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KU-BAND SMALL ATENNA FOR SATELLITE EARTH STATIONS WITH IMPROVED RADIATION DIAGRAM

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Abstract

The mechanical and electrical design characteristics of a small offset antenna with elliptical aperture for receiving earth stations intended for the 11.7÷12.5 GHz Broadcasting Satellite Service (BSS), with improved antenna radiation pattern in the plane of the geostationary satellite orbit (GSO), were presented in a previous article published in Aerospace Research in Bulgaria. The antenna was manufactured by "Bulgaria SAT" company and its parameters and antenna pattern were measured by the Technical University in Sofia. In this article are presented specific elements of the production process and measured antenna characteristics. The results from measurements show that the antenna characteristics make this antenna suitable for use not only for BSS emissions reception, but also as a VSAT transceiver antenna in a much wider frequency band. Measured antenna pattern in the two main planes and at both linear polarizations were used in support of the revision of the ITU-R Recommendation S.1717 and were submitted for inclusion in the databank associated to this recommendation.

1. Introduction

A design of a small offset antenna with an elliptical aperture 70×50 cm with improved radiation pattern was presented in [1] as an alternative of the reference radiation pattern for BSS receiving antennas in Recommendation ITU-R BO.1213 with 60 cm circular aperture and bandwidth of ~3° (2.86°) at a half power level. The last is an existing reference antenna radiation pattern intended for BSS receiving earth stations for Region 1 and 3 of the International Telecommunication Union, Sector 'Radiocommunication' (ITU-R) in the band 11.7÷12.5 GHz referred to Appendix 30 of the Radio Regulations (RR) of ITU-R [2]. It is the basis of the analyses for the identification of the need for coordination of the new submitted systems for additional use of the BSS band. The reference antenna pattern does not allow too close positions of satellites in the systems for additional use of the BSS band. However, given the numerous submissions, it becomes increasingly difficult to find a position at the geostationary orbit (GSO) for new BSS system, which can be successfully coordinated under the provisions of Article 4 of Appendix 30 of the PP.

In 2012, "Bulgaria SAT" EAD was awarded by the national regulatory authority ‘Commission for regulation in communications’ (CRC) with permission to use GSO position 1.9°E for BSS system in case of a successful coordination. Both sides of this position the satellites of other countries’ BSS systems in operation are positioned at ~3° away. This circumstance required to conduct research and develop a new construction antenna for BSS receiving stations with improved radiation pattern enabling achievement of greater side-lobe suppression in the off-axis angles ~3° from the axis of the antenna and better cross-polarization discrimination. Based on constructive and electrical design characteristics of BSS receiving antenna a new reference antenna pattern was proposed and adopted by the Study Group 4 as Recommendation ITU-R BO.2063 [3]. The "Bulgaria SAT" EAD set up manufacturing of the antenna based on the design parameters, as well as, measurements of the basic constructive and electrical parameters: gain cross-polarization discrimination, radiation patterns of the antenna in the two major planes - in azimuth plane with the geostationary orbit and in the vertical plain along the elevation of the antenna.

2. Constructive and electrical characteristics of the developed antenna

The proposed antenna design is based on paraboloid shape main reflector, cut out with an oval rim. The rim shape is selected in a way to introduce reduction in the main lobe of the antenna, with edge illumination kept in control for low sidelobes, while the antenna gain still see a minimal reduction. To achieve a proper edge illumination level for oval (not circularly symmetric rim) a special dual mode feed horn was developed. In general cases, a single mode horn combined with an elliptical aperture will be sufficient to provide edge illumination good enough for the low first side lobes. However the induced currents on the reflector will have a component, degrading the cross-polar pattern of the antenna. In order to suppress the cross-polar component and improve the cross-polar pattern and antenna performance over the frequency band of operation (10.7÷12.75 GHz), a second order circular mode (TM11) is excited in the horn [4]. The phase relation between the modes is controlled with the proper selection of the horn length after the mode launcher and aperture flaring. The flaring causes excitation of additional high-order modes, however it was determined that their amplitudes are low enough to impair the horn pattern and particularly cross-polarization component level. Since the proposed antenna has an offset geometry it still has a rise of the cross-polar component levels in the Azimuth plane, but the proposed technique helps these levels to be kept within predefined maximum limits. For further reduction of the spillovers and improvement of the horn (primary) pattern a quarter-wave choke is introduced around the horn aperture. The prototype horn was precisely machined out of aluminum block on a Computer Numerical Control machine. All these measures led to bore-sight cross-polar discrimination of around -45 dB across the whole band. Additional measurements were conducted on casted aluminum samples, and they show a slight degradation of the cross-polar performance to -35dB, which is still a satisfactory result for receive-only antenna as will completely exclude the probability of cross-polar interference on the received channel.

