SUN TRANSITS IN GEO SATELLITE SYSTEMS IN THE ASPECT OF RADIO WAVES PROPAGATION

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Abstract. The article includes description of process of Sun transits, including indispensable information on the parameters employed to show their impact on these phenomena. On this basis the date, the start time and the end time and the duration time of Sun transits could be presented for a given location. The main considerations are pertinent to propagation studies. The part of results connected with Sun transits for the limited frequencies of K_u band (downlink) in satellite systems, depending on the antennae, is presented in this article.

Keywords: wave propagation, technical parameters, thermal noises, sun fades, solar outages, solar interferences

ZJAWISKO INFLUENCJI SŁONECZNYCH W SATELITARNYCH SYSTEMACH GEO W ASPEKCIE PROPAGACJI FAL RADIOWYCH

Streszczenie. Artykuł zawiera opis zjawiska influencji słonecznych, ukazując niezbędne informacje na temat zastosowanych parametrów, aby przedstawić ich wpływ na te zdarzenia. Na tej podstawie data, czasy początku i końca oraz czas trwania influencji słonecznych mogą zostać określone dla danej lokalizacji. Rozważania dotyczą badań propagacyjnych. W artykule dla łącza downlink zamieszczono część wyników, w zależności od zastosowanych anten, dla granicznych częstotliwości pasma K_u powszechnie wykorzystywanego w łączności satelitarnej.

Słowa kluczowe: propagacja fal, parametry techniczne, szumy cieplne, zaniki słoneczne, blokady słoneczne, interferencje słoneczne

Introduction

Sun transits, also known as: Sun outages, Sun fades, solar outages or solar interferences, occur around the spring and autumn equinoxes when the overwhelming noise from the Sun swamps the intended signal from the satellite. These phenomena affect all satellite links from time to time (twice a year). At these times the day and night are about the same length. During vernal and autumnal equinoxes the Sun crosses the equator and traces an arc that is directly behind the geo-arc of satellites. The heat which is emitted by the Sun is becoming a strong source of radiation at all frequencies, including the microwave frequencies used to satellite communication (C band, X band, K_u band, and K_a band). During both equinoxes, the reception equipment should accept any interference received, including solar interference that may cause undesired operation. As a consequence, satellite reception can be momentarily interrupted, because the station is incapable of distinguishing between desired communication signal and energy from the Sun. Therefore due to interferences, this phenomenon disrupts the proper reception of geostationary satellite signals.

The effects of solar interferences range from momentarily degradation of satellite signals (increase of BER) to total destruction of the signal (a lack of communication between terminal and satellite). In practice, digital systems are a little more resilient in this respect than analog systems. To prevent equipment damage due to the radiated energy from the Sun being focussed into the unit (fortunately, it's rare with recent projects), this danger can be avoided by the use of appropriate temporary or permanent instruments (guards) to receiving stations.

1. Energy from the Sun

At the present time, it is possible to estimate the exact date, the start and the end time and the duration time of Sun transits. Their effects depend on the location of the earth station, satellite location above the equator and earth station equipment (e.g., antenna beamwidth of earth station or focal resolution, accuracy of antenna pointing and the station keeping accuracy of the satellite). Thus, the region of sky scanned for the Sun interferences is associated with antenna beamwidth of ground station. Furthermore, the effects of solar interferences depend on the size of the receive antenna, as well as a frequency of reception satellite signal due to the impact of all noise sources.

The Sun as a meaningful source of extraterriestrial natural noises contributes to temporarily interferences with the satellite signal. It is also of immense importance for the satellite links operating at frequencies below 2 GHz. At high frequencies of at least 2 GHz or more, the impact of Moon and nonthermal radiation are additionally visible (e.g., the constellations of Cassiopeia A, Cygnus or planetary nebula – Crab). The noise temperature of the Sun (as a powerful broadband transmitter of microwaves) is in excess tens of thousands of Kelvin. This thermal energy is strong enough to cause an outage when the Sun passes directly behind the satellite (when viewed from the Earth). The Sun moves further north, the Sun's alignment with the satellite and station on the ground moves ever so little. When the Sun, satellite and station on the ground are exactly aligned with each other, peak outage time appears. Therefore, the outage duration increases when the Sun becomes more aligned with the satellite and ground station. In practice, the Sun fades will appear for several days both before and after the peak. Further, the interferences will arise at roughly the same time each day and could repeat on a daily basis for one week or more. The interferences decrease moderately as the Sun starts moving away from the satellite and station alignment, until another solar outage when the Sun starts heading south (during autumnal equinox).

