern is formed as a cluster. Incidents of broadband and narrowband interference are studied in the article.

Keywords: hybrid reflector antenna; spatial interference filtering; adaptive algorithms; antenna radiation pattern;simulation modeling

1. Introduction

Multibeam antennas, built either on the basis of adaptive phased antenna arrays or hybrid reflector antennas have been among the most perspective directions for developing satellite navigation in Russia where the population distribution is uneven. Hybrid reflector antennas have a great advantage over multibeam adaptive phased antenna arrays when installed on space vehicles in terms of cost and mass reduction since the amplification coefficient for the antenna is very high (exceeding 35–40 dB) [1].

Among the main problems, which an engineer encounters when building adaptive multibeam hybrid reflector antennas is the development and research of methods and algorithms for object angular attitude to interference. In [2–5] an algorithm for hybrid reflector antennas amplitude-phase distribution synthesis had been developed. This algorithm considers both adaptive phased antenna arrays and reflector antennas.

In order to ascertain the effectiveness of the proposed methods it is necessary to conduct an experimental investigation. However, the production of hybrid reflector antenna models and their further testing using anechoic chambers and complex electronic test equipment is a complicated and expensive task. Mathematical modeling methods are an efficient substitute to the aforementioned methods. The significant reduction of cost, time and labor – essential to

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the research of complex electronic devices – are among the main advantages of mathematical modeling, which has made them very popular nowadays.

Modern computer-aided design software enables the simulation process to be significantly simplified. MATLAB is one of the most popular computing environment having multiple tools for complex mathematical operations, including complex numbers, vectors and matrices. MATLAB is also an excellent program for visualizing obtained experimental results [6, 7].

2. Description of computer models

We have developed several computer models, which imitate the functional adaptation process of the hybrid reflector antenna using MATLAB (R2011b). These models use Microsoft Windows XP / 7 operating systems. This adds to the versatility for testing the computer models that may be performed on most computers using standard repositories and software; this software is necessary for further editing of obtained results (images, tables, etc).

The computer models realize methods described in [1–5]. These methods include the synthesis of the amplitude phase distribution in hybrid reflector antennas, which forms a counter service area and nulls in the radiation pattern in the direction of at least three sources of interference. The other methods include a one for determining the direction of the interference signal source without using additional antennas and a method of data transmission by multiplexing the bandwidth applying perspective signal simulation methods.

The computer model of the system for adaptive forming of the amplitude phase distribution of the multibeam hybrid reflector antenna is designed for imitating the formation of a counter service area and nulls in the radiation pattern in direction of at least three sources of the interfering signal.

The model consist of a module for interference imitation that generates signals from different directions, a module for imitating desired signals that generates signals from different directions, a module for interference adaptation, and a module for building the service area counter.

The computer model imitates the following: the formation of a radiation pattern of the radiated antenna array in any direction within the limits of the rated angular sector, the formation of the service area counter, interference attacks and desired signals coming from different directions. The model also provides digital control of weighted coefficients; this enables us to do the following: adapt the radiation pattern, imitate the spatial selection of desired signals and interference, imitate adaptation to the interference situation in each beam, provide the desired adaptation requirements to interference during the adaptation process and immediately react to changes in the interference scenario.

The computer model for the system of determining the direction to the source of interference and spatial suppression of interference is designed to imitate interference from at least three sources. It activates the desired spatial methods for interference suppression.

The model consists out of a module for imitating desired interference with a given distributive law, which radiate from a given direction, a module for imitating desired signals, a module for imitating a system of signal suppression.

The computer model enables to imitate the formation of a radiation pattern of a radiating hybrid reflector antenna relay in any direction (within the limits of the rated angular sector). The following are also imitated with the help of the computer model: interferences of a given type with a given distribution law from different directions, desired signals, the algorithm for determining the direction of the source of interference, the work of the spatial selection system for desired signals, and digital control of weighted coefficients. This enables adaptive nulling in the radiation pattern.

