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PHOTOMETRICAL RESEARCH OF GSS «INTELSAT 10-02»

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ABSTRACT. On example of the studies the obtained coordinate and photometrical data GSS «Intelsat 10-02» is shown as possible surveillance with the help of ground-based optical facilities dynamic state satellite and his behaviors on orbit.

The analysis of variation character of the light curves in B,V,R filters, time intervals between the flashes, the color indexes variation shows that the systems of stabilization of the platform, the transceiving antennas and the solar panels worked in operating normal mode during the dates of observation. The solar panels orientation relative to the Sun maintains well enough, rotated practically along the equtor plane tracking the Sun's path (the Earth's rotation). Orientation to axis of the rotation of the platform practically remains to be unchanged to direction on the centre of the masses of the Earth.

Some photometric characteristics of active three-axis stabilized communicative geostationary satellite (GSS) "Intelsat 10-02" (28358/2004 022 A) were calculated on the basis of electrophotometrical observations that were carried out on the 6^{th}, 7^{th} 12^{th}, 13^{th} and 14^{th} of October, 2010 on its entry and exit from the Earth's shadow. The longitude of the sub point GSS was $359^0.0\ E$, the inclination to the equator was $i=0^0.05$, the eccentricity was $e=0.00$. The following characteristics were computed: average effective reflecting areas $S\gamma_\lambda$ for the phase angle $\psi=0°$, spectral reflection coefficients γ_λ for the *B, V, R* filters for the phase angle $\psi=0^0$, the color index variation *(B-V), (V-R)* for the phase angle $\psi=25°$.

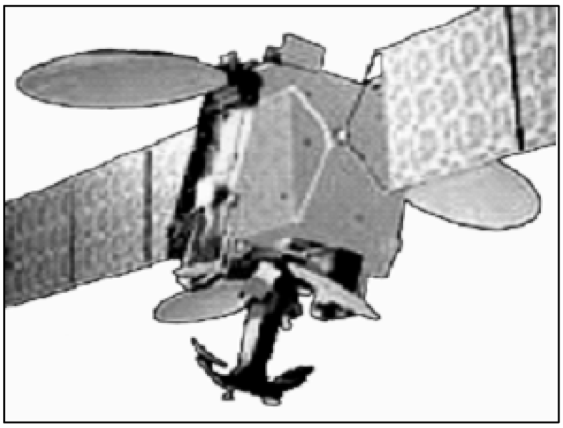

Figure 1

The appearance of satellite "Intelsat 10-02" is shown on the figure 1 alongside on the left [1], the total span of the solar batteries (SB) wings is 45m. "Eurostar-3000" platform is close to a parallelepiped, two of five sectional solar panels with independent orientation towards the Sun are mounted on its lateral surfaces. Two antennas of about 2m in diameter and two antennas of about 1m in diameter are mounted on the GSS platform. The GSS is stabilized and maintained in the given sub-satellite point according to its mission.

The observations were conducted suburban of Odessa in the *B, V, R* filters on 0.5m telescope using photomultiplier FEU-79. The electron signals passed through a wide-band amplifier and a pulse counter then were received on microcontroller ATMega16 and fed into the PC through serial port RS232. To reduce to the standard photometric system we used G2V stars, similar to the Sun, from the WBVR catalogue of the Sternberg State Astronomical Institute [2]. The mean quadratic error of magnitude for all dates was within the range of $0^m.02$ - $0^m.05$.

The analyzing of light curves of active stabilized satellites of certain form and dimensions allows determining of spectral reflection coefficients γ_λ for *B, V, R* filters close to their real values. The set of photometric characteristics of different types of the known active GSS is to facilitate interpretation of light curves of unknown satellites and as a consequence to accelerate satellite identification. The complex analysis the coordinate and photometric characteristics data makes it possible to checking the current state of a satellite (operating or normal mode, emergency state, ending of operational life, fragmentary state), and to reveal the source of a satellite's emergency state. As it was repeatedly noted [3, 4, 5], the observations carried out on the GSS entry and exit from the Earth's shadow allow to improve substantially the temporal resolution of photometrical observations and hence to make more precise the detailing of the field structure of reflective surface of satellites.

As per McCue et al. [6] the satellite magnitude m_{sat} can be equated as follows:

$$m_{sat} = -m_{sun} - 2.5\ \lg\ [S\gamma F(\psi)/d^2]$$

with m_{sun} – the Sun's magnitude, S – an object's cross-sectional area, γ – reflection coefficient, d –topocentric distance to the satellite, $F(\psi)$ – phase function. This equation was used to calculate the GSS photometric characteristics. For diffusing of the reflection of the light from flat surface phase function possible to present as:

$$F(\varepsilon,\theta) = \cos\varepsilon \cdot \cos\theta,$$

where ε and θ - corresponding to angles of the fall and reflections of the light to plane of the solar panels.