2. Experimental results

We can distinguish many factors affecting the reception of microwaves. Many articles include studies of the effects of rain. The other ones are connected with technical parameters (e.g., antenna aperture, antenna mispointing, dish efficiency, coupling loss, etc.). Sometimes it is necessary to compensate poor quality of signal via modifications of technical parameters. For this reason the knowledge about technical equipment is of great importance to the design and implementation of high-quality satellite systems. Currently, we can safely inspect and predict the Sun transits to estimate their impact on the quality of a satellite signal. Actual monitoring and measurements should be carried out in appropriate conditions. The predicted results for Lublin city will be presented in this article for the Eutelsat Hot Bird 13A satellite (13ºE) according to the limited (bounded) middle frequencies of the carrier from K_u band (downlink) and antenna aperture. Antenna aperture has been changed twice (from 0.6 m – it is the minimal recommended aperture for receiving signals in Poland, to 1.2 m – the doubled minimal value). The results of solar interferences for Geostationary Orbit Satellite (for vernal and autumnal equinoxes in year 2018) for the antenna aperture equalling 0.6 m and frequency equalling 10.7 GHz (lower bound of bandwidth) are presented in Table 1 and Table 2. The analogous results but for the frequency equalling 12.75 GHz (upper bound of bandwidth) are presented in Table 3 and Table 4. All solar outage events are listed in date order and grouped according to the early and late seasons.

Table 1. Vernal equinox in year 2018 for the frequency equalling 10.7 GHz and antenna aperture equalling 0.6 m

Data	Start	End	Outage window duration
22.02	12:23	12:27	00:04
23.02	12:19	12:31	00:12
24.02	12:17	12:33	00:16
25.02	12:16	12:34	00:18
26.02	12:15	12:34	00:19
27.02	12:14	12:35	00:21
28.02	12:14	12:35	00:21
1.03	12:13	12:35	00:22
2.03	12:13	12:35	00:22
3.03	12:13	12:34	00:21
4.03	12:14	12:33	00:19
5.03	12:14	12:32	00:18
6.03	12:15	12:31	00:16
7.03	12:17	12:29	00:12
8.03	12:19	12:26	00:07

Table 2. Autumnal equinox in year 2018 for the frequency equalling 10.7 GHz and antenna aperture equalling 0.6 m

Data	Start	End	Outage window duration
5.10	11:57	12:04	00:07
6.10	11:54	12:06	00:12
7.10	11:52	12:08	00:16
8.10	11:50	12:09	00:19
9.10	11:49	12:09	00:20
10.10	11:49	12:10	00:21
11.10	11:48	12:10	00:22
12.10	11:48	12:09	00:21
13.10	11:48	12:09	00:21
14.10	11:48	12:08	00:20
15.10	11:48	12:08	00:20
16.10	11:49	12:07	00:18
17.10	11:50	12:05	00:15
18.10	11:51	12:03	00:12
19.10	11:54	12:00	00:06

As we can conclude, according to the closest Sun's alignment within the prescribed time limits, during vernal equinox (February and March equinox) the maximum deph was between 27.02 and 4.03. Deph has a minimum value from 22.02 to 24.02 and from 6.03 to 8.03. It has a medium value between 25.02 and 26.02, similarly to 5.03. During autumnal equinox (October equinox) the maximum deph was between 10.10 and 14.10. Deph has a minimum value from 5.10 to 7.10 and from 17.10 to 19.10. It has a medium value between 8.10 and 9.10, the same as between 15.10 and 16.10.

As already noted, the results for the frequency equalling 12.75 GHz, in the case of antenna aperture equal 0.6 m, for vernal and autumnal equinoxes in year 2018 are shown in Table 3 and Table 4. For this signal frequency during vernal equinox (February and March equinox) the maximum deph was between 27.02 and 3.03. Deph has a minimum value from 23.02 to 25.02 and from 5.03 to 7.03. This parameter has a medium value 26.02, similarly to 4.03. During autumnal equinox (in October) the maximum deph was between 10.10 and 14.10, similarly as in the case of the earlier-mentioned frequency equalling 10.7 GHz. Deph has a minimum value from 6.10 to 8.10 and from 16.10 to 18.10. It has a medium value for two days: 9.10 and 15.10.