There are a number of limitations accepted for the model: the main maximum of the hybrid reflector antenna radiation pattern is orientated towards the signal source in a direction determined by the user. The front of the wave from the desired signal source is considered to be flat. The direction to the interference source is characterized by azimuth θ and elevation φ, which are counted from the direction to the nadir. The amplitude of the interference signal is significantly greater than the amplitude of the desired signal; it is received by the side lobes of the radiation pattern.

For interference signals we have employed two types of interfering noises: narrowband (harmonic) and broadband.

3. Simulating the functional hybrid reflector antenna in various interference environments

In order to assess the quality of the functional adaptative nulling of a multibeam hybrid reflector antenna in environments with interference, we have simulated its performance under one broadband interfering noise that had the following characteristics:

- the magnitude of the interference exceeded that of the signal by 60 dB (3000 times in amplitude);
- the average frequency of the interfering noise was equal to f_0 of the central cluster; the width of the interfering noise band was 70 MHz;
- the interference attack direction was φ and θ, where φ was the elevation from the antenna plane; θ was the azimuth.

The output signal of hybrid reflector antenna without any adaptation is shown in Fig. 1.

There is a number of ways the interference can affect the system:

- only one cluster is suppressed;
- two neighboring clusters are suppressed with interference between them;
- three neighboring clusters suppressed with interference between them.

Let’s consider all three variants.

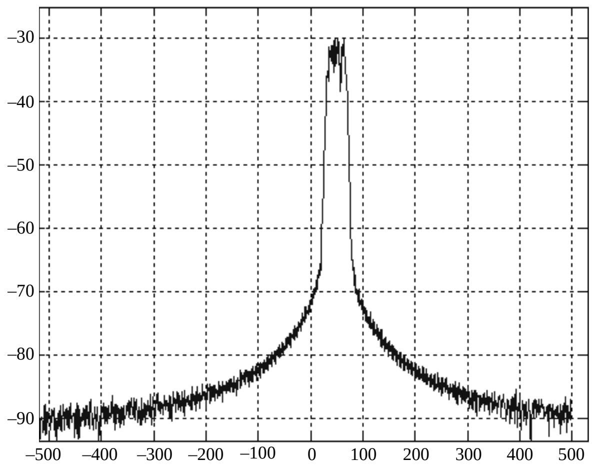

Figure 1. The output signal of a hybrid reflector antenna without any adaptive processing

A. Broadband interference attacking one cluster

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The simulation of the hybrid reflector antenna system adaptive process to the attack of a broadband interfering noise on the fifth cluster had the same characteristics as shown above. The angular coordinates of interfering signal were: $\varphi = 80°$, $\theta = 210°$.

Figs. 2 and 3 demonstrate null formation in the radiation pattern, which is formed by the adaptive system during interference attack to the main lobe of cluster 5. This results in the decrease of the antenna's power gain in the neighboring clusters: the broadband interference signal also suppresses them affecting their side lobes.

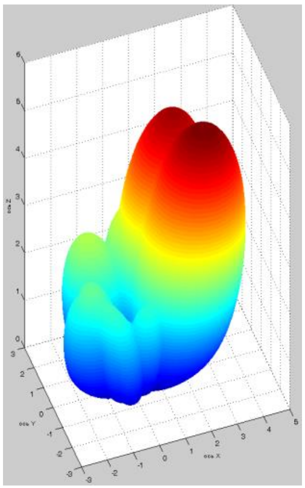


Figure 2. 7-beam radiation pattern of hybrid reflector antenna under broadband interference attack on the cluster 5