The analysis light curves the "Intelsat 10-02"

The phase light curves and color indexes of satellite "Intelsat 10-02" are presented below in Fig. 2-9. The computation of solar panels and platform angle of orientation with specular flashes at the light curves with vectors normal to the reflective surface was conducted in the satellite-centric equatorial coordinate system by applying the methods suggested by Yepishev V.P. and described in his work [9].

In row of the table, left to right, serial number and date of the observations, moments of the observations first and the second maximum of the light curves GSS in scale of universal time UT, time of stay of the satellite in shadowe of the Earth Δt minute, geocentric equatorial coordinates GSS α_{geoc} and δ_{geoc} in degres, value of the phase angle ψ and angle Q inclination of the panels SB to direction on Sun for moments of the observations, as well as minimum value of this angle Q_{min} on interval of the observation in the night (in degree).

Table 1. Results of the calculations of the position GSS and conditions of his illumination for moments fixing maximum light.

№ n/n	Data obser.	UT	Δt (min.)	α_{geoc}, °	δ_{geoc}, °	Ψ, °	Q, °	Q_{min}, °
1	06.10.2010	$1^h43^m54^s$	55	39.76	-0.01	27.36	13.63	9.55
		$2^h08^m13^s$		45.83	-0.01	32.76	16.37	
2	07.10.2010	$1^h43^m22^s$	52	40.60	-0.01	27.45	13.63	10.58
		$2^h06^m00^s$		46.63	-0.01	32.44	16.18	
3	12.10.2010	$1^h37^m55^s$	30	44.41	-0.01	27.43	13.72	7.98
		$2^h02^m24^s$		50.03	-0.01	32.63	16.30	
4	14.10.2010	$1^h59^m58^s$	20	51.17	-0.01	32.54	16.26	13.52

Table 2. Results of the determination to orientation of the solar batteries panels for moments of the GSS maximum light

№ n/n	Data obser.	UT	$\alpha_\odot$, °	$\delta_\odot$, °	α_{obser}, °	δ_{obser}, °	α_n, °	δ_n, °
1	06.10.2010	$1^h43^m54^s$	191.56	-5.02	216.37	6.82	204.01	0.92
		$2^h08^m13^s$	191.71	-5.03	222.44	6.82	207.05	0.92
2	07.10.2010	$1^h43^m22^s$	192.48	-5.40	217.21	6.82	204.89	0.72
		$2^h06^m00^s$	192.62	-5.40	222.81	6.82	207.72	0.72
3	12.10.2010	$1^h37^m55^s$	197.05	-7.30	220.76	6.82	208.97	-0.23
		$2^h02^m24^s$	197.20	-7.31	226.88	6.82	212.03	-0.23
4	14.10.2010	$1^h59^m58^s$	199.05	-8.05	228.28	6.82	213.68	-0.63

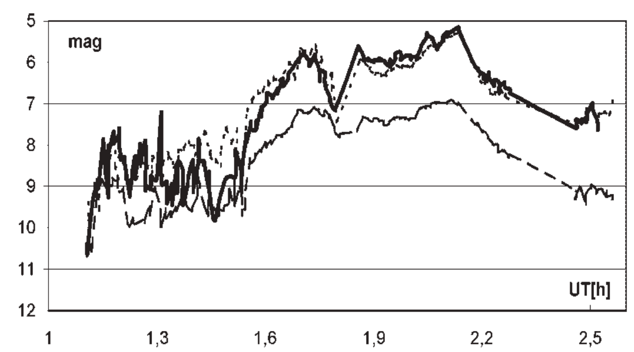

Figure 2. The light curves for “Intelsat 10-02” exited from shadow on 06.10.10. V – solid line, R ---, B – –.

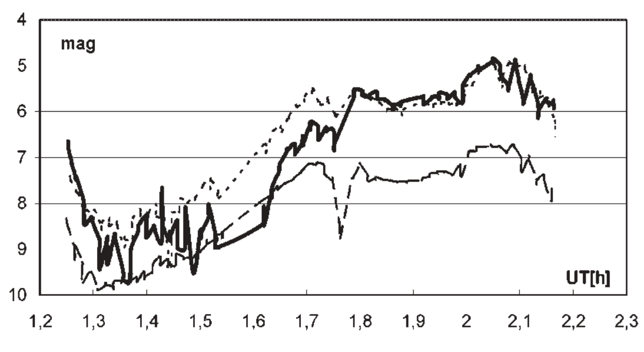

Figure 4. The light curves for “Intelsat 10-02” exited from shadow on 07.10.10. V – solid line, R ---, B – –.