The prototype of the main reflector is milled out of large single piece aluminum block which lead to surface deviation of 0.05 mm RMS against the ideal parabolic shape. Such deviation will introduce 0.02 dB antenna gain reduction [5], [6], which is an insignificant value, comparable with the error of the measurement instrument. Additional antenna gain loss may occur due to imperfect surface roughness, however estimations are for 0.02÷0.05 dB (antenna surface was brushed). The prototype antenna will not count for the large surface deviations which occur in stamped regular production, due to material spring-back leading to undesired pattern deviations and side-lobe level increase.

3. Measurement of radiation patterns of the developed antenna

The measurements were performed on an open far-field antenna range. The distance between the source and the antenna under test was approximately 100 m. Measurements were carried out at frequencies 10.7 GHz, 11.725 and 12.75 GHz describing the entire Ku-band 10.7÷12.75 GHz used for broadcasting of DTH TV programs. The measurements are performed according to recommendations in IEEE Standard Test Procedures for Antennas (IEEE Std 149-1979), with spectrum analyzer externally locked to the source generator. All measurements are performed by azimuth rotation, but with the antenna rotated around the boresight direction in cardinal planes (0° and 90°). The measurements in each cut plane at a given frequency are conducted up to 100° from the antenna boresight and consist of 201 data points in accordance with Annex 2 of Recommendation ITU-R S.1717 [7] determining the format of electronic data for inclusion in the data bank of the ITU-R for the measured diagrams of antennas for earth stations. This format was proposed in [8] and adopted by WP4A [9]. The antenna gain measurement accuracy is assessed as better than 0.25 dB.

The four figures presented below show the measured radiation diagrams for vertical polarization in azimuth ($\varphi_k = 0°$) co-polar (Fig. 1 and Fig. 2) and cross-polar (Fig. 3 and Fig. 4) planes at 10.7 GHz and 12.75 GHz of the antenna operating frequency band. For comparison are shown diagrams generated following the equations of the current reference pattern for BSS receiving antennas of Recommendation ITU-R BO.1213, included in Annex 5 of Appendix 30 of the RR [2] and equations of the developed as an alternative radiation pattern for BSS receiving antennas in Recommendation ITU-R BO.2063 [3] resulted from the

Bulgarian proposal [10]. It is clearly seen that the measured radiation diagrams of the developed antenna are better than the analytical:

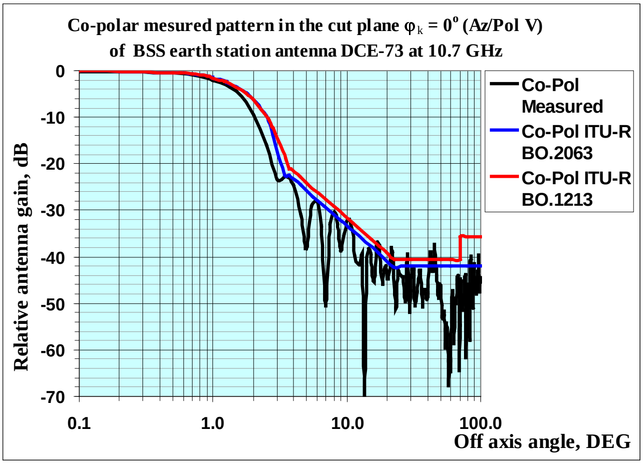

Fig. 1. Co-polar measured radiation diagrams for vertical polarization in azimuth ($\varphi_k = 0°$) at 10.7 GHz

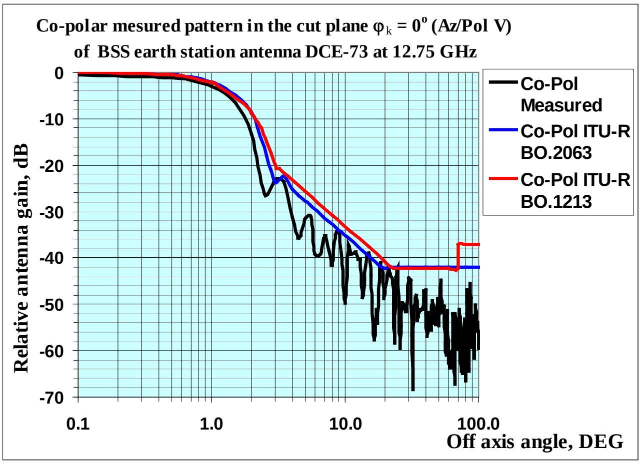

Fig. 2. Co-polar measured radiation diagrams for vertical polarization in azimuth ($\varphi_k = 0°$) at 12.75 GHz

