RECOMMENDATION ITU-R BO.1506

A methodology to evaluate the impact of solar interference on geostationary (GSO) broadcasting-satellite service (BSS) link performance

(Question ITU-R 220/11)

(2000)

The ITU Radiocommunication Assembly,

considering

a) that the GSO link can be optimized for arid regions, with very small link margin thus it is sensitive to interference;

b) that such interference-sensitive GSO links will have performance levels driven by other sources of fading and degradation than rain;

c) that one of these degradations is caused by solar transits in the main beam of the receiving antennas and that these degradations could be severe for links with small margins or large antenna diameters;

d) that the performances of GSO links are used in some methodologies to determine acceptable interference levels between systems,

recommends

1 that, in designing GSO BSS links, the methodology attached in Annex 1 of this Recommendation may be used to assess the level of performance degradation on GSO BSS links resulting from solar transit.

NOTE 1 – It should be noted that some GSO systems can implement operational measures (such as site or satellite diversity) in order to diminish the impact of the solar transit on the system performances.

ANNEX 1

A methodology to evaluate the impact of solar interference on GSO BSS link performance

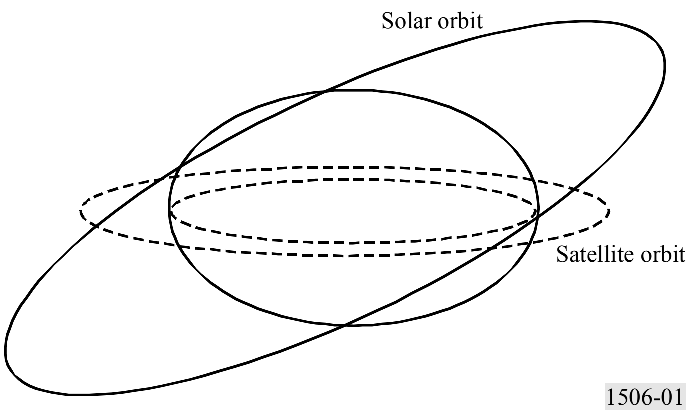
1 General approach

The solar transit in the GSO receiver is a phenomenon that can be easily assessed as the geometry is well known. The following method is proposed to fully describe the solar transit effect on GSO link budgets thus allowing for proper assessment of the performances of some links that do not need margins to compensate for rain fades. The impact of solar transit is not a fade but an increase of the system noise temperature that can be significant for some low margin, low noise GSO links.

The proposed method is based on the well-defined geometry of Sun position relative to a specified location on the Earth: the Sun is approximately a 0.53° diameter disk as seen from an Earth point. The solar transit effect is significant when the disk intersects the main beam of the BSS receiving antenna. The impact may be determined by using either a detailed approach or a simplified approach. The detailed approach varies the antenna gain over the optical disc of the Sun in accordance to the assumed antenna gain pattern. The simplified approach assumes a constant antenna gain over the optical disc of the Sun corresponding to the gain towards the centre of the Sun's disk.

The geometry is described in Fig. 1. The Sun can be considered as a noise source moving in a well-defined trajectory across the sky. During the period of the spring and autumn equinoxes, the Sun is located at or near the intersection of the equatorial and ecliptic planes. During this time, the Sun is in line with the receiving BSS antenna and the GSO BSS satellite. This leads to an increase of the antenna noise temperature that affects the BSS receiver figure-of-merit (*G*/*T*) of the link and thereby degrading the carrier-to-noise ratio (*C*/*N*). Depending on the link clear-sky margin this degradation can result in link outage for a short period of time.

FIGURE 1



2 Methodology

The methodology is based on the calculation of the relative position of the Sun to the boresight of the receiving antenna, and thus on the estimation of the antenna noise temperature increase due to solar interference.

Step 1: Select the duration over which the calculations are performed on the basis of the beginning and end dates. Select the time step as a function of the antenna size for which the calculations are done.

Step 2: For each time step considered, determine the orbital parameters of the Sun:

$$w = 282.9404$$

$$e = 0.016709$$

$$M = 356.0470 + 0.98560\ T$$

where:

w: argument of perihelion (degrees)

e: eccentricity

M: mean anomaly (degrees)

T: time (days).

Step 3: Convert these orbital elements into the equatorial, rectangular, geocentric coordinates (X_{Sun}, Y_{Sun}, Z_{Sun}). The eccentric anomaly E is defined by:

$$E = M + e \sin(M)\ (1.0 + e \cos(M))$$

then:

$$\mathrm{X1} = D_{Sun}\ (\cos(E) - e)$$

$$\mathrm{Y1} = D_{Sun} \left(\sqrt{1 - e^2} \right)\ \sin(E)$$

and:

$$V = A \tan 2\ (\mathrm{Y1}, \mathrm{X1})$$

$$R = \sqrt{\mathrm{X1}^2 + \mathrm{Y1}^2}$$

with:

D_{Sun}: distance between the Earth and Sun centres

$A \tan 2()$: function that an x, y coordinate pair to the correct angle.

