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THE CONDITIONS OF AN ACTIVE EQUATORIAL GSS ENTERING THE EARTH'S SHADOW

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ABSTRACT. In this article we describe the conditions of an active GSS entry and exit from the Earth's shadow relative to the plane of the Earth's equator with a small inclination of the orbit to the equator.

Geostationary satellites is the agreed definition for geosynchronous satellites with periods of rotation around the Earth's centre of mass from 22^h to 26^h, the eccentricity of not more than 0.3 and the inclination of the orbital plane to the equator of up to 15°. Therefore any GSS is to immerse repeatedly into the Earth's shadow for different time in during a year.

The active GSS that orbit along the plane of the Earth's equator have an orbital inclination to the equator close to 0^0. The mentioned GSS are to enter and exit from the Earth's shadow close to the vernal and autumnal equinoxes on the conditions provided below (see formula (1)). Besides the conditions of formula (1), the time of immersing, emerging and passing into the shadow for passive GSS depend on the inclination of the GSS orbital plane to the equator, the direction of the GSS motion relative to the shadow: towards or away from the shadow.

It is often mentioned [1, 2, 3, 4], that the photometric observations of GSS on entry and exit from the shadow arouse a special interest as they allow to improve the temporal resolution of photometrical observations and hence to make more precise the detailing of the field structure of reflective surface of satellites. Therefore it is necessary to calculate the time of the observed satellite entry and exit from the Earth's shadow.

The Sun's declination changes from +**ε** ($+23^0\,26'$) to -**ε** ($-23^0\,26'$) throughout a year between the summer and winter solstices. And during a year the Earth's shadow moves correspondingly relative to the plane of geostationary orbit that is located along the plane of the Earth's equator (see Fig.1).

The shadow of the equatorial region passes through a GSS for the dates when the Sun is close to the vernal and autumnal equinoxes, so the GSS is passing into the shadow for the longest period - for about 70 minutes. The shadow of the Earth's polar regions passes through a satellite before and after the equinox, so the duration of its passing into the shadow shortens to several minutes.

The following two conditions must be met for a GSS entering the Earth's shadow:

$$|\delta_s - \delta_t| < \rho_s, \text{ и } |\alpha_s - \alpha_t| < r_t, \quad (1)$$

with δ_s – the satellite declination , δ_t – the shadow axis declination, α_s and α_t – the right ascension of the satellite and shadow axis correspondingly.

The length of the chord along which the satellite traversed the shadow is

$$r_t = \rho_s \sqrt{1 - \left(\frac{\delta_s - \delta_t}{\rho_s}\right)^2} \text{ [radians]}, \quad (2)$$

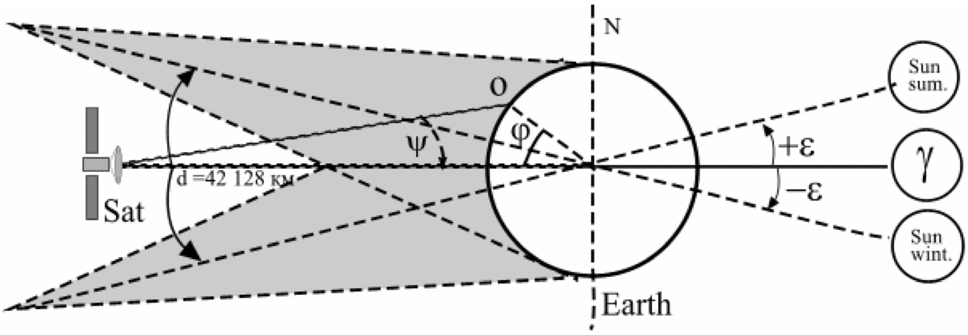

Figure 1. The Earth's shadow motion on the geostationary orbit during a year. The signs are described in the text below.

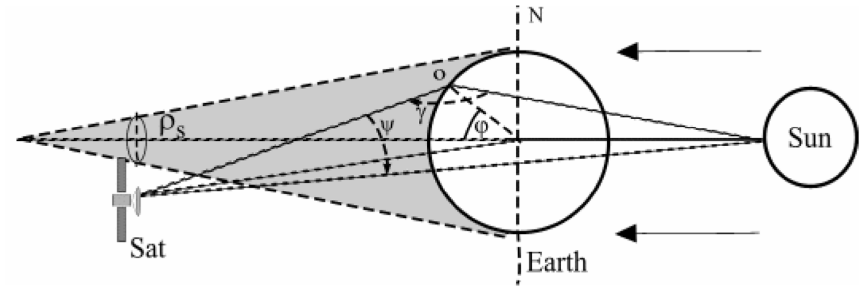

Fig. 2. The equatorial GSS location before its entering the Earth's shadow close to the equinox.