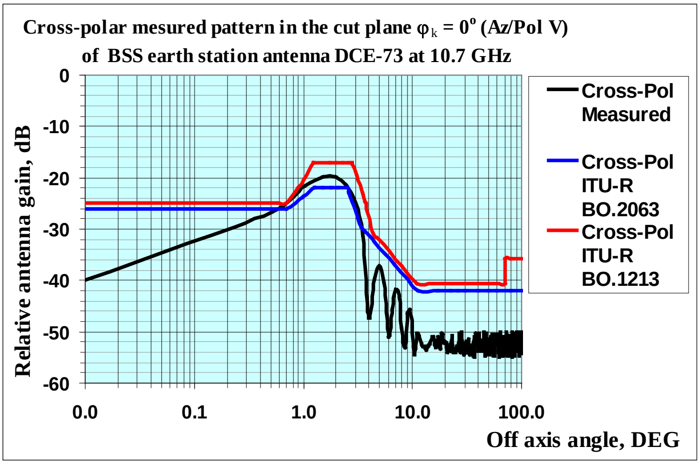

Fig. 3. Cross-polar measured radiation diagrams in $\varphi_k = 0°$ (Az/Pol V) at 10.7 GHz

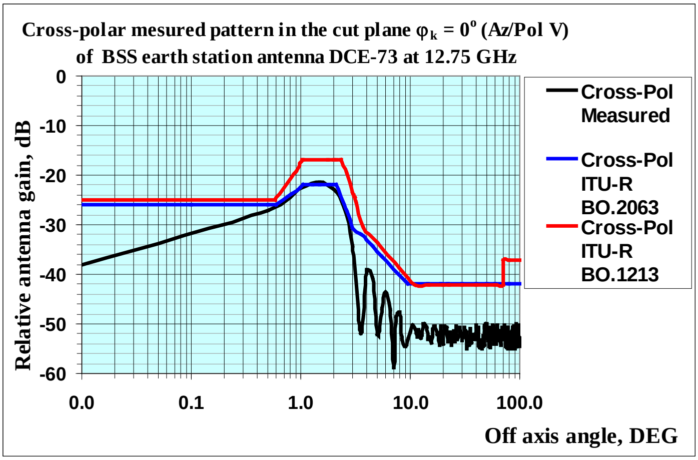

Fig. 4. Diagram of cross-polar measured radiation in $\varphi_k = 0°$(Az/Pol V) at 12.75 GHz

- co-polarization pattern (Fig. 1 and Fig. 2), especially in the off-axis antenna angles 1.5°÷3°, which are essential for the operation of satellite systems at close positions of the satellites on GSO;
- cross-polarization pattern (Fig. 3 and Fig. 4) providing better cross-polarization discrimination, which allows reception of co-frequency channels at both polarizations, i.e. developed antenna contributes to a more efficient use of the frequency-orbital resources in the frequency bands for broadcasting-satellite service.

In Fig. 5 is presented a comparison between the co-polar gain of the developed antenna DCE-73 at the middle frequency 11.725 GHz, at which measurements are also made, and the gain for the corresponding off-axis angles calculated using equations for the radiation diagram in Recommendation ITU-R BO.2063 [3] for 0.6 m antenna size, as well as, a comparison between the antenna gain based of this recommendation and Recommendation ITU-R BO.1213, which was adopted as a reference diagram for the planned BSS band [2]. From the curves shape it is evident that the equations in Recommendation ITU-R BO.2063 provide greater side-lobe gain suppression within the scope of the most important off-axis angles for effective use of GSO and BSS spectrum than that according the equations in Recommendation ITU-R BO.1213. The radiation pattern of the real antenna provides significantly greater side-lobe gain suppression than the analytical ones in both recommendations, especially in the off-axis angle sector 2°÷3°.

