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MONITORING OF THE ORBITAL POSITION OF GEOSTATIONARY SATELLITE BY SPATIALLY SEPARATED RECEPTION OF SIGNALS OF DIGITAL SATELLITE TELEVISION

The results of determination of Eutelsat-13B geostationary satellite orbital position in 2015–2016 using European station network for reception of DVB-S signals from the satellite are presented. The network consists of five stations located in Ukraine and in Latvia. The stations are equipped with radio engineering systems developed at the MAO. The measured parameter is time difference of DVB-S signal arrival (TDOA) in the network stations. The TDOA and satellite coordinate errors have been estimated using a numerical satellite motion model as ±2.6 m and ±35 m, respectively. Software applications for the numerical model is taken from OREKIT free space dynamics library.

Keywords: orbit of geostationary satellite, DVB-S, TDOA, and radio interferometer.

In August 2011, the MAO carried out an observation of *HotBird-9* geostationary satellite by two receivers of digital satellite television signals distanced 150 km from each other [1]. The experiment was conducted to develop an independent method for controlling the future *Lybid* Ukrainian geostationary satellite and was based on the radio inteferometry method and the passive radar method. It should be noted that the mentioned approach is considered by the European Space Agency as an alternative to conventional geostationary satellite ranging. The corresponding PaCoRa (Passive Correlation Ranging) project was implemented in 2010–2013 [2]. Today, the MAO has established European network for passive correlation monitoring (PCMN) of geostationary telecommunication satellites consisting of five stations located in Ukraine and in Latvia.

EUROPEAN GEOSTATIONARY SATELLITE MONITORING NETWORK

The network stations are located in Kharkiv, Mukacheve, Rivne, Mykolaiv (Ukraine) and in Ventspils (Latvia). The distance between the stations along the latitude and longitude is approximately 1000 km. The station in Ventspils started regular monitoring in December 2015, the station in Rivne has been doing monitoring since March 2016. Till February 2016, the station located in Kyiv was part of network as well. In addition to the stations, the network comprises a center observation data processing located in Mykolaiv. The network is equipped with radio-technical complex developed at the MAO. Detailed description of the hardware and software complex is given in [3]. The station equipment enables per-second GPS (Global Positioning System) synchronized recording of DVB-S (Digital Video Broadcasting-Satellite) signal fragments from the output of quadrature detector of digital satellite TV receivers. Duration of fragment is 200 μs, and length of respective sample with a nominal sampling rate of 51.2 MHz is 10 240. Given the structure of DVB-S signal these second-by-second samples of complex signal are converted to the samples of real signal to be archived and sent via Internet to the observation data processing center where correlation analysis of samples is made and second-by-sec-

