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Specialized software for the adaptive nulling unit of a hybrid reflector antenna*

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Abstract. This paper considers the development of specialized software for a hybrid reflector antenna adaptive nulling unit; it conducts the calculation of a desired amplitude and phase distribution of the feed array in counter service area formation and interference cancelling.

Keywords: hybrid reflector antenna; spatial interference filtering, adaptive algorithms, specialized software

1. Introduction

Adaptive multibeam antenna systems are currently gaining significant popularity among designers of satellite communications equipment. Such systems enable the user to flexibly control traffic depending on the channel traffic load – this includes the formation of multibeam radiation patterns within the limits of the service area. Another advantage of these systems is their high level of noise immunity to jamming and industrial (undeliberate) interference by employing spatial interference suppression methods.

Adaptive multibeam antenna can be built either on the basis of phased antenna arrays with scanner beams, or multibeam antennas – built on the basis of hybrid reflector antennas. Phased antenna arrays with a numerical radiation pattern formation enables flexible control of the directions of the main maxima of each partial radiation pattern in a wide range of angles; it can also form deep nulls in the radiation pattern in direction of the source of interference.

However, phased antenna array have some major drawbacks: they are excessively large in size, their hardware – particularly the beamforming network – is quite complicated. All of these factors eventually sum up in the high cost of this type of system [1]. Adaptive hybrid reflector antennas have smaller scanning angles – a feature that is negligible for geostationary satellites and highly elliptical orbit satellites and can easily be compensated by a simpler

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design of the antenna. Antenna arrays with focusing quasi-optical reflectors and fewer elements are considerably more perspective than other types of arrays. Hybrid reflector antennas combine the advantages of reflector antennas and phased antenna arrays, enabling the formation of configurable multibeam radiation patterns and radiation patterns with special forms together with providing spatial signal and interference filtering.

The design of complex electronics requires the engineer to include modeling – a key stage of designing – into the development process. Modeling enables the engineer to ascertain the effectiveness of the proposed methods and algorithms, any technical solutions and schematics without being necessitated to construct a full-scale prototype of the tested device. In hybrid reflector antenna designing one of the most complicated devices is the adaptive unit – it is required for controlling amplitude and phase distribution of the radiating array of the antenna. Technically, the adaptive unit is an adaptive processer on the base of a signal processor; adaptive nulling is performed using specialized software.

In [2–3] a development of synthesis algorithms for amplitude and phase distribution in hybrid reflector antennas – designed for the adaptive processor – has been reviewed. The main idea of these algorithms is the following: if the signal/noise limit is exceeded, an adaptive nulling mechanism is launched in one of the beams. The algorithm then assesses the ability to suppress the interfering signal through possible amplitude and phase distribution options, which are cached in the system’s memory. Since each beam in a hybrid reflector antenna is assigned to a specific service area, it is possible to detect the direction from which the interfering signal comes within a relatively small area. This reduces the time required for the system to select the best option for interference suppressing.

To assess the effectiveness of these algorithms we have developed a model of the receiving sector of an adaptive hybrid reflector antenna. As the basis for this model we have selected an adaptive unit that had been built on the basis of a new generation low-consumption multi-core signaling microprocessor 1892VM14Ia [6, 7]. Its integrated circuit is produced using CMOS technology with a minimal topological element size of 40nanometers. The microprocessor is a crystal system with high productivity; it includes two DSP kernels, two CPU ARM Cortex-A9, a system of correlators and integrated input/output buses. Phased antenna array control algorithms are introduced using specialized software. The microprocessor development board is connected to a personal computer via a JTAS emulator. Computer modeling allows the user to access all necessary tools using only one interface. The operational system for 1892VM7Ia integrated circuit is Linux.

MCStudio – an integrated software modeling environment – has been designed for the described integrated circuit; it provides a complete development and debugging cycle for the program. This environment is versatile since it can function on any IBM PC. The integrated design environment includes the following: an environment for designing programs for CPU and DSP kernels, a C++ environment for program adjustment in the source codes and a debugger for the debugging circuit module for the specified integrated circuit or the whole device.