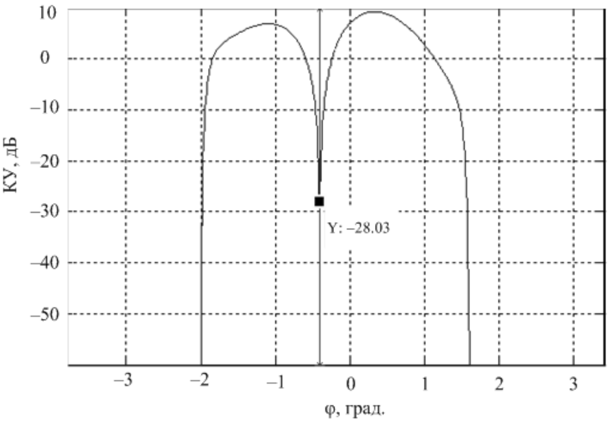
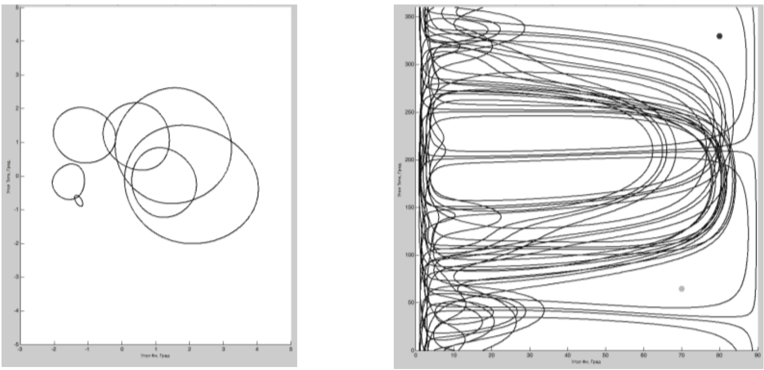


Figure 3. Cross-section of radiation pattern for cluster 5 with a vertical plane $\theta = 210°$ under broadband interference attack on cluster 5

As demonstrated in Figs. 2 and 3, during adaptive nulling in a hybrid reflector antenna to one broadband interfering signal there is an insignificant degradation of the whole radiation pattern. The antenna gain for cluster nulling is reduced by two times; the widening of the main lobe reaches 3°. The antenna gain is 28 dB. In result of the adaptive nulling the total service area was reduced (Fig. 4).



a) *b*)

Figure 4. Counter radiation pattern during cluster 5 suppression:
a) Level minus 3 dB; *b)* Level minus 35 Db

B. Broadband interference attack between two clusters

Let's simulate an adaptive nulling mechanism to one broadband interfering signal that impacts between clusters 5 and 6. The characteristics of the signal are identical to the ones in the previous situation with the exception that the angular coordinates of the signal are $\varphi = 80°$, $\theta = 270°$.

In Fig. 5 we can see a three dimensional view of a 7-beam radiation pattern for a hybrid reflector antenna, which is impacted by a broadband interference signal between clusters 5 and 6. A negligible decrease in the antenna gain can be visible in these two clusters. This decrease is explained by the fact that the main power of the interference signal is accepted by the side lobes. In Fig. 6 we can see a counter radiation pattern of a hybrid reflector antenna showing an insignificant reduction of the total service area. This can be compensated by a redistribution of the beams.

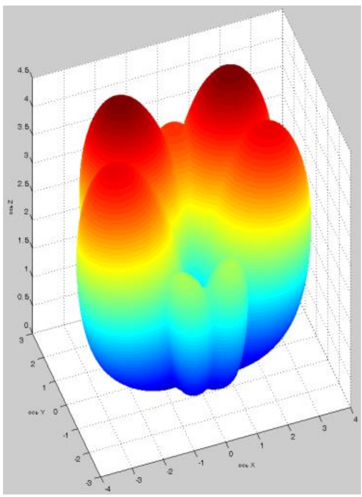
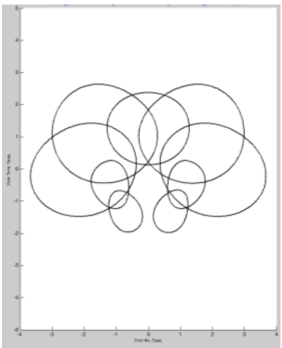
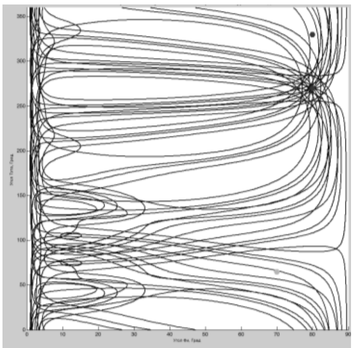