The longitude of the Sun, lonSun, is then determined by:

$$\mathrm{lonSun} = V + w$$

and finally:

$$X_{Sun} = R \cos(\mathrm{lonSun})$$

$$Y_{Sun} = R \sin(\mathrm{lonSun}) \cos(\mathrm{ecl})$$

$$Z_{Sun} = R \sin(\mathrm{lonSun}) \sin(\mathrm{ecl})$$

where ecl is the obliquity of the ecliptic that can be estimated with: ecl = 23.4393°.

Step 4: Determine the equatorial, rectangular, geocentric coordinates (X_{ES}, Y_{ES}, Z_{ES}) for the earth station (ES) and the GSO satellite (SAT):

$$X_{ES} = R_{Earth} \cos(\mathrm{lat}_{ES}) \cos(\mathrm{lon}_{ES} + (\omega_{Earth}\ T))$$

$$Y_{ES} = R_{Earth} \cos(\mathrm{lat}_{ES}) \sin(\mathrm{lon}_{ES} + (\omega_{Earth}\ T))$$

$$Z_{ES} = R_{Earth} \sin(\mathrm{lat}_{ES})$$

where:

R_{Earth}: Earth radius (6 378 km)

lat_{ES}, lon_{ES}: latitude and longitude of the earth station

ω_{Earth}: angular speed of the Earth, (rad/days) ($2\pi = 6.2831$)

T: time step considered (days).

and for the GSO satellite:

$$\mathrm{X}_{SAT} = (R_{Earth} + H)\cos(\text{lat}_{SAT})\cos(\text{lon}_{SAT} + (\omega_{Earth}\,T)) = (R_{Earth} + H)\cos(\text{lon}_{SAT} + (\omega_{Earth}\,T))$$

$$\mathrm{Y}_{SAT} = (R_{Earth} + H)\cos(\text{lat}_{SAT})\sin(\text{lon}_{SAT} + (\omega_{Earth}\,T)) = (R_{Earth} + H)\sin(\text{lon}_{SAT} + (\omega_{Earth}\,T))$$

$$\mathrm{Z}_{SAT} = (R_{Earth} + H)\sin(\text{lat}_{SAT}) = 0$$

with:

$\text{lat}_{SAT} =$ 0

H: altitude of the GSO satellite (35 786 km).

Step 5: The angle α between the Sun, S, the earth station, E, and the GSO satellite, G, can be obtained by:

$$\overrightarrow{ES} \bullet \overrightarrow{EG} = \left|\overrightarrow{ES}\right| \left|\overrightarrow{EG}\right| \cos(\alpha)$$

so:

$$\alpha = A\cos\left\{\frac{(\mathrm{X}_{Sun} - \mathrm{X}_{ES})(\mathrm{X}_{SAT} - \mathrm{X}_{ES}) + (\mathrm{Y}_{Sun} - \mathrm{Y}_{ES})(\mathrm{Y}_{SAT} - \mathrm{Y}_{ES}) + (\mathrm{Z}_{Sun} - \mathrm{Z}_{ES})(\mathrm{Z}_{SAT} - \mathrm{Z}_{ES})}{\sqrt{\left[(\mathrm{X}_{Sun} - \mathrm{X}_{ES})^2 + (\mathrm{Y}_{Sun} - \mathrm{Y}_{ES})^2 + (\mathrm{Z}_{Sun} - \mathrm{Z}_{ES})^2\right]\left[(\mathrm{X}_{SAT} - \mathrm{X}_{ES})^2 + (Y_{SAT} - \mathrm{Y}_{ES})^2 + (\mathrm{Z}_{SAT} - \mathrm{Z}_{ES})^2\right]}}\right\}$$

This angle is the off-axis angle of the Sun viewed from the antenna.

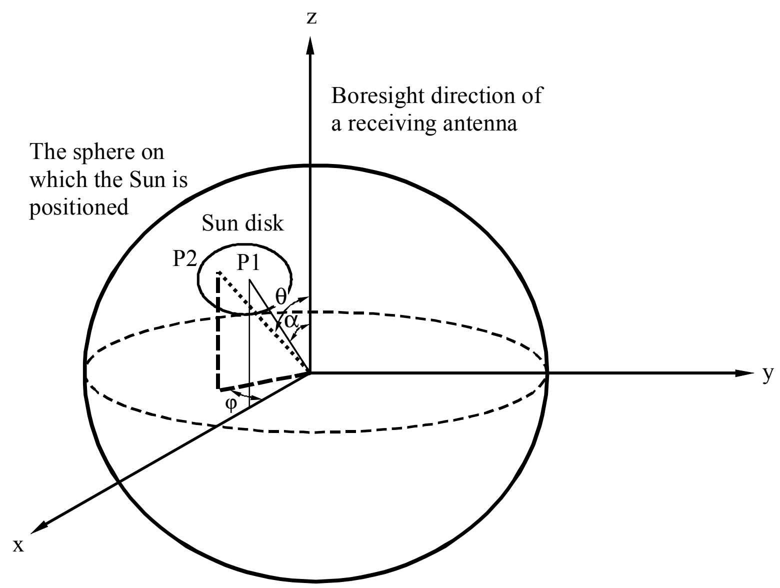
Step 6: Determine the value of the antenna gain over the Sun's disk: $\iint\limits_{Sun} G(\theta, \varphi)\,\mathrm{d}\Omega$

where θ is the off-axis angle and φ is the azimuth angle.

a) Detailed approach

The Sun is modelled by a disk positioned on a sphere centred on the receive earth station. The sphere represents the space seen by the antenna using the spherical angles θ and φ.

