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SUN INTERFERENCE PREDICTIONS FOR THE KOMPSAT TT&C STATION

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ABSTRACT

The Sun interference event predictions for the KOMPSAT TT&C station were performed to analyze the frequency of the events and the impact on the TT&C link. The KOMPSAT orbit was propagated including only J2 geopotential term for maintaining the Sun-synchronism and no other perturbations were included. Local time of ascending node of the KOMPSAT satellite was set to $10^h50^m00^s$. The TT&C station was assumed to locate in Taejon and have 9 meter antenna for S-band link. One year of simulation from 1999/07/01 were performed out of 3 years of mission lifetime of KOMPSAT satellite. Total four times of Sun interference events were occurred during 1 year of simulation and those lasted about 50 seconds altogether. The C/N degradation of the TT&C system was calculated about 4 dB. The Sun interference events of 50 seconds of one year are 0.0076 percents of the S-band contact time when the 30 minute of contact time is assumed in a day.

1. INTRODUCTION

Korea Multi-Purpose SATellite (KOMPSAT) will be launched at the year of 1999 and used for cartography of Korean peninsula. Low Earth Sun-synchronous orbit with altitude of 685 km will be used for the KOMPSAT spacecraft. The orbital altitude will be maintained within 685 ± 1 km range and the local time of ascending node will be controlled within $10^h35^m \sim 11^h00^m$ during the normal mission life of 3 years (ETRI 1997). The Tracking, Telemetry and Command (TT&C) links will be maintained using 9 meter S-band antenna system located in Taejon.

The Sun interference will be occurred when the Sun is just behind the spacecraft view from the ground antenna system. During the moment, the noise temperature of the receiving antenna rises abruptly and the communication link is failed due to the noise from the Sun. Because of this phenomenon, Sun interference also called Sun outage.

For a geostationary satellite system, the Sun interference happens once a day for several minutes during a few days near the spring and fall equinoxes. The number of outages and their duration depend on the minimum tolerable Carrier-to-Noise (C/N) ratio and on the actual C/N ratio at the receiver input during the Sun interference (Vuong & Forsey 1986). It also depends on the movement of the Earth with respect to the Sun. This phenomenon commonly leads to total disruption of service in conventional C- or Ku - band networks, pushing the availability of the network down to a range of 99.98 percent (Mohamadi & Lyon 1988). For the geostationary satellite system, the Sun outage phenomenon is well predicted and the Sun outage prediction programs have been developed by many authors (Lin & Yang 1989, Garcia 1984, Lee *et al.* 1991).

For the Low Earth Orbit (LEO) satellite systems such as KOMPSAT system, the Sun interference event is considered uncommon because the satellite continuously moves on the sky. But when the Sun interference happens, it can cause tracking, telemetry and command link failure between the ground system and the spacecraft.

In this paper, the Sun interference event simulations for the KOMPSAT TT&C station will be performed to predict the frequency of the event and impact on the TT&C link. The KOMPSAT orbit is propagated including only J2 geopotential term for maintaining the Sun-synchronism and no other perturbations are included. Local time of ascending node of the KOMPSAT satellite is set to $10^h 50^m 00^s$. The TT&C station is assumed to locate in Taejon and have 9 meter antenna. One year of simulation from 1999/07/01 has been performed out of 3 years of mission lifetime of KOMPSAT satellite. The Sun interference event prediction program for the low Earth orbit satellite system has been developed for this purpose.

2. MODELING EPHEMERIDES OF THE SUN AND THE SATELLITE

The azimuth and elevation angles of the satellite and the Sun must be known to predict the Sun interference. The topocentric azimuth and elevation angles are derived from the geocentric right ascension and declinations using standard coordinate transformation formula (Escobal 1965). The orbit of the satellite is propagated using Markely & Jeletic's (1991) analytical formula considering only J2 geopotential term for maintaining Sun-synchronism. In practice, the satellite orbit is perturbed by many other sources such as non-homogeneous distribution of the Earth's masses, gravitational forces of the Sun and Moon, solar radiation force, and atmospheric drag, *etc.* But for the simulation purposes, J2 geopotential term is enough to represent the Sun-synchronous orbital characteristics of the KOMPSAT satellite.