Figure 5. 7-beam radiation pattern of hybrid reflector antenna under broadband interference attack between clusters 5 and 6



a)



b)

Figure 6. Counter radiation pattern under broadband interference attack between clusters 5 and 6: *a* Level minus 3 dB; b) Level minus 35 dB

C. Broadband interference attack between three clusters

Let's now simulate an adaptive nulling mechanism to one broadband interference signal that impacts between clusters 1, 5 and 6. The characteristics of the signal are identical to the ones in the previous situation with the exception that the angular coordinates of the signal are $\varphi = 85°$, $\theta = 0°$.

Fig. 7 demonstrates a three dimensional view of a 7-beam radiation pattern of a hybrid reflector antenna, which is impacted by a broadband interference signal between clusters 1, 5 and 6. In Fig. 8 we can see a counter radiation pattern of a hybrid reflector antenna. The analysis of the figures shows that there had been a negligible degradation of the radiation pattern expressed in the decrease of the antenna gain for suppressed clusters and the widening of the main lobes of the radiation pattern. The total service area shows signal disruptions at signal level of minus 3 dB; if the levels are lower, it is possible to receive a signal.

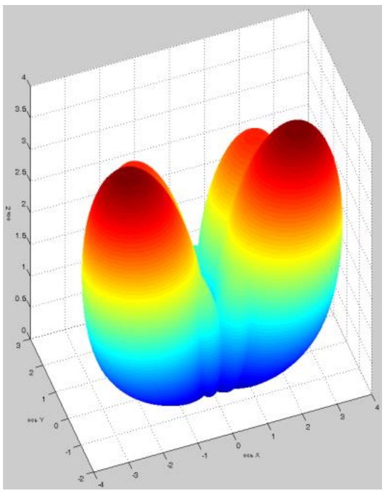
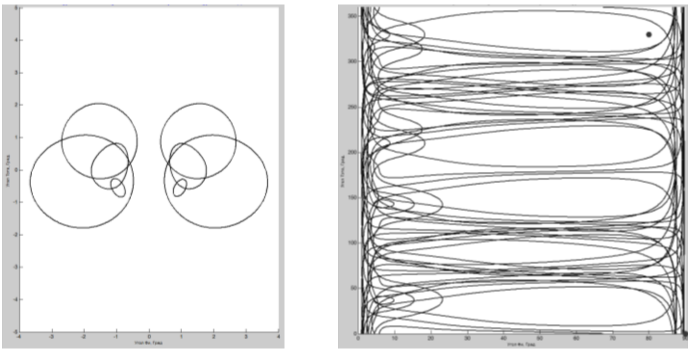


Figure 7. 7-beam radiation pattern of hybrid reflector antenna under broadband interference attack between clusters 1, 5 and 6



a) *b*)

Figure 8. Counter radiation pattern under broadband interference attack between clusters 5 and 6: *a)* Level minus 3 dB; b) Level minus 35 dB

As the calculation results for the radiation pattern of an adaptive hybrid reflector antenna show, the suppression of one broadband interfering signal in direction of the first side lobes of the radiation pattern and in direction of the slope of the main lobe had resulted in the interference suppression level being minus 35–40 db. The signal level in the rest of the service area remains unchanged. During interference suppression in direction of the main lobe of the radiation pattern a deterioration of the antenna gain level to 2 dB is observed; the level of interference suppression is minus 25 dB, which is enough for satellite communication.