2. Developing specialized software for the adaptive nulling unit of a hybrid reflector antenna

Specialized software enables the forming of a radiation pattern in any direction within the working degree of curvature. It also renders possible numerical control of weighted coordinates – this allows for adaptive nulling of the radiation pattern, providing it with a desired path, a given form and null formation in the direction of the interfering signal source, the spatial selection of the desired signal, i.e. the shifting of a partial single-degree beam within a small area (for interference cancelling), adaptive nulling in each partial beam to the interference environment, maintaining a given level of adaptive nulling to interference during the adaptive process and immediate reaction to changes in the interference situation.

The software for the adaptive unit (comprising a processor and memory) calculates and controls the phase-shifters and controlled amplifiers for the desired amplitude and phase distribution of the radiating array.

The programs key function is the minimizing the value of the objective function $F(x)$. Parameter values for achieving a minimal value of the objective function are chosen using successive iterations

$$F(\bar{x}) = \max\{ f_1(\bar{x}), f_2(\bar{x}), f_3(\bar{x}),...., f_k(\bar{x})\}.$$

For the first iteration we have taken an equal amplitude syn-phase distribution of feed element's array (each array comprises 7 to 19 feed elements). Next, the algorithm calculates the antenna gain for each beam on the basis of the equal amplitude distribution and determines the maximal value of the difference between the required and the available amplification $(\left|E(\theta,\varphi)_{цель,i}\right|^2 - \left|E_i(\theta,\varphi)\right|^2)$. The algorithm then changes the value of the amplitude and phase of each beam for the purpose of reducing the difference between the required and actual amplification. This process is repeated until the difference between the two for each station reaches its minimal measurement. The number of iterations can be programmed, or the algorithm will cease working as soon as the minimum in changes has been achieved.

The software for the adaptive nulling unit model of a multibeam hybrid reflector antenna has two functioning modes – a multi-beam mode and a counter beam mode.

For the first mode the adaptive nulling unit, solidary with the antenna system, covers the required service are with a set of narrow beams. Incorporating a multi-beam signal distribution allows the frequency resource to be reused multiple times: there is a spatial discrimination between the beams.

In the second mode the adaptive unit forms a radiation pattern identical to the service area of the system; power can be flexibly distributed within the limits of the area.

Both modes can visibly complement each other: for example, in conditions without any interference it is preferable to use a multi-beam mode – it will provide contact in a global service area. If interference is intense, it is best to switch to the counter mode with its capacity for counter radiation pattern formation.

The software for the adaptive nulling unit of the hybrid reflector antenna comprises a software module for beam formation in the given amplitude and phase distribution and adaptive nulling to interference, a software module for phase signal, delay and frequency detection and a software module for allocating desired data.

All modules are synchronized between each other are timed from one clock oscillator – the frequency of which depends on the frequency of data production by the analog-to-digital converter. The *P*-circuit of signal processing can be seen in Fig. 1. Here ADC is the analog-to-digital converter, FGEN is the beam forming circuit in a given amplitude and phase distribution and adaptive nulling to interference, NAVSRCH is the signal detection circuit, PHTRACK is the tracking circuit for signal phase, PRSTRACK is the signal delay tracking circuit, FTRACK is the tracking circuit for intermediate signal frequency, DEMOD is the code receiving and data demodulating circuit.

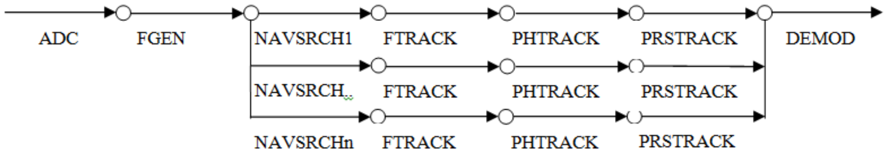

Figure 1. *P*-circuit for signal processing

A. A beam-forming module in a given amplitude and phase distribution and adaptive nulling to interference

A beam-forming circuit in a given amplitude and phase distribution and adaptive nulling to is realized using C++. Auxiliary c_complex and c_matrix classes realize mathematical operations on complex numerals, vectors and matrices.