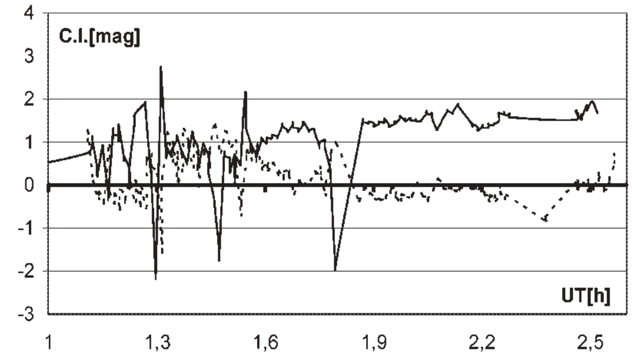

Figure 3. The color index variation for “Intelsat 10-02” exited from the shadow on 06.10.10. (B-V) solid line , (V-R) ---.

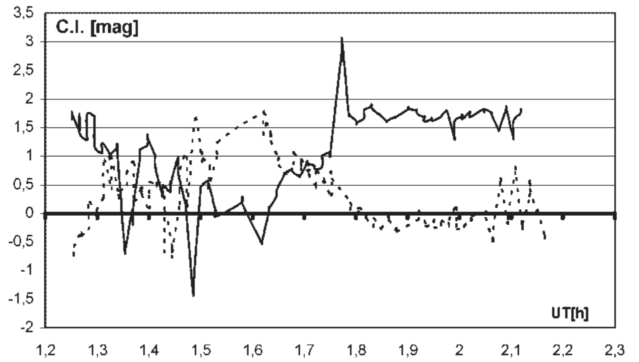

Figure 5. The color index variation for “Intelsat 10-02” exited from the shadow on 07.10.10. (B-V) solid line , (V-R) ---.

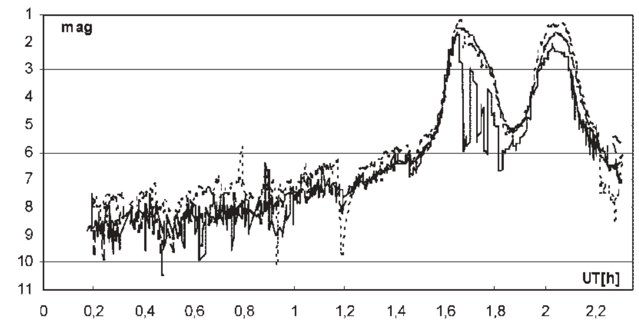

Figure 6. The light curves for “Intelsat 10-02” exited from shadow on 12.10.10. V – solid line, R ---, B – –.

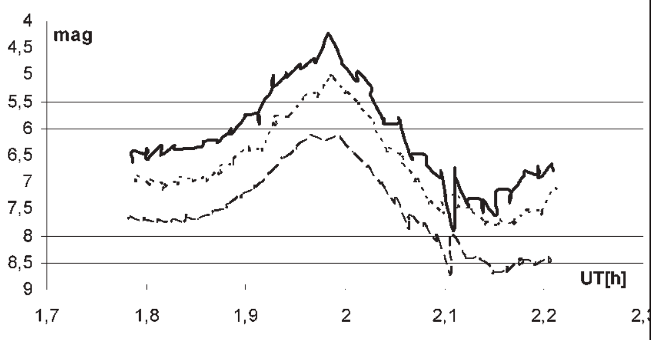

Figure 8. Second maximum of the the light curves for “Intelsat 10-02” exited from shadow on 14.10.10. V – solid line, R ---, B – –.

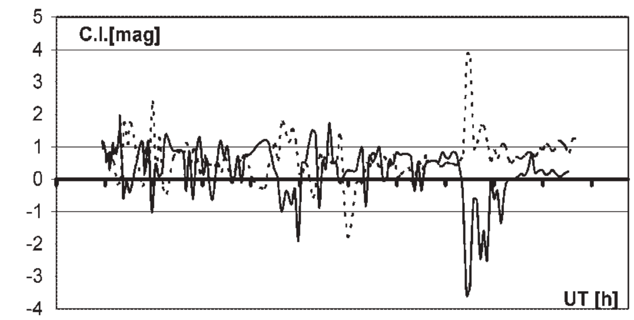

Figure 7. The color index variation for “Intelsat 10-02” exited from the shadow on 12.10.10. (B-V) solid line , (V-R) ---.