The positions of the Sun, Moon and all the other planets are tabled in Astronomical Almanac published by U.S. Naval Observatory. But it is troublesome to find the position of the Sun every time using the Almanac. In this study, formula from Flandern & Pulkkinen (1979) is used for predicting the position of the Sun in geocentric coordinate system. The formula consists of the product of coefficients, polynomial functions, and trigonometric functions derived from algebraic manipulator. The position of the Sun is predicted within 1 arc minute accuracy at any give time.

The angle between the satellite and the Sun view from the ground antenna is called offset angle and is important parameter for Sun interference. Figure 1 shows the offset angle (θ_0) in topocentric azimuth-elevation coordinate system. The offset angle (θ_0) is derived from the cosine law of spherical triangle as in Equation(1).

$$\theta_0 = \cos^{-1}[\cos(El_{sun})\cos(El_{sat})\cos(Az_{sun} - Az_{sat}) + \sin(El_{sun})\sin(El_{sat})] \qquad (1)$$

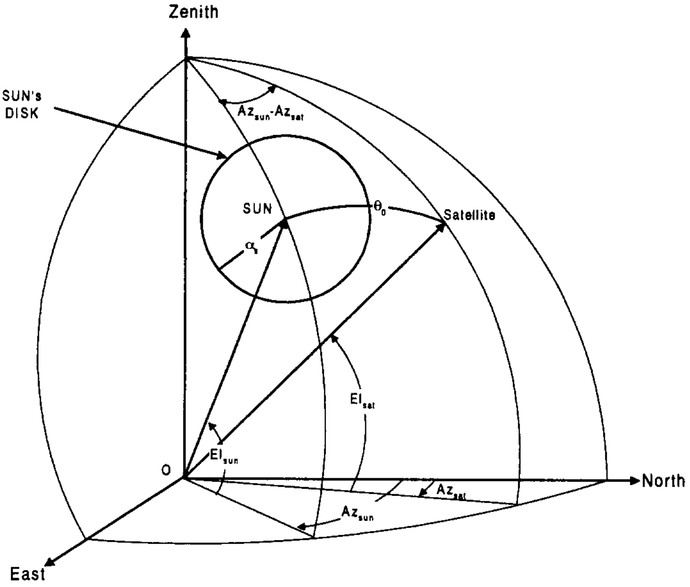


Figure 1. The offset angle in topocentric azimuth-elevation coordinate system.

where, El is elevation angle, and Az is azimuth angle from ground antenna.

3. MODELING OF THE ANTENNA GAIN PATTERN AND NOISE TEMPERATURE

In order to estimate the antenna noise temperature at the time of Sun interference, ground station antenna gain pattern should be defined. The actual gain pattern of the antenna could be obtained from the actual measurement. Simplified antenna gain pattern from Ha (1986) is used in this study as in Equation(2).

$$G(\theta_0) \cong \left(\frac{-2.78\theta_0^2}{\theta_{HPBW}^2}\right) \tag{2}$$

where, θ_0 is offset angle and θ_{HPBW} is the half-power-beam-width of the antenna. The apparent noise temperature of the Sun is very high, and the noise received in the side-lobes of the Earth-station antenna may also be important. The apparent noise temperature of the quiet Sun at 4 GHz varies from 23000 K at sunspot minimum to 90000 K at sunspot maximum (CCIR 1986). It is difficult to find the noise temperature of the Sun considering all factors. The approximation formula from Vuong & Forsey (1986) as shown in Equation(3) is used for the simulation. In this study, 2.0 for F is used for the S-band link.

$$T_{\mathrm{SUN}} = 120000F^{-0.75}(K) \tag{3}$$

where, F is frequency in GHz unit and the formula can be used 1 - 10 GHz range.

The Sun is not a point source but a disk of 0.5 degrees diameter from the Earth station antenna. When the disk of the Sun is inside the antenna beam of the Earth station, an increase of the noise temperature due to the Sun can be calculated using double integrals in terms of the disk of the Sun as in Equation(4) (Mohamadi & Lyon 1988).

$$\Delta T_{\text{ant}} = P\frac{T_{\text{SUN}}}{4\pi}\iint_{\text{Sun's disk}} G(\theta,\phi)\sin\theta d\theta d\phi \tag{4}$$

where, p is single polarization attenuation factor, T_{sun} is Sun's black body temperature, $G(\theta, \phi)$ is gain pattern of the antenna, and θ and ϕ are angles in spherical polar coordinates.