FIGURE 2



φ: azimuth angle
θ: off-boresight angle (boresight is defined by z-axis)
α: elevation angle between the center of the Sun to the z-axis
z-axis: boresight direction of a receiving station
P1: centre point of the Sun
P2: point on the Sun disk

1506-02

The z-axis is in the direction of the pointing direction of the receive antenna.

The computation can use the axis symmetry of the geometry: the points with the same gain form arcs. These result from the intersection of a plan perpendicular to the axis antenna z with the portion of sphere containing the Sun.

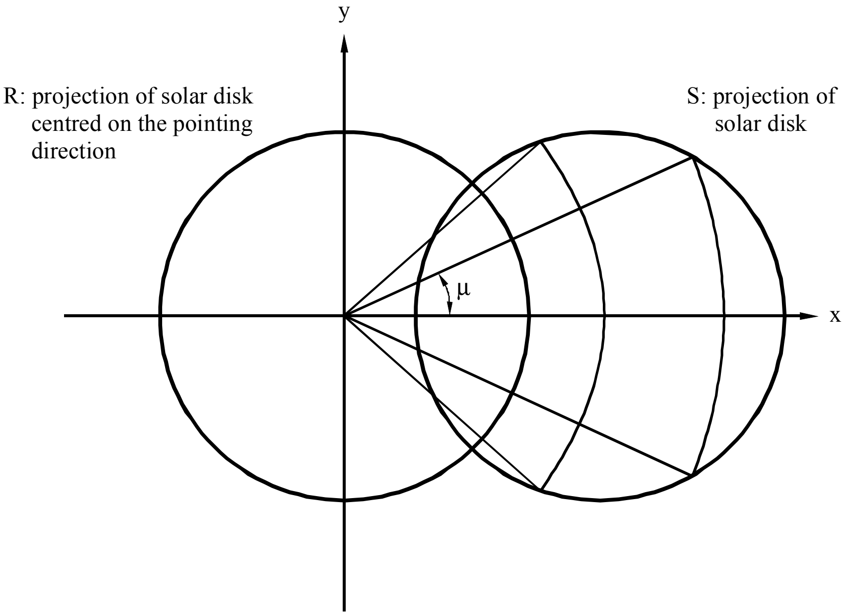
The value of the integral is so determined by the addition of the different lengths of the iso-gain arcs, multiplied by the value of the gain for the arc.

If β is the half angle of view of the Sun (0.266°), there are two cases:

Case 1: If $\alpha > \beta$:

FIGURE 3

Projection of the Sun on the xy plan*



* For simplificatioin, the picture shows a projection of the solar disk which is circular. In reality it is not circular.

1506-03

The disk R is the projection of the Sun when it is centred on the z axis. When the Sun is not on the z-axis, the calculations of the receive antenna gain in the direction of the Sun are done through the integration over iso-gain arcs, which have an half-aperture μ that can vary from 0 to π. To determine the overall gain in the direction of the Sun's disk $\iint_{Sun} G(\theta, \varphi)\, \mathrm{d}\Omega$, the following formula applies when μ is smaller than π:

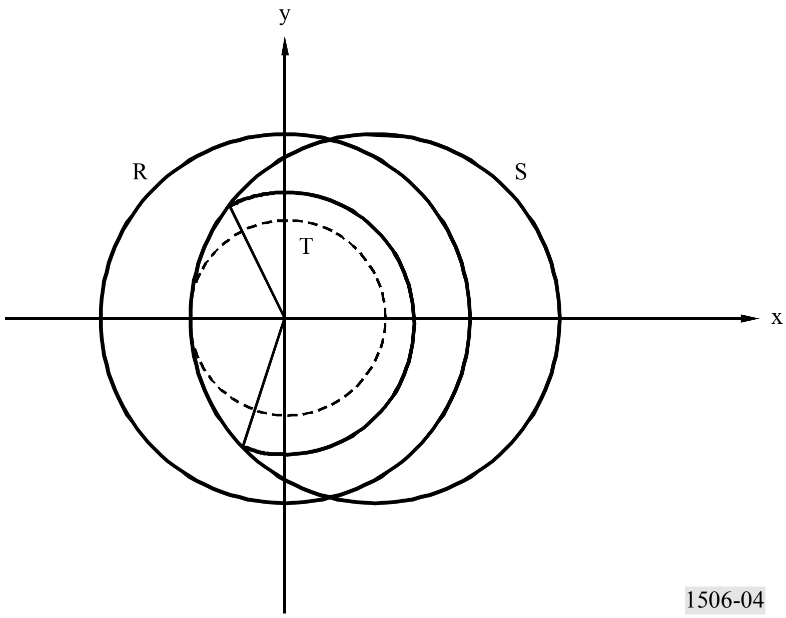
$$\iint_{Sun} G(\theta, \varphi)\, \mathrm{d}\Omega = \sum_{\theta=\alpha-\beta}^{\theta=\alpha+\beta} 2\ \mu\ \sin(\theta)\ G(\theta)\ \Delta\theta$$

where:

$$\mu = A\cos\left\{\frac{[\cos(\beta) - \cos(\theta)\ \cos(\alpha)]}{\sin(\theta)\ \sin(\alpha)}\right\}$$