Table 3. Vernal equinox in year 2018 for the frequency equalling 12.75 GHz and antenna aperture equalling 0.6 m

Data	Start	End	Outage window duration
23.02	12:24	12:26	00:02
24.02	12:20	12:30	00:10
25.02	12:18	12:32	00:14
26.02	12:17	12:33	00:16
27.02	12:16	12:33	00:17
28.02	12:15	12:33	00:18
1.03	12:15	12:33	00:18
2.03	12:15	12:33	00:18
3.03	12:15	12:33	00:18
4.03	12:15	12:32	00:17
5.03	12:16	12:30	00:14
6.03	12:17	12:29	00:12
7.03	12:20	12:26	00:06

Table 4. Autumnal equinox in year 2018 for the frequency equalling 12.75 GHz and antenna aperture equalling 0.6 m

Data	Start	End	Outage window duration
6.10	11:58	12:03	00:05
7.10	11:54	12:06	00:12
8.10	11:53	12:07	00:14
9.10	11:51	12:08	00:17
10.11	11:50	12:08	00:18
11.10	11:50	12:08	00:18
12.10	11:49	12:08	00:19
13.10	11:49	12:08	00:19
14.10	11:49	12:07	00:18
15.10	11:50	12:06	00:16
16:10	11:51	12:05	00:14
17.10	11:52	12:03	00:11
18.10	11:55	12:00	00:05

On the basis of analysis carried out so far we can conclude that very important factor is the antenna aperture. This technical parameter is taken as the average diameter of a dish in metres to ascertain compliance with international engineering practice. The results indicate that the major diameter is a better choice than minor diameter. Against this background, the larger the antenna aperture, the shorter the duration and intensity of solar interferences and vice versa.

The solar interferences in year 2018 during both equinoxes for the same frequencies as before, but for the antenna aperture equalling 1.2 m are presented in tables from 5 to 8.

Table 5. Vernal equinox in year 2018 for the frequency equalling 10.7 GHz and antenna aperture equalling 1.2 m

Data	Start	End	Outage window duration
26.02	12:22	12:28	00:06
27.02	12:20	12:30	00:10
28.02	12:19	12:30	00:11
1.03	12:19	12:30	00:11
2.03	12:18	12:30	00:12
3.03	12:19	12:29	00:10
4.03	12:20	12:28	00:08
5.03	12:22	12:25	00:03

Table 6. Autumnal equinox in year 2018 for the frequency equalling 10.7 GHz and antenna aperture equalling 1.2 m

Data	Start	End	Outage window duration
8.10	11:58	12:01	00:03
9.10	11:55	12:03	00:08
10.10	11:54	12:04	00:10
11.10	11:53	12:04	00:11
12.10	11:53	12:04	00:11
13.10	11:53	12:04	00:11
14.10	11:53	12:03	00:10
15.10	11:54	12:01	00:07

The results in the case of frequency equalling 10.7 GHz indicate that, according to the closest Sun's alignment within the prescribed time limits, during vernal equinox (February and March equinox) the maximum deph was between 28.02 and 2.03. Deph has a minimum value from 4.03 to 5.03 and 26.02. It has a medium value within two days: 27.02 and 03.03. During autumnal equinox (October equinox) the maximum deph was between 11.10 and 13.10. Deph has a minimum value from 8.10 to 9.10, similarly to 15.10. It has a medium value for two days: 10.10 and 14.10.

The results for the upper bound of bandwidth (12.75 GHz) are presented in Tables 7 and 8 for vernal and autumnal equinoxes, respectively.

Table 7. Vernal equinox in year 2018 for the frequency equalling 12.75 GHz and antenna aperture equalling 1.2 m

Data	Start	End	Outage window duration
26.02	12:23	12:27	00:04
27.02	12:21	12:29	00:08
28.02	12:20	12:29	00:09
1.03	12:19	12:30	00:11
2.03	12:19	12:29	00:10
3.03	12:20	12:28	00:08
4.03	12:21	12:27	00:06

Table 8. Autumnal equinox in year 2018 for the frequency equalling 12.75 GHz and antenna aperture equalling 1.2 m