Because the quiet Sun's electromagnetic radiation at centimeter wavelengths is randomly polarized, and the satellite communication links use only one of circular or linear polarization, the single polarization attenuation factor, p is set to 0.5.

Equation(3) is integrated numerically in the θ direction. Since the integrand does not change in the ϕ direction, the result of the ϕ integration is simply the extent of the Sun's disk, $2\phi_i$ direction as in Equation(5) (Lin & Yang 1989).

$$\Delta T_{\text{ant}} = P\frac{T_{\text{SUN}}}{4\pi}\int_{\theta_0-\alpha_s \text{ or } 0 \text{ whichever is larger}}^{\theta_0+\alpha_s} G(\theta,\phi)\sin\theta\ 2\phi_i d\theta \tag{5}$$

where, α_s is apparent radius of the Sun, 0.25°, θ_0 is offset angle, and ϕ_i is, π for $\theta_0 - \alpha_s \leq 0$ and $\theta \leq \alpha_s - \theta_0$, otherwise $\cos^{-1}\{(\cos\alpha_s - \cos\theta\cos\theta_0)/(\sin\theta\sin\theta_0)\}$.

Gaussian quardrature method in Press *et al.* (1986) is used for integration of Equation(5).

The degradation of the carrier to noise ratio(C/N) is derived in Equation(6) using an increase of the noise temperature due to the Sun.

$$\Delta(C/N) = 10\log[(T_{sys} + T_{ant})/T_{sys}] \text{ (dB)} \tag{6}$$

where, T_{sys} is system noise temperature of the receiving point when no Sun interference. System noise temperature of 500 K is assumed for the simulation of 9 meter KOMPSAT antenna system.

4. SUN INTERFERENCE PREDICTIONS FOR THE KOMPSAT GROUND SYSTEM

A single TT&C station located in Taejon and the spacecraft with local time of ascending node of $10^h\ 50^m\ 00^s$ is used for the Sun interference prediction. The simulation parameters are shown in Table 1.

Firstly, the KOMPSAT satellite orbit was propagated every 1 minute interval to search the possible Sun interference condition is satisfied. The condition is such that both azimuth differences and elevation differences between the satellite and the Sun are less than 5 degrees. Total of 17 times of possible Sun interference was founded in the first simulation. Figure 2 shows the polar plot of the KOMPSAT azimuth and elevation during the morning pass time for a year. Only the morning pass times were simulated because the Sun interference could not occur during the night time passes. The KOMPSAT will rise from the southern horizon and set to northern horizon in the morning time passes. Figure 3 shows the polar plot of the Sun azimuth and elevation during the KOMPSAT pass.

Table 1. KOMPSAT orbital elements and station coordinates($10^h50^m00^s$ LTAN*).

Simulation Epoch	(year/month/day hour:min:sec UT)	1999/07/01 00:00:00
KOMPSAT Orbit	Semi-Major Axis(km)	7063.27
	Eccentricity	0.00115
	Inclination(deg)	98.127
	Right Ascension of Ascending Node(deg)	81.108
	Argument of Perigee(deg)	90.0
	Mean Anomaly(deg)	0.0
Ground Station	Longitude(deg)	127.37
	Latitude(deg)	36.4
	Height(m)	0.0

* LTAN(Local Time of Ascending Node)

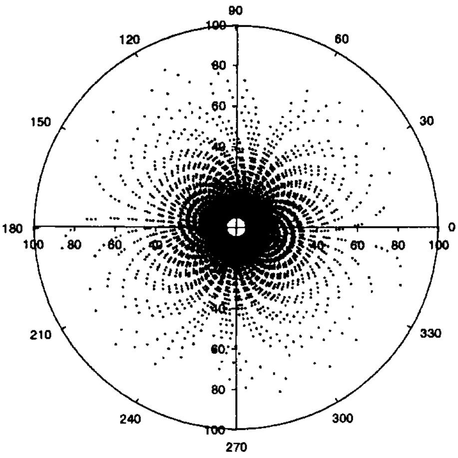


Figure 2. KOMPSAT azimuth vs. elevation plot.