Case 2: If $\alpha < \beta$:

FIGURE 4



The calculation above is valid for all the arcs which correspond to iso-θ lines of less than $(\beta - \alpha)$ (represented by the dotted circle T above). For lower values of θ, the computation of the gain over the portion of Sun disk, is simplified by the z axial symmetry of the geometry:

$$\iint G(\theta, \varphi)\, \mathrm{d}\Omega = \sum_{\theta=0}^{\theta=\beta-\alpha} 2\pi \sin(\theta)\, G(\theta)\, \Delta\theta$$

where:

$G(\theta)$: linear isotropic antenna gain (function of the off-axis angle θ)

$\Delta\theta$: angular increment.

b) Simplified approach

The Sun only subtends approximately 0.53° (θ_{Sun}) as viewed from the Earth and if we assume that over θ_{Sun} the normalized antenna gain (G_n) will average out to be G_n towards the centre of the Sun ($G_{n_{Sun}}$), then $\iint_{Sun} G(\theta, \varphi)\, \mathrm{d}\Omega$: can be approximated by:

$$\iint_{Sun} G(\theta, \varphi)\, \mathrm{d}\Omega = 2\pi\, G_{n_{Sun}} \left[1 - \cos\left(\frac{\theta_{Sun}}{2}\right)\right]$$

Step 7: Determine the value of the gain over the entire space: $\iint_{Space} G(\theta, \varphi)\, \mathrm{d}\Omega$

Due to the z-axis of the antenna patterns from the ITU-R Recommendations, the calculation is straightforward:

$$\iint_{Space} G(\theta,\varphi)\,\mathrm{d}\Omega = \sum_{\theta=0}^{\theta=\pi} 2\pi \sin(\theta)\ G(\theta)\ \Delta\theta$$

where:

$G(\theta)$: the linear isotropic antenna gain, only depending on the off-axis angle θ

$\Delta\theta$: the increment of angle.

Step 8: Determine the temperature of the Sun: $T_{Sun} = 120\,000 \times \gamma \times f^{-0.75}$

where f is the frequency and γ is the polarization factor, set here to 0.5, due to the fixed polarization of the antenna and the random polarization of the Sun.

Step 9: Determine the temperature increase at the receive antenna:

$$\Delta T = \frac{\iint_{Sun} T_{Sun} \times G(\theta,\varphi)\,\mathrm{d}\Omega}{\iint_{Space} G(\theta,\varphi)\,\mathrm{d}\Omega} = \frac{T_{Sun} \times \iint_{Sun} G(\theta,\varphi)\,\mathrm{d}\Omega}{\iint_{Space} G(\theta,\varphi)\,\mathrm{d}\Omega}$$

Step 10: Determine the degradation of the receiver's C/N ratio as follows:

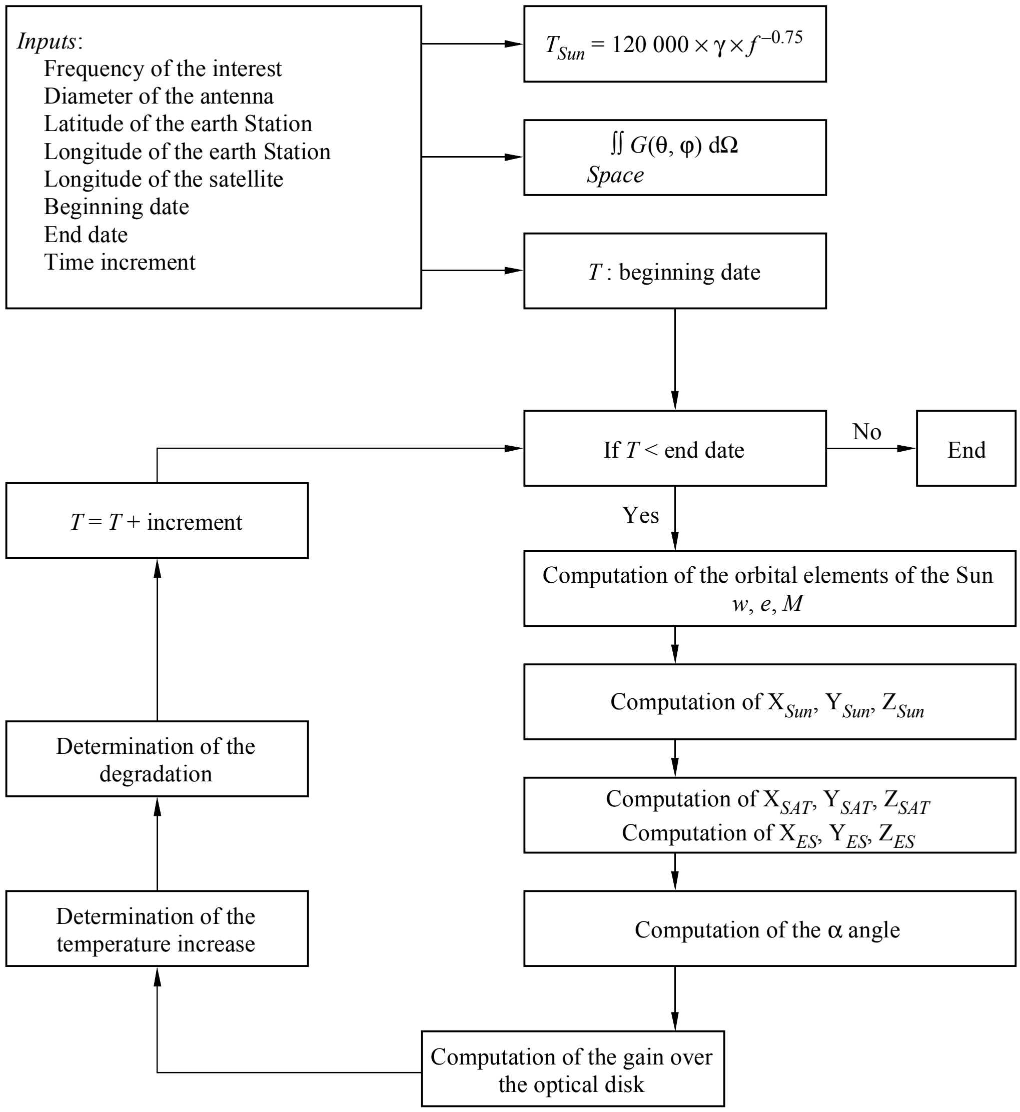
$$\Delta(C/N) = 10\log\left(\frac{T_0 + \Delta T}{T_0}\right)$$