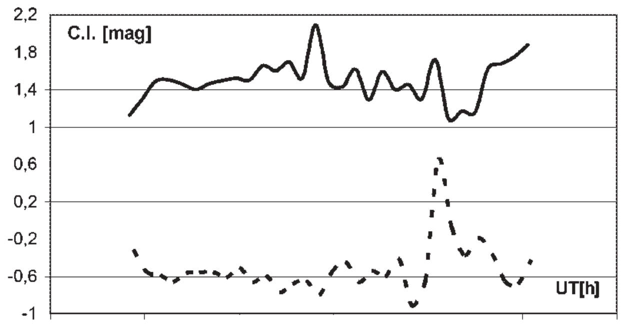

Figure 9. The color index variation for “Intelsat 10-02” exited from the shadow on 14.10.10. (B-V) solid line , (V-R) ---.

The first three rows of this table are identical the such of the table 1. Next, in row left to right, are shown Sun equatorial coordinates ($\alpha_{\odot}$, $\delta_{\odot}$) at the moments of the observations GSS, observer (α_{obser}, δ_{obser},) coordinates and directions normal to panel SB (α_n, δ_n) - in degree.

Only the second maximum of the light curve was recorded successfully in details on the night of 13/14.10.2010. Almost simultaneous brightness variation similar to the previous three light curves was observed in three filters. This is noted also for fixsed change the factors of the colour in all observant nights. Only October 12 2010 fixed mirror flashes reached maximum value before $m \approx 1^m$, but object was seen during half of the hour by naked eyes.

The obtained results interpretation

In the light flow, reflected from satellite "Intelsat 10-02", the main contribution give its solar battery panels (in all filter) in spite of the fact that factor of their reflection is less than 20%. There is one more additive of the light, reflected from antennas and lateral verges of the satellite's body in yellow and red area of the spectrum. It is conditioned by golden colour of the platform details and it is comparatively non-significant. After the GSS exits from the shadow, the Sun except panels well illuminated the lower part of the satellite's body where are placed various instruments, including smaller, than diameter of the antennas. In this time the light flow reflected to the observer's direction still is weak. Much weakly is illuminated also the front side of the satellite's body, which may be seen by observer. So on area of the light curve before first flash are observated of the light fluctuations practically in all filters with amplitude about 1^m.

While the Sun rises over horizon and its height increases, the lateral side of the satellite's body started to illuminate better, and while panel is turning, the angle of light reflection to observer's direction is decreasing. The satellite's light in all filters, fluctuating, grows before maximum with some additional jump in the yellow area of the spectrum. Greater values of the colour-index in these moments are conditioned not so much by optical features of the satellite's surface details, as by their mutual shadowing. The maximum of the light consists as if it were of two parts. At this moment the panels are most aptly oriented respectively the Sun and observer. But a part of remote panel is not seen by observer. It is overlapped by the body of the satellite.

Beginning since 6-th of October 2010, in maximum of the light GSS, into the observer's field of view gradually, from observation to observation was started to get the image of the Sun, solar glare, which was moving under some angle on the panel's surfaces. In the first night of observation the edge of glare has fallen in the observer's direction at the edge of one panel only, making insufficient increasing of GSS light at the end of the maximum. But in the 7-th of October 2010 the part of glare was seen along both panels. But, commencing its way from the end of panel which is remote from observer for a while it has fallen into shadow of the satellite's body and then was passing on lateral side of the satellite's body with antenna, oriented in the space otherwise than SB panels, that has brought about reduction of the light, and has finished its procession on the second panel nearest to observer, just once again increasing the GSS light.

To the night 12.10.2010 this glare was seen practically completely, having increased light of the GSS on 4^m, and has conditioned zero value of the colour-index (B-V). During shadowing by satellite's body and by nearest big antenna, it disappears from the observer's field of vision for 20 minutes, reducing the GSS light to accustomed 5^m, but then, passing on the second panel, it once again was increased. To the last night 14.10.2010, the conditions of the glare's visibility vastly grew worse that is confirming and the colour-index value (B-V). The GSS light is decreased, but value of the colour-index is increased.

From performed calculations it is seen that the most favorable observation of solar glare should be expected to 11.10.2010, when the declinations $\delta_{\odot}$ and $\delta_{obs.}$ on absolute value were equal. But, it is pity, in that night, because of bad conditions, observations were not conducted. Therefore, the maximum of the GSS light is closest to ideal "mirror" on the light curve for 12.10.2010. Thus and the obtained values of the satellite's orientation and its SB panels for this date are to be the most exact.