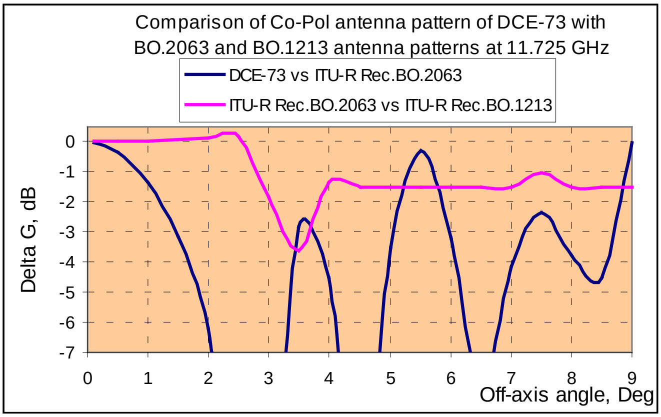

Fig. 5

3. Evaluation of the results from using the developed antenna

In order to establish the effect of using more effective radiation pattern of Recommendation ITU-R BO.2063 developed based on the design parameters of the antenna of "Bulgaria SAT" EAD, the excess of the criterion „Max. EPM Degradation ≤ 0.45 dB" is analyzed. The results of this analysis are used by the ITU-R Radiocommunication Bureau to establish the need for coordination of newly submitted BSS satellite system with submitted before it systems in the planned BSS band. The software MSPACEg of the ITU-R Radiocommunication Bureau, designed for this purpose, is used. The analyzes are made for the reference diagram of Recommendation ITU-R BO.1213 for BSS receiving antennas of the test systems as applied to the ITU-R Radiocommunication Bureau and for the radiation pattern of Recommendation ITU-R BO.2063. A sample of the results from analyzes, in a form of outputs from MSPACEg, are presented in

Attachment 1. In green are marked all systems, groups of emissions, and BSS channels dropped out as potentially affected by newly submitted BSS system as a result of application of the radiation pattern of Recommendation ITU-R BO.2063: 4 systems, 25 groups of emissions, and 21 BSS channels from the great groups of emissions. As a newly submitted system the Bulgarian submission from 2012 in the planning BSS band 11.7÷12.5 GHz at position 1.9° is used.

From the comparisons presented in Fig. 5, it is obvious that the use of the developed antenna DCE-73 as receiving BSS antenna will minimize interference in real conditions, since the distance between the positions of the affected systems and the Bulgarian system are exactly in the off-axis angle sector 2°÷3°. In this angular sector differences in the real antenna gain and the calculated ones according to Recommendation ITU-R BO.2063 is more than 5 dB in favor of the real antenna.

5. Conclusion

Through the development of the BSS receiving antenna (Fig. 6) from "Bulgaria SAT" EAD the following results were achieved:

1. Based on the design data of the developed BSS receiving antenna, presented in [1], [10] and other contributions, a new Recommendation ITU-R BO.2063 [3] were proposed and adopted following the ITU-R procedures as an alternative of the existing reference pattern for BSS receiving antennas [2] taken from Recommendation ITU-R BO.1213;

2. The measurement data of the radiation patterns of "Bulgaria SAT" EAD BSS receiving antenna for both polarizations in two orthogonal planes allowed to finalize the proposed revision of Recommendation ITU-R S.1717 by inclusion of actual data for all components in its new Annex 2 [7];

3. Measurement data of the developed by "Bulgaria SAT" BSS receiving antenna with improved radiation pattern presented in the format of Annex 2 to Recommendation ITU-R S.1717 were included in the data bank to this recommendation [8, 9].

Fig. 6 "Bulgaria SAT" BSS receiving antenna

The following conclusions can be made:

1. The measurement data of the radiation pattern of the developed from "Bulgaria CAT" BSS receiving antenna shows that it is possible to develop a BSS receiving antenna with the aperture, equivalent to 0.6 m antenna with a circular aperture, with an improved radiation pattern complying with Recommendation ITU-R BO.2063 [4], developed based on the design parameters of this antenna, which confirms that the Recommendation ITU-R BO.2063 is feasible and can be proposed to replace the existing in the RR reference radiation pattern for BSS receiving antennas [3]. This would result in the identification of less number of potentially affected systems and will facilitate the coordination process and consequently will lead to more effective use of frequency-orbital resources;

2. The use of the developed antenna (DCE-73) as a BSS receiving antenna will allow closer spacing of BSS satellite systems and thus will lead to extremely improve under real conditions the use of frequency-orbital resources in one of the most overloaded bands for distribution of satellite TV programs.