Data	Start	End	Outage window duration
9.10	11:57	12:02	00:05
10.11	11:55	12:03	00:08
11.10	11:54	12:04	00:10
12.10	11:54	12:04	00:10
13.10	11:54	12:03	00:09
14.10	11:54	12:02	00:08
15.10	11:56	12:00	00:04

These data indicate that during vernal equinox (February and March equinox) in year 2018 the maximum deph was between 28.02 and 2.03. Deph has a minimum value for two days: 26.02 and 4.03. This parameter has a medium value 27.02, similarly to 3.03. During autumnal equinox (in October) the maximum deph was between 11.10 and 13.10. Deph has a minimum value within two days: 9.10 and 15.10. It has a medium value also for two days: 10.10 and 14.10.

Generally during both equinoxes, with the increase in antenna aperture the number of days with outages significantly declined. This becomes particularly evident for both frequencies for all bounded days from Tables 5–8, in comparison to the first and the last days from Tables 1–4. As we can observe, the differences are equal several days for each bounded day in the frequency range covered. As might be expected, the increase in the antenna aperture leads to minimize the number of days with outages, which is desirable.

3. Results and discussion

This article presents the process of Sun transits. The article includes information on the parameters employed and their impact on these phenomena. One of them is antenna aperture. In practice, the duration of the solar interferences is inversely related to the antenna aperture and frequency of the satellite receive dish (the smaller the antenna aperture, the great outage window duration and intensity of the interferences).

The main scientific objective was to analyze the impact of solar interferences on the quality of satellite transmissions during vernal and autumnal equinoxes (twice a year). Solar outages may cause total loss of signal sometimes.

On this basis the date, the start time and the end time and the outage window duration for the limited frequencies of K_u band (downlink) in satellite systems, depending on the antenna aperture for the given location was presented. In this context the essential information could be used in practical applications. All data due to quite substantial repeatability may be accommodated by defining the terminal equipment over subsequent years, as soon as the links that should meet the quality requirements of signal by defining the specific parameters. Therefore, we can use the tabular data to achieve the forecast of solar outages for the future with quite good precision in the selected geographical area. Tests have shown that the predicted times of solar interferences are close to what is de facto viewed in practice. These data are also important to reduce the risk of interruption of the connection. So, another application could be present in the link budget analyses. Because of it, it is possible to use a transponder at an alternative time relative to solar outages as a concrete knowledge of when these events appear is meaningful. If we do wish more reliable data transfer connection at that time, it is possible to use an another satellite.

Apart from that, if we consider alongside the solar outages – another information, e.g., free space attenuation, degradation due to hydrometeors (especially rainfall), influence of the Earth atmosphere (especially total gaseous absorption) we could determine reasonably comprehensive link budget analyses. Therefore, the accurate results may be used to characterize the receiver by the minimum acceptable quality of signal which takes into account undesirable weather conditions and solar interferences.

4. Conclusions

The solar interferences during vernal and autumnal equinoxes may last several minutes either side of the peak each day. As can be seen from the analyses presented in Tables 1–8, the outage will last longer for the smaller the antenna. In this sense, determination of solar outage findings with satellite systems (for selected parameters) for planning and management in the city is significant. Fortunately, as may be expected the sustainable city for planning and management uses to determine the large satellite. It abundantly shows in many examples that we can use these data for manufacturers and users of satellite equipment. Moreover, the results can be applied to dynamical changes in transmission parameters (e.g. to improve energy efficiency).

These data can be useful for calculating signal quality in practice. Only if elderly satellites have lapsed into severe inclined orbits, results might be inaccurate as a sign for the future. So, the satellite's inclination should be check before measurements or predictions. The predictions of solar outages associated with a particular location and satellite combination (by using astronomical algorithm) can be applied to provide information about the days when energy from the Sun interferes with the excepted signals. Therefore, this knowledge may be useful to ensure the proper reception signals and minimize the risk of lack of communication (e.g., it is possible to book transponder time to relay information in good time – not when solar outage appears just to coincide with transmission of information on the downlink).

Data about solar outages can be useful for improve the knowledge about propagation of wave. Nevertheless, to put additional data into practice in a considerable way is a challenge requiring further efforts about modelling remote sensing, signal attenuation, noise increase or total signal degradation. Currently, the similar studies are lead many of numerical forecast models. It is planned to estimate the maximum safe distance of margin during solar outage events and conduct regression analysis.

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