The *P*-circuit for employing the adaptive function is shown in Fig. 2.

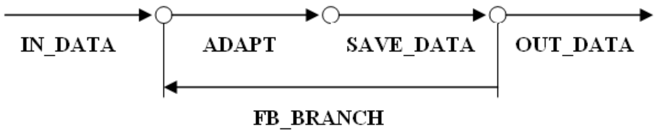

Figure 2. *P*-circuit for employing the adaptive nulling function

In Fig. 2 IN_DATA is the reading of input data in the complex view; input_vector_buffer is the production vector with antenna elements in a complex form; sum_signal is the total array signal in a complex form; inv_noise_matrix is the inverse correlative interference matrix; weights_buffer is the array weighted coefficients buffer; averaging is a parameter for determining the convergency speed for the adaptive algorithm; ans_container is a structure containing the calculated weighted coefficients and the inverse correlative interference matrix for further iterated adaptive nulling; ADAPT is the adaptive nulling; SAVE_DATA is the saving of intermediate weighted coefficients and the inverse interference matrix in the container; FB_BRANCH is the transfer of the container with intermediate data to the next iteration; OUT_DATA is the transfer of the calculations to the numerical processing unit for intermediate interference canceling.

B. Signal search module

Signal search is accomplished using syn-phase *I* and *Q* quadrate content of received signals. The process is divided into two types – full search and fine search.

Full search is performed in the absence of prior data on the frequency signals within the field of vision, data on delays, Doppler frequency shifts, receiver coordinates.

Search is performed within frequency ranges from minus 5 … plus 5 kHz with a step of 500 Hz. Thus, the search range in frequency ω_i is divided into 20 cells. Besides frequency search it is necessary to perform delay search. The detection criterion is selected depending on the desired probability of detection

$\sqrt{I_p^2 + Q_p^2} \geq h$, where h is the detection limit.

The duration of the accumulation of the analyzed signal depends on the signal-to-noise relation for the received signal and the desired probability of the correct detection; its range is between [1...10] ms.

Fine search is performed with any prior data on delays, receiver time and the last successful signal receiving session, the position of the receiver, etc. Any prior data narrows the search frequency range, consequently, saving time required for connection.

The search can be performed using correlators, matched filters, discrete-time convulsion, fast Fourier transform to frequency.

When using parallel correlators, the search range in frequency ω_i and delay τ_i is broken up into several areas, the limits of which correspond in time to the limits of signals shifting of the range-measuring code. Thus, the value of the code symbols in each area remains constant allowing us to perform a frequency search.

The *P*-circuit of the search is shown in Fig. 3. Here, INS is the input signal; ACUSELF is the circuit for accumulating the input signal in a selected frequency; CORPRS is the circuit for correlative processing with the code signal; SOLVEIQ is the circuit for decision-making considering the processed *I* and *Q*.

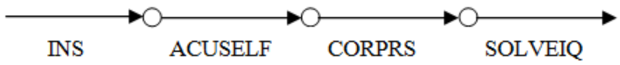

Figure 3. *P*-circuit of correlative signal search on in a selected frequency (CORFS)

When applying the circuit for phase tracking after the correlator, a phase discriminator is added. It automatically sets the frequency in which the signal has been detected though a feedback sequence.

The *P*-circuit for frequency tracking can be seen in Fig 4. Here, INS is the input signal; CORFS is the signal correlator circuit; PHTRACK is the signal phase tracking circuit; FILTER is the rectifier filter; FBBRANCH is the feedback branch in which the correction signal for the intermediate navigational signal frequency generator is formed; OUTS is the output signal.