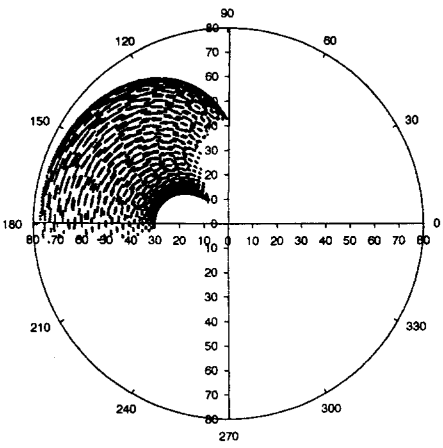


Figure 3. Sun azimuth and elevation plot.

Figure 3 clearly shows that the KOMPSAT is contacted during the morning time when the Sun is located between the East and the South. Figure 4 shows the annual variations of the elevation of the Sun when the KOMSPAT is passed on the station. The times of KOMPSAT passes are similar during a year but the maximum and minimum elevation angles of the Sun show the seasonal variations.

Secondly, the KOMPSAT satellite orbit was propagated every 1 second interval using the epoch and orbital elements found in the first simulation. The offset angles were calculated every 1 second interval. When the offset angle is calculated less than 2 degrees, antenna noise temperature and C/N degradation are estimated. Total of 4 times of possible Sun interference was found in the second simulation. Table 2 shows the Sun interference time and related parameters during a year. The Sun interference times in Table 2 are derived from the simulation, and the actual Sun interference times will be varied according to the actual orbital parameters of the KOMPSAT spacecraft. All of the Sun interference events for the KOMPSAT are occurred during the winter season.

Figure 5 shows the degradation of system carrier-to-noise ratio during the Sun interference time

Table 2. Sun interference predictions for the KOMPSAT system.

Case	Y/M/D	H:M:S	Duration(sec)	Minimum Offset Angle(deg)	Maximum Noise Temp.(K)	Maximum $\Delta(C/N)$ (dB)
1	1999/11/28	10:39:59	12	1.5	109	0.9
2	1999/12/17	10:40:06	15	1.1	766	4.0
3	2000/02/07	10:31:13	13	1.2	597	3.4
4	2000/02/26	10:31:58	10	1.3	415	2.6

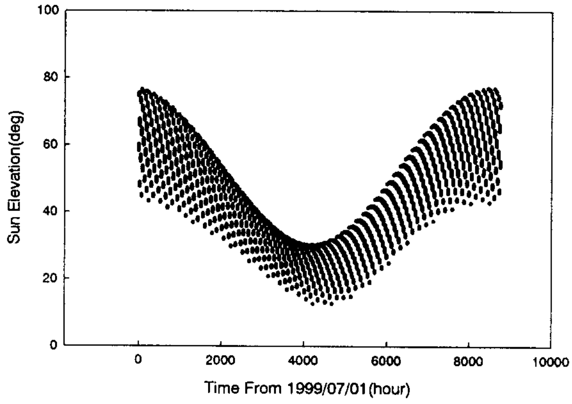
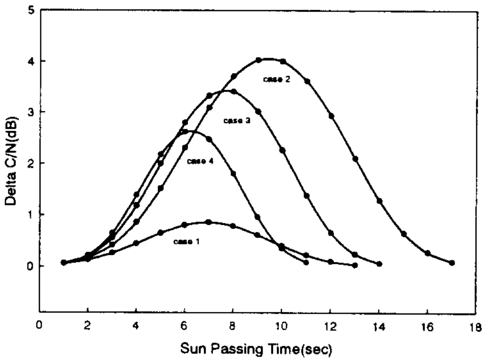


Figure 4. Annual variations of the Sun elevation for the KOMPSAT pass time.