with $\delta_t = -\delta_\odot$, $\alpha_t = \alpha_\odot - 12^h$, ρ_s – the shadow cone diameter, $\rho_s = \dfrac{R_\oplus + d\cos\gamma tg\vartheta}{d\cos\gamma}$ = 08°25' = 6235.6 [km], where d = 42 128 km – the geostationary orbit radius, ϑ – the angle between the shadow axis and its generatrix for the cone-shaped shadow ($tg\vartheta = R_s/R_{SE}$, $R_s = R_\odot - R_\oplus$ = 696000 km; $R_\odot$ – the Sun's radius, $R_\oplus$ – the Earth's radius, R_{SE}= 1.49597·10^8 km – the Earth-Sun average distance), $\cos\gamma = (\mathbf{u}_\odot \cdot \mathbf{u}_s)$, γ – the Sun-satellite-observer angle, with $\mathbf{u}_\odot$ and $\mathbf{u}_s$ – unit vectors in corresponding directions, $\mathbf{u}_\odot$ = [cos $\alpha_\odot$cos $\delta_\odot$, sin $\alpha_\odot$cos $\delta_\odot$, sin $\delta_\odot$], $\mathbf{u}_s$ = [cos α_s cos δ_s, sin α_s cos δ_s, sin δ_s].

The curves for the variation of duration of the GSS passing into the Earth's shadow and the phase angle variation on entering the shadow for different dates close to the autumnal equinox are defined with formula (2) and shown on the Fig. 3 and Fig. 4.

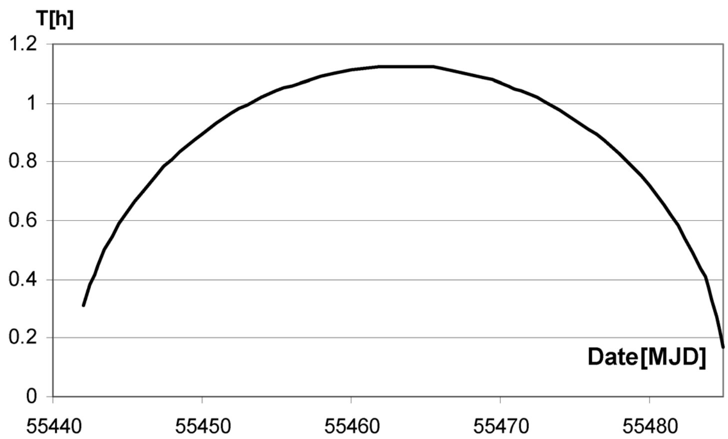

Fig.3. The duration of the GSS passing into the shadow. The X-axis shows the modified Julian date. The entering starts on 02.09.2010 = 55442[MJD], the maxima corresponds to 23.09.2010.The last date of entering the shadow is 16.10.2010.

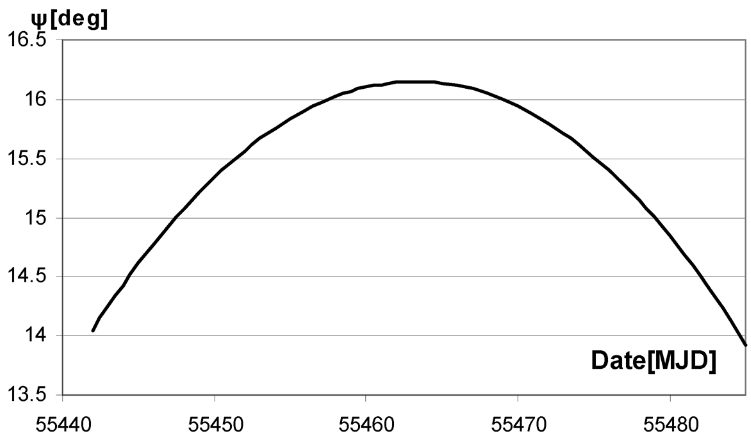

Fig. 4. The phase angle ψ variation on entering the shadow for different dates.

The calculations are made for the geostationary coordinate system, the equatorial GSS declination is 0^0. The cone-shaped Earth's shadow is assumed as a basis. For other shadow shape that heeds the presence of penumbra, the blurriness of the umbra-penumbra boundary and refraction, the time of the GSS entry and exit from the Earth's shadow as well as the phase angles are to be slightly different from those given on the Fig.3 and Fig.4. And the actual observed boundary dates for the equatorial GSS entry and exit from the Earth's shadow are shifted relative to the equinox (the 23rd of September) to the 30th of August and the 23rd of October accordingly. The observer located on the equator is to observe the satellite entry the shadow at the same time as the observer not located on the equator.

However it must be noted that on carrying out observations it is impossible to register accurately either the moments of total immersion or the moment of the exit start from the shadow. Such limits in observations caused mainly by the optical characteristics of telescopes, the atmosphere properties and the light detector sensitivity.

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