References

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Attachment 1

Input File Name: C:\BRIFIC\IFIC-2809_08.12.2015\S_IFIC2809\Databases\AP30_30A\SPS_ALL_IFIC2809.mdb
Output Database Name: C:\BRIFIC\IFIC-2809_08.12.2015\S_IFIC2809\Databases\AP30_30A\SPS_ALL_IFIC2809.OUT.MDB
Date/Time of Creation: 12/31/2015 5:16:47 AM
Version of Analysis: 16
MSPACEg software version: 7.5.0.0
EPM degradation limit : 0.45 dB
Co-polar orbital separation limit = 9.00 Cross-polar orbital separation limit = 9.00 (degrees)
All Networks/Assignments from Input File or SNS/SPS Database Were Considered in Analysis

Adm. Symbol	Orbital Position (Deg. E)	Sat.Network Id.	Sat.Network Beam Name	Program Beam Name	Affected Channels	Max. EPM Degradation with BO.1213 (dB)	Max. EPM Degradation with BO.2063 (dB)
BUL	-1.20	BUL02000	BUL02000	BUL02000	22,24,26,28,30,32,34,36,38,40	4.397	2.091
GRC	-1.20	GRC10500	GRC10500	GRC10500	2,6,8,10,12,14,16,18	2.416	0.7
NOR	-0.80	NOR12100	NOR12100	NOR12100	28	7.578	6.087
S	5.00	S 13800	S 13800	S 13800	27,29,31,33,35,37,39	4.885	1.975
S	5.00	S 13900	S 13900	S 13900	30	3.073	<0.45
S	5.00	SIRIUS-2-BSS	NOR2	SI2ADN2A	20	1.986	<0.45
S	5.00	SIRIUS-2-BSS	NOR2	SI2ADN2D	20	1.958	<0.45
S	5.00	SIRIUS-2-BSS	NOR2	SI2DN2A	24,30,32,38,40	6.046	3.233
S	5.00	SIRIUS-2-BSS	NOR2	SI2DN2D	24,30,32,38,40	5.951	3.149
S	5.00	SIRIUS-2-BSS	NOR3	SI2DN3A	28,34,36	5.995	3.200
S	5.00	SIRIUS-2-BSS	NOR3	SI2DN3D	28,34,36	5.898	3.111
S	5.00	SIRIUS-2-BSS	STR2	SI2ADS2A	19	2.129	<0.45
S	5.00	SIRIUS-2-BSS	STR2	SI2ADS2D	19	2.100	<0.45
S	5.00	SIRIUS-2-BSS	STR3	SI2ADS3A	3,21	2.487	<0.45
S	5.00	SIRIUS-2-BSS	STR3	SI2ADS3D	3,21	2.415	<0.45
S	5.00	SIRIUS-2-BSS	STR1	SI2DS1A	27,35	7.962	4.920
S	5.00	SIRIUS-2-BSS	STR1	SI2DS1D	27,35	7.962	4.920
S	5.00	SIRIUS-2-BSS	STR2	SI2DS2A	29,31,33,37,39	7.962	4.920
S	5.00	SIRIUS-2-BSS	STR2	SI2DS2D	29,31,33,37,39	7.962	4.920
S	5.00	SIRIUS-2-BSS	STR3	SI2DS3A	1,23,25	2.795	<0.45

МАЛКА АНТЕНА ЗА ЗЕМНИ СТАНЦИИ ЗА ВРЪЗКА СЪС СПЪТНИЦИ В KU-ОБХВАТА С ПОДОБРЕНА ДИАГРАМА НА ИЗЛЪЧВАНЕ

П. Петков, Е. Александрова , М. Заяков

Резюме

В [1] са представени проектираните механични и електрически характеристики на малка антена с изместена фокална ос с елиптична апертура, предназначена за приемни земни станции за спътниково-радиоразпръскване (BSS) в обхвата 11.7÷12.5 GHz, с подобрена диаграма на излъчване в равнината на геостационарната орбита (GSO). Антената е разработена от „България САТ” ЕАД и параметрите ѝ и диаграмата ѝ са измерени от Техническия университет в гр. София. В настоящата статия са представени специфични елементи на производствения процес и измерените характеристики на антената. Резултатите от измерванията показват, че антенните характеристики позволяват тя да бъде използвана не само за приемане на BSS излъчвания, но също и като предавателна VSAT антена в доста по-широк честотен обхват. Измерената диаграма на антената в двете главни равнини и на двете линейни поляризации са използвани за целите на ревизиране на Препоръка ITU-R S.1717 и са подадени за включване в банката данни, свързана с тази препоръка [10].