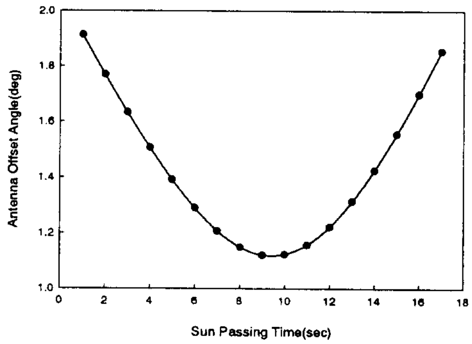


Figure 5. System C/N degradation during the Sun pass time.

Figure 6. Antenna offset angle variations during Sun pass time (Case 2).

for 4 cases in Table 2. Case 1 seems to have no impact on the antenna receiving system. The other three cases take more than 10 seconds' duration and C/N degradation are more than 2 dB.

Figure 6 shows the variations of offset angle during the Sun interference for case 2. Figure 7

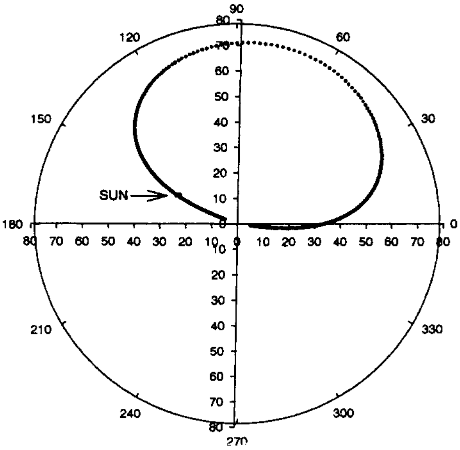


Figure 7. Azimuth and elevation variations of the satellite and the Sun during the pass time (Case 2).

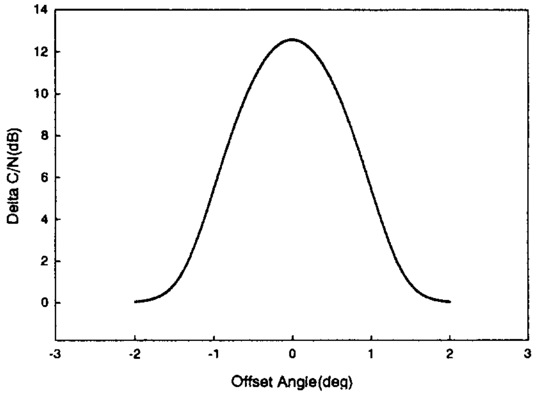


Figure 8. C/N degradation for the offset angles.

shows the polar plot movement of the KOMPSAT satellite and the Sun during the pass time of 11 minutes in case 2. The position of the Sun is shown almost fixed during the pass time.

Figure 8 shows the profile of the C/N degradation for the various offset angles. The C/N degradation reaches about 12.6 dB when the offset angle is 0 degree. When the offset angle is 1.21 degrees, the C/N degradation is 3 dB. The offset angle of 1.21 degrees will be a good choice for the Sun interference prediction program.

5. CONCLUSIONS

The Sun interference events for the Sun-synchronous low Earth orbit satellite system have been examined. The frequencies and impacts of the Sun interference events were analyzed using computer simulation. The analytical orbit propagator including only J2 term of geopotential was used for orbit prediction and the low precision formula of 1 arc minute accuracy was used for Sun ephemeris prediction. The 9 meter S-band TT&C antenna in Taejon was assumed. The KOMPSAT was assumed to have local time of ascending node of $10^h 50^m 00^s$. One year of simulation from 1999/07/01 has been performed out of 3 years of mission lifetime of KOMPSAT satellite.

The noise temperature of the TT&C antenna was estimated to be raised up to 8500 K and the C/N degradation of the system to be about 12.5 dB when the Sun is just behind the KOMPSAT satellite view from the antenna. But the case was not happened in the simulation. Total four times of Sun interference events were occurred during 1 year of simulation and it lasts about 50 seconds altogether. The maximum C/N degradation of the TT&C system was calculated about 4 dB. The Sun interference events of 50 seconds in one year is 0.0076 percents of the S-band contact time when the 30 minute of contact time is assumed in a day. Although the Sun interference event makes small impact on the availability of the TT&C system, the satellite ground control system should be designed and operated with the consideration for the criticality of the event.

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