D. Simulating hybrid reflector antenna performance under attack from one narrowband interfering signal

In order to assess the capabilities of adaptive hybrid reflector antennas for suppressing both broadband and narrowband interfering signals we have simulated adaptive nulling mechanisms to narrowband interfering signal with the following characteristics:

- the power of the interference exceeded the power of the signal by 72 dB (4000 times in amplitude);
- the narrowband interference frequency fell behind f_0 of the central cluster by 10 MHz in order to better illustrate and analyze the spectrogram;
- the interference attack was directed from a elevation level of φ and an azimuth θ.

Narrowband interference generally impacts only the cluster it strikes. This phenomenon, unlike that of broadband interference, is explained by the beams of the hybrid reflector antenna being subjected to frequency-division multiplexing. In this case, narrowband interference for neighboring clusters will have the characteristics of out-of-band interference that will be filtered in the receiving path.

In this aspect let’s simulate the adaptive nulling mechanism for a hybrid reflector antenna to narrowband interference on the example of a single cluster. Let’s look at two situations:

- interference strikes the main lode of the radiation pattern;
- interference strikes the side lobe of the radiation pattern.

In Fig. 9 we can see a narrowband interference spectrum at antenna array output.

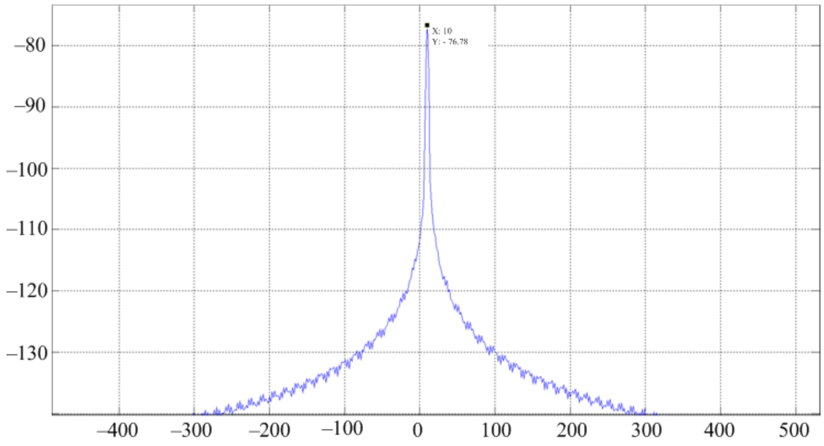


Figure 9. Narrowband interference spectrum at radiating antenna array output

During narrowband interference attack on the main lobe, its angular coordinates are: φ = 80°, θ = 210°. Adaptive nulling results in interference suppression. However a significant decrease in antenna gain results in direction of the source of interference.

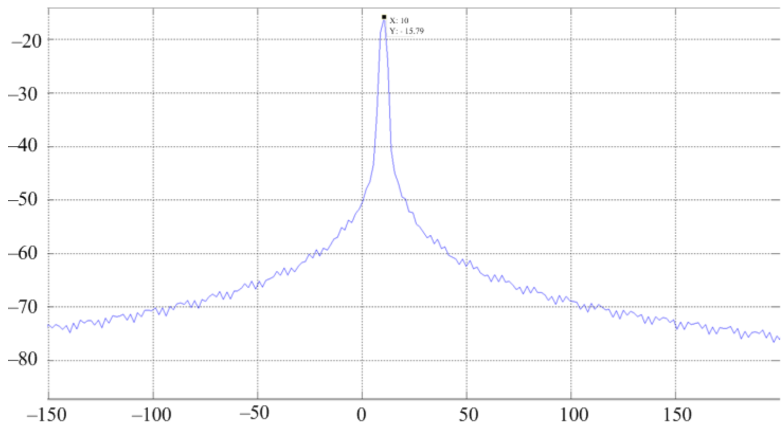


Figure 10. Narrowband interference spectrum attacking main lobe at radiating antenna array output after adaptive nulling

As seen in the figures, the interference cancellation ratio for narrowband interference on the main lobe of the radiation pattern has a satisfactory result of almost 61 dB (–15.79 – (–76.78) = 60.99).