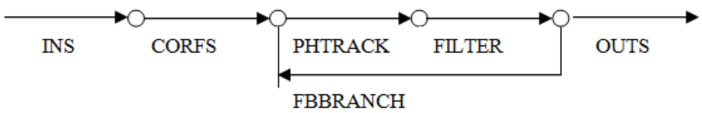

Figure 4. *P*-circuit for signal phase tracking

The delay tracking circuit also implies a discriminator, rectifier filter and feedback circuit for the formed correction signal. The discriminator uses the delayed and anticipated signals, which were formed in the correlator. The difference of this circuit from the phase tracking circuit is that the feedback circuit is connected to the clock generator with a 3-bit shift register.

The *P*-circuit for delay tracking is demonstrated in Fig. 5. Here, INS is the input signal; CORFSD is the signal correlator circuit for delayed and anticipated yields; DTRACK is the signal delay tracking circuit; FILTER is the rectifier filter; FBBRANCH is the feedback branch in which the correction signal is formed for the clock generator; OUTS is the output signal.

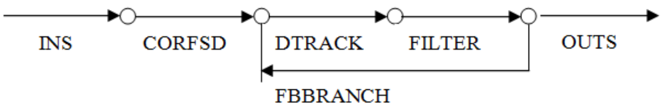

Figure 5. *P*-circuit for signal delay tracking

The frequency tracking circuit comprises a discriminator, rectifier filter and feedback circuit. The time required for signal accumulating in the discriminator circuit is 1 ms if a navigational signal correlator with search cells in a frequency of 500 Hz is used.

The *P*-circuit for frequency tracking is demonstrated in Fig. 6. Here, INS is the input signal; CORFSF is the signal correlator circuit; FTRACK is the signal phase tracking circuit; FILTER is the rectifier filter; FBBRANCH is the feedback branch in which the correction signal is formed for the navigational signal intermediate frequency generator; OUTS is the output signal.

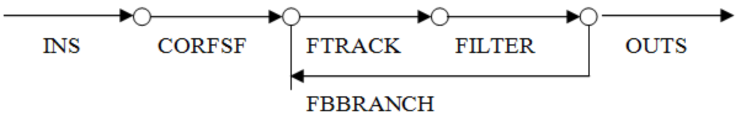

Figure 6. *P*-circuit for intermediate signal frequency tracking

C. Desired data selecting unit

Since the message symbols clocked with a frequency of 500 Hz are modulated by a code (clocked with a frequency of 1000 Hz), it is necessary to allocate the code symbols from the received packet before allocating the message symbols.

The *P*-circuit for data allocating is shown in Fig. 7. Here, INS is the input signal; PRSPULSE is the timed pulse of the range-measuring code allocation unit, PRSFORM is the forming unit; PRSPROBE is the pseudorandom number generator sequence symbol allocation unit; MOD2SUM is the module 2 adder unit; DATAPULSE is the data symbols frequency impulse forming unit; DATACCUM is the data symbols allocation unit, OUTS is the output signal.

The allocated data is transferred for further processing.

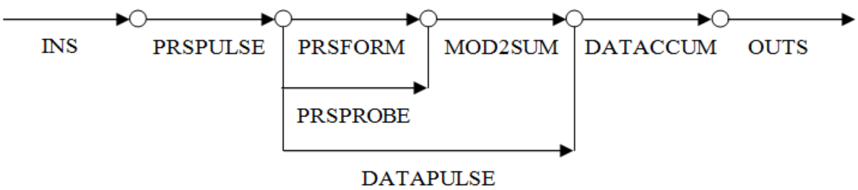

Figure 7. *P*-circuit for data allocation

3. Conclusion

Thus, we have described specialized software developed for the adaptive nulling unit of a hybrid reflector antenna. The software:

a) forms the radiation pattern of the radiating antenna array in a hybrid reflector antenna (within the working degree of curvature);

b) numerically controls the weighted coefficients enabling adaptive nulling of the radiation pattern, which sets the required direction and shape for the radiation pattern and forms nulls in direction of interference.

The software for the adaptive nulling unit may be used for conducting experiments and tests on adaptive hybrid reflector antenna models, testing adaptive algorithms in interference environments, controlling radiation patterns, forming counter service areas.

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