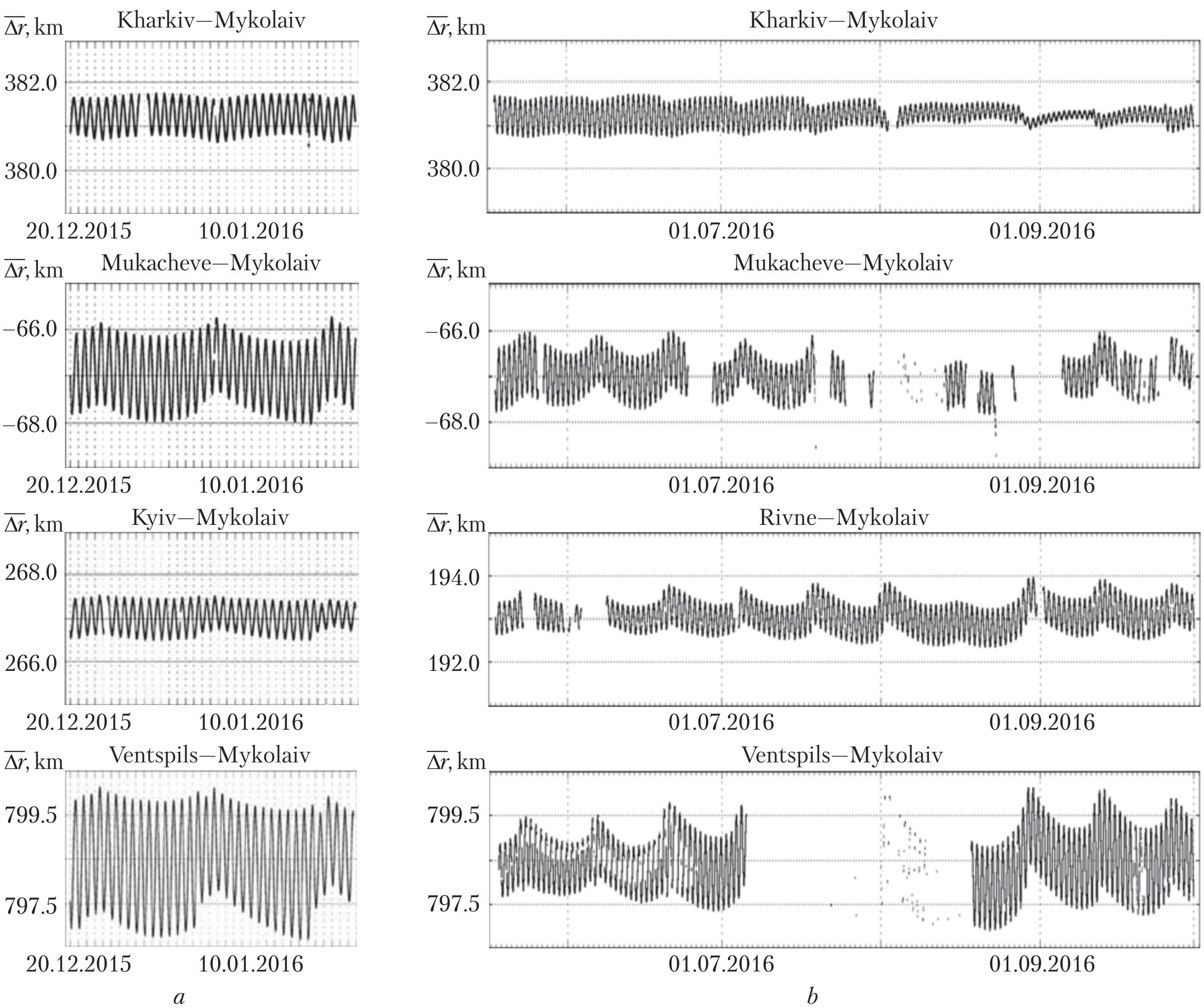

Fig. 1. Slant distance difference $\overline{\Delta r}$, oobtained by PCMN: *a* — within the period from 19.12.2015 to 30.01.2016 and *b* — from 18.05.2016 to 30.09.2016; $\overline{\Delta r}$ curves are given for the following pairs (upside down): *a* —Kharkiv—Mykolaiv, Mukacheve—Mykolaiv, Kyiv—Mykolaiv, Ventspils—Mykolaiv, *b* — Kharkiv—Mykolaiv, Mukacheve—Mykolaiv, Rivne—Mykolaiv, Ventspils—Mykolaiv

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ond TDOA (Time Difference of Arrival) is calculated [4]:

$$\Delta\tau_i = \left(\frac{n_{xi}}{k \cdot f_n} + \tau_{iPPS}\right) - \left(\frac{n_0}{k \cdot f_n} + \tau_{0PPS}\right) + \Delta\tau_{hi}, \quad (1)$$

where $\Delta\tau_i$ is TDOA calculated for the i-th and 0-th stations; n_{xi} is shift of correlation function maximum from the beginning of the sample obtained by the i-th station; n_0 is given shift of the middle part of the 0th station sample; k is measured coefficient of proportionality between the valid and the nominal sampling rate of ADC; $\Delta\tau_{hi}$ is measured instrumental delay caused by difference in electric length of receiving paths and relative shift of synchronization time of the stations as a result of, for example, different length of antenna drop cables of their GPS receivers; τ_{0PPS}, τ_{iPPS} are PPS (Pulse-Per-Second) of GPS receivers; n_{xi} and n_0 are measured in units of sampling rate. The size of middle part of the 0th station sample is equal to volume of correlator's sample and is always less than ADC sample volume; $k = 0.97655$ is constant for selected type of ADC; τ_{PPS} depend on geostationary position of controlled satellite and for *Eutelsat-13B* are equal to 1270, -215, 642, 0, 2660, and 888 μs for the stations in Kharkiv, Mukacheve, Rivne, Mykolaiv, Ventspils, and in Kyiv, respectively. Reliability of TDOA estimated by formula (1) has been confirmed in [4] by comparing with the model values obtained using the controlled satellite ephemerides given in www.space-track.org in TLE format.

A special software enabling to find orbital position of controlled satellite by measured TDOA has been developed at the Astronomic Observatory of the National University of Odesa. The orbital parameters are determined by the least square method using the two models of satellite motion: the SGP4/SDP4 analytical model and the numerical model for integrating the satellite motion equation. In the latter case, the satellite orbit is determined taking into account the perturbations caused by the Sun and the Moon gravity (JPL (Jet Propulsion Laboratory) Planetary and Lunar Ephemerides DE405/DE406) and the gravity of non-spherical Earth (EIGEN-6S [5]) taken into account. The software applications for the motion models are taken from OREKIT free space dynamics library (ORbital Extrapolation KIT).