The angular coordinates of narrowband interference attaking the main lobe are: φ = 18°, θ = 358°. In result of adaptive nulling even greater suppression of interference takes place (Fig. 11); a desired signal is emitted (zero frequency peak). In this situation the cancellation ratio for narrowband frequency is (–15.79 – (–89.2) = 73.41 dB. Such a significant difference in the cancellation ratio between narrowband and broadband interference is explained by the fact that the desired signal spectrum occupies a wide band and because further signal processing increases the signal-to-noise ratio in the signal path.

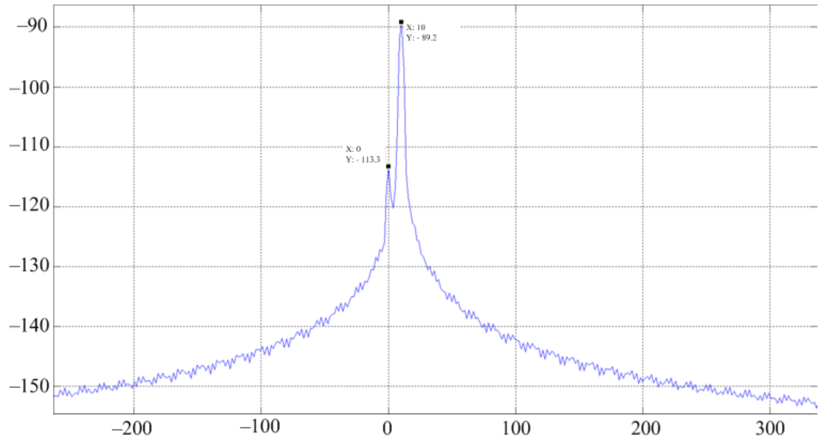


Figure 11. Narrowband interference spectrum attacking main lobe at radiating antenna array output

Thus, the simulation results demonstrated that an adaptive hybrid reflector antenna is capable of effectively suppressing narrowband interference with a significant cancellation ratio (up to 60 dB) under interference attack on the main lobe. The cancellation ratio during interference suppression to the side lobes of the radiation pattern can be increased to over 70 dB.

4. Conclusion

Thus, we have conducted a simulation of functional adaptive nulling for multibeam hybrid reflector antennas under interference using the developed computer models – systems for forming adaptive amplitude-phase distribution for multuibeam hybrid reflector antennas, which enable the realization of the developed methods of forming a counter service area and nulls in the radiation pattern in direction of at least three sources of interfering signals, together with a system for detecting the direction to the source of interference and the spatial suppression of the interfering signal.

We have discussed various scenarios of interference cancelling:

- simulating the suppression of broadband and narrowband interference with different directions of impact;
- suppressing a separate cluster:
- suppressing two and three clusters of the side lobes.

The conducted simulation for situations of interference suppression on the first side lobe, the slope of the main lobe and the main lobe has proved the capacity of the developed algorithms. During interference suppression in direction of the first side lobe of the radiation pattern and the slope of the main lobe, the level of interference suppression reached a maximum of minus 45–50 dB; the signal level in the remaining service area remained unaltered. The suppression of interference in direction of the main lobe of the radiation pattern showed deterioration in the antenna gain to 1 dB; the level of interference suppression reached minus 25 dB.

Since each beam of the adaptive hybrid reflector antenna, built according to a cluster scheme, forms a null independently from other beams, the long beams are provided with a cancelling for side lobes of the radiation pattern that can be attacked by interference.

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