where T_0 is the initial system noise temperature.

3 Algorithm to take into account the solar transits in the link budgets

In the analysis that uses dynamic link budgets for the interference analysis like non-GSO/GSO scenarios, the solar interference can be inserted in the link budgets according to the following algorithm. This algorithm can thus provide the solar impact on the performance (percentage of time during which a C/N level is met) of the links analysed. It also can be used to compute the duration of degradation as well as occurrences.

FIGURE 5



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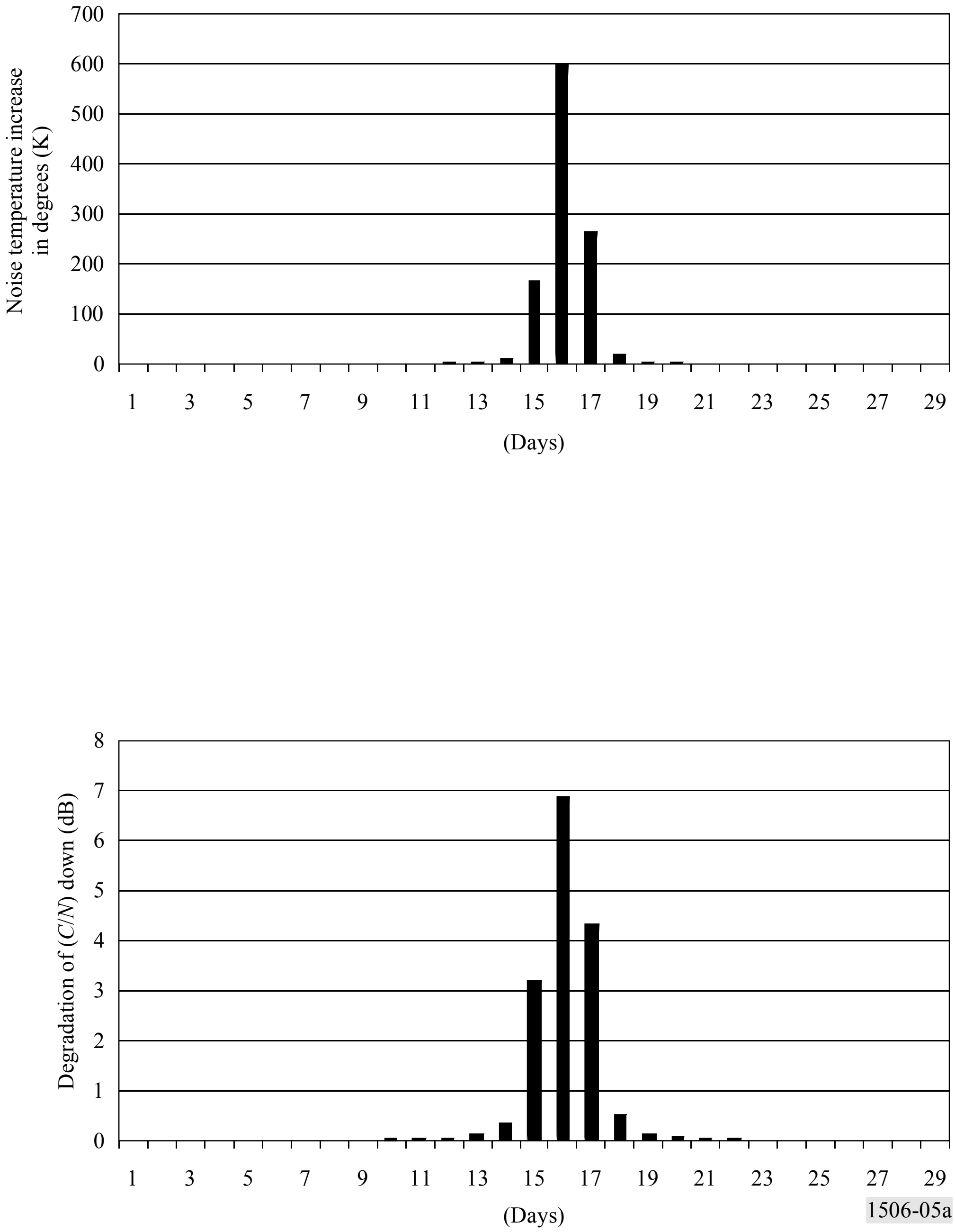
4 Application of the methodology to different antenna sizes