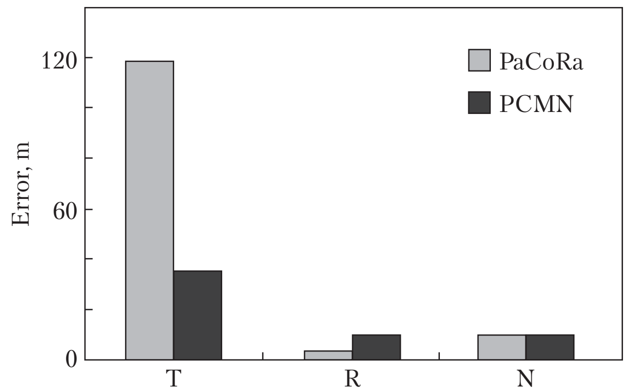

Fig. 2. Satellite coordinate errors for PaCoRa and PCMN. Letters T, R, and N correspond to tangential, radial, and normal coordinates, respectively

RESULTS OF OBSERVATIONS OF *EUTELSAT-13B*

Time dependence of measured slant distance difference $\overline{\Delta r}$, obtained by PCMN within the periods from 19.12.2015 to 30.01.2016 and from 18.05.2016 to 30.09.2016 is presented in Fig. 1, *a* and *b*, respectively. The slant distance differences $\overline{\Delta r}$ are calculated by averaging the second-by-second values $\Delta r = \Delta\tau \cdot c$ during 60 s, where $\Delta\tau$ is TDOA for given pair of stations, c is light velocity in vacuum. Fig. 1, *a* features $\overline{\Delta r}$ curves obtained for the following pairs (upside down): Kharkiv–Mykolaiv, Mukacheve–Mykolaiv, Kyiv–Mykolaiv, Ventspils–Mykolaiv, while Fig. 1, *b* shows the values for the same pairs of stations except for Kyiv–Mykolaiv replaced by Rivne–Mykolaiv. The statistical analysis shows that the median of standard deviation Δr is ±2.6 m for all pairs of stations. The computations show that the numerical model gives more accurate approximation of measured TDOA than the SGP4/SDP4 analytical model.

The errors of PaCoRa and PCMN are showed in Fig. 2. Letters T, R, and N on the diagram correspond to tangential, radial, and normal coordinates of the satellite in local orbital frame. From the mentioned data one can see that in the case of PCMN the maximum error is obtained for the tangential coordinate is 35 m, i.e. by 84 m less than the error for PaCoRa. It should be noted that the PCMN errors are estimated as standard deviation of satellite coordinates by epoch of orbit elements resulted from the processing of measured TDOA using the numerical model for integrating the satellite motion equations, whereas the PaCoRa errors are obtained by numerical modelling [6]. Unfortunately, the modelling parameters are not given in [6].

CONCLUSIONS

Eutelsat-13B satellite has been observed by means of the European Passive Correlation Monitoring Network consisting of five distanced stations for reception of DVB-S signals from the satellite within a period of almost a year, from December 2015 till September 2016. The TDOA error is ±2.6 m. The satellite coordinate error is estimated as ±35 m using the numerical model for integrating the satellite motion equations.

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МОНІТОРИНГ ОРБІТАЛЬНОГО ПОЛОЖЕННЯ ТЕЛЕКОМУНІКАЦІЙНОГО ГЕОСТАЦІОНАРНОГО СУПУТНИКА МЕТОДОМ БАЗИСНОГО ПРИЙОМУ СИГНАЛІВ ЦИФРОВОГО СУПУТНИКОВОГО ТЕЛЕБАЧЕННЯ

Наведено результати визначення орбітального положення геостаціонарного супутника «Eutelsat-13B», отримані протягом 2015–2016 рр. за допомогою європейської мережі станцій прийому сигналів DVB-S, випромінюваних супутником. До складу мережі входять п'ять станцій, розташованих в Україні і Латвії.. Станції оснащені радіотехнічним комплексом, розробленим в НДІ «МАО». Вимірюваним параметром є різниця у часі приходу сигналу DVB-S до станцій мережі або TDOA (Time Difference Of Arrival). Похибки визначення TDOA і координат супутника, які були отримані з використанням чисельної моделі руху супутника, дорівнюють ±2,6 та ±35 м відповідно. Програмна реалізація чисельної моделі була взята з астродинамічної бібліотеки OREKIT з відкритими кодами.

Ключові слова: слова: орбіта геостаціонарного супутника, DVB-S, TDOA, радіоінтерферометр.

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МОНИТОРИНГ ОРБИТАЛЬНОГО ПОЛОЖЕНИЯ ТЕЛЕКОМУНИКАЦИОННОГО ГЕОСТАЦИОНАРНОГО СПУТНИКА МЕТОДОМ БАЗИСНОГО ПРИЁМА СИГНАЛОВ ЦИФРОВОГО СПУТНИКОВОГО ТЕЛЕВИДЕНИЯ

Приведены результаты определения орбитального положения геостационарного спутника «Eutelsat-13B», полученные в течение 2015—2016 гг. с помощью европейской сети станций приема сигналов DVB-S, излучаемых спутником. В состав сети входят пять станций, расположенных в Украине и Латвии. Станции оснащены радиотехническим комплексом, разработанным в НИИ «НАО». Измеряемым параметром является разность времени прихода сигнала DVB-S на станции сети или TDOA (Time Difference Of Arrival). Ошибка определения TDOA и координат спутника, которые были получены с использованием численной модели движения спутника, равняются ±2,6 м и ±35 м соответственно. Программная реализация численной модели была взята из астродинамической библиотеки OREKIT с открытыми кодами.

Ключевые слова: орбита геостационарного спутника, DVB-S, TDOA, радиоинтерферометр.