In the table 3 are shown calculated some photometric and optico-geometrical parameters of investigated GSS for the dates of observations.

In the table are given: spectral area of observation (filter), the star magnitudes M of GSS light reduced to the phase angles 25° and 0°, colour-indices (B-V) and (V-R) reduced to the phase angle 25°, and also geometric albedo A_{geom} and efficient reflection areas S_λ.

Table 3. The GSS «Intelsat 10-02» calculated photometric and optico-geometrical parameters.

Date, The Sun declination	Filter	M ψ =25°	M ψ = 0°	B-V ψ =25°	V-R ψ =25°	A_{geom}	S_λ, [м²] ψ =0°
06.10.2010	B	9.39	9.12			0.11	9.47
$\delta_{\odot}$= -04°58'	V	8.82	8.54	0.57	1.07	0.15	13.45
	R	7.75	7.47			0.24	21.56
07.10.2010	B	9.14	8.87			0.13	11.88
$\delta_{\odot}$ = -05°21'	V	8.75	8.48	0.39	1.02	0.16	14.30
	R	7.73	7.46			0.24	21.95
12.10.2010	B	7.89	7.62			0.42	37.42
$\delta_{\odot}$ = -07°14'	V	7.80	7.53	0.09	0.50	0.38	34.14
	R	7.30	7.03			0.36	32.61

Remark: The spectral reflection factors are calculated for average efficient reflection area of diffusive plane reduced to zero phase angle. In our case they are coinciding with the values of geometric albedo A_{geom}, i.e., integral characteristics, averaged on the whole reflecting area, including various details of constructions with various optical properties.

From provided in the table 1-4 data and described above dynamics of the GSS "Intelsat 10-02" visible light change is clearly seen that the SB panels are rotating in the small time lag around only one axis, which is perpendicular to equatorial plane. But the normal vector to the SB panels lies in the equatorial plane, making full turn overnight, accompanying Sun. Herewith number of the panels periodic moving is completely includes into the satellite's rotation period on its orbit. Both maximums on the satellite's light curve, from observation to observation, happen to one and same phase angle value (tabl. 1.). Regrettably insufficient time duration of each observation doesn't provide enough safely to define the period one, apart taken, tumbling of the panels tracing visible moving of the Sun disk.

Conclusions

The analysis of the GSS light change in three filters, corresponding to its colour-indices (the Figs. 2-9) and the time-lag values between the flashes, shows; that the systems of platform stabilizations, receive- transmitting antennas and SB in our observation dates functioned in staff operating duty. On length of the observed nights orientation panels SB beside satellite "Intelsat 10-02" was fairly well saved for directions on Sun. The tumbling of the panels SB occurred, probable whole, around axis perpendicular to the equatorial plane, tracing visible motion of the Sun (caused by rotation of the Earth and GSS, accordingly). The orientation to main axis of the platform, within error of the calculations, remained to be unchangeable to direction on the Earth masses centre.

The obtained coordinate and photometric information on GSS shows that using the ground-based optical facilities is possible effective control of the satellite dynamic condition [10], and estimation of the its visible surfaces details optical features and behavior the satellite on its orbit.

Table 4. Calculation results of the directing cosine (X_n, Y_n, Z_n) of normal vector to the surface of solar batteries (SB) and platform (P) for the chosen moments of the time.

	Satellite element	**Date**	**UT**	X_n	Y_n	Z_n	ψ, °	F_n, °
1	SB	6.10.2010	$2^h07^m03^s$	-0.8994	-0.4366	0.0210	33.42	1.2031
2	SB	7.10.2010	$1^h42^m15^s$	-0.8963	-0.4432	0.0175	27.97	1.0026
3	SB	12.10.2010	$1^h39^m21^s$	-0.8817	-0.4717	0.0003	27.66	0.0172
4	SB	14.10.2010	$1^h57^m58^s$	-0.8442	-0.5359	-0.0065	31.88	-0.3724
5	P	6.10.2010	$2^h08^m07^s$	-0.8984	-0.4387	0.0210	33.66	1.2031
6	P	7.10.2010	$2^h03^m00^s$	-0.8960	-0.4436	0.0175	32.57	1.0026
7	P	12.10.2010	$1^h39^m33^s$	-0.9289	-0.3703	0.0004	27.70	0.0229
8	P	14.10.2010	$1^h58^m58^s$	-0.8431	-0.5378	-0.0066	32.11	-0.3781

Where: ψ is phase angle; F_n is geodesic latitude of normal vector to the surface of SB.

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