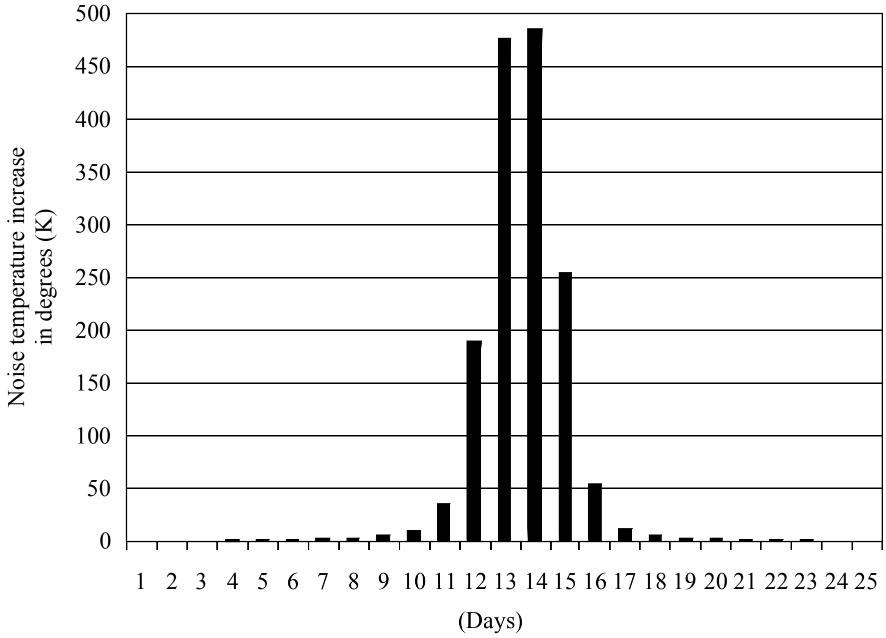
The detailed approach described in the previous sections has been applied to different antenna sizes. In all the cases the initial noise temperature used is 155 K, at 12.5 GHz and the antenna patterns used are according to Fig. 8, Annex 5 of RR Appendix S30.

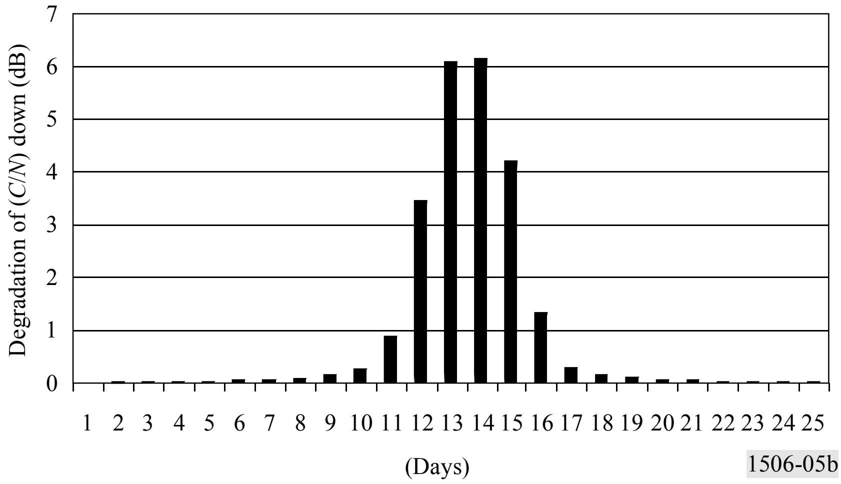
For 3 m:



1506-05a

For 1.8 m:





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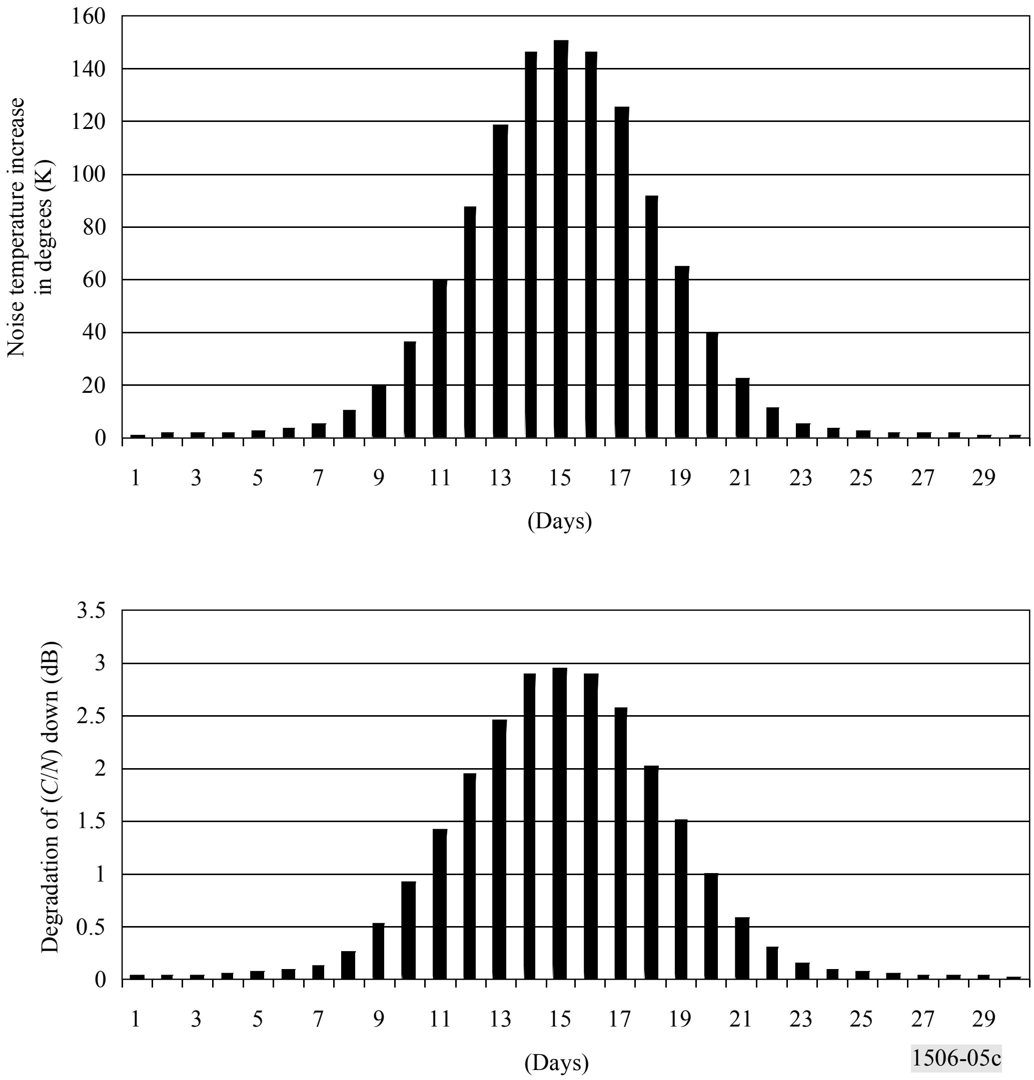
For 0.6 m:

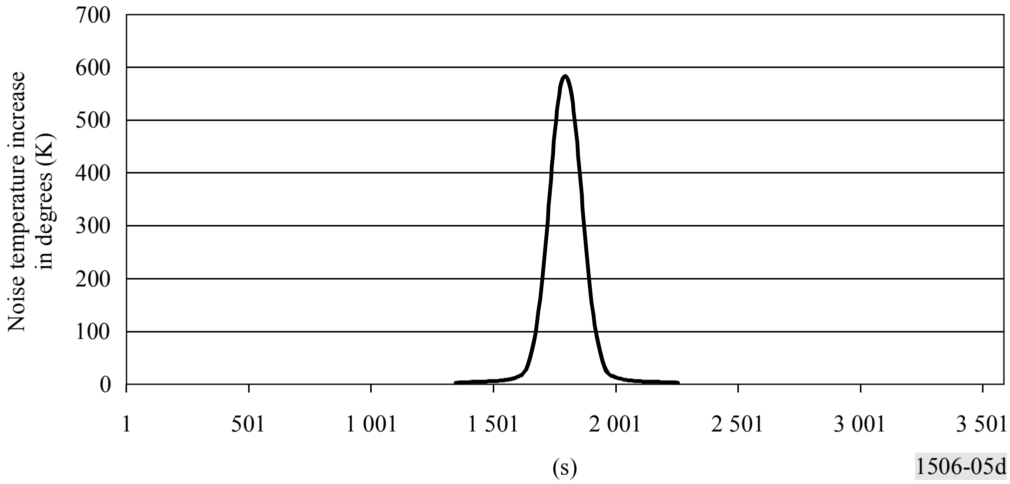


As was expected the results show that the depth of the degradation of the *C*/*N* is a function of the antenna size and the duration of the solar transit increases as the antenna diameter decreases.

5 Variation during a day

Computations have been done based on the detailed approach to show a time profile of the degradation of *C*/*N* as a function of the time of the day close to the equinox period. The time step is set to 1 s.

For a 3 m antenna:



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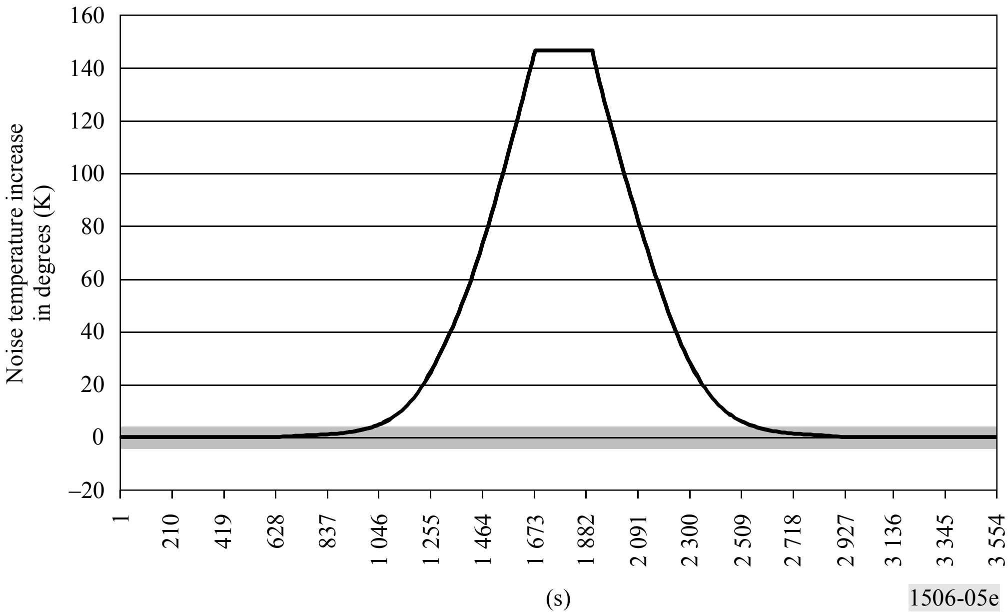
For a 0.6 m antenna:



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6 Comparison of two approaches for different antenna sizes

The examples below show the results obtained using the two approaches to assess the Sun interference to GSO BSS links. Table 1 shows the estimated antenna noise temperature increases obtained using two approaches. In the simplified approach, the antenna gain over the Sun's optical disc is assumed to be constant and corresponds to the gain towards the centre of the Sun's disk. This generally results in the estimated maximum temperature increase to be higher than that obtained using the detailed approach. As shown in Fig. 6, for smaller antenna apertures typically used in BSS systems, e.g. ≤ 1.8 m, there is a maximum difference of about 5%. However, this difference rapidly rises to 30% for a 3 m antenna.

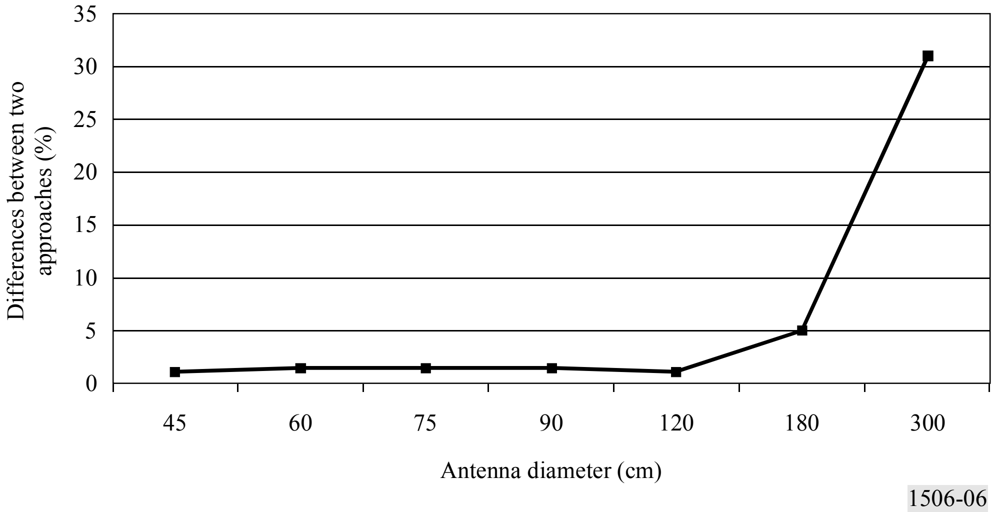
TABLE 1

Maximum temperature increase via different antenna diameters

Antenna diameter	Maximum temperature increase (detailed approach) (K)	Maximum temperature increase (simplified approach) (K)
45 cm	91.8	93.0
60 cm	146.6	148.8
75 cm	200.1	202.9
90 cm	254.2	257.6
1.8 m	529.0	557.1
3.0 m	594.6	780.5

FIGURE 6

Percentage differences in the temperature between two approaches



7 Conclusion

The solar transit can cause a significant degradation of a GSO BSS link during the period of the spring and autumn equinoxes during which the Sun is seen from time to time in close alignment to the pointing direction of GSO receive earth station antennas.

The impact on a link performance depends on the size of the antenna and the initial noise temperature of the link. For large antennas with high gain, the degradation of the C/N can be up to about 7 dB (for a link with initial noise temperature of 155 K) but occurs fewer times than for small antennas with wider beams.

The detailed approach gives greater detail and accuracy but increases the analysis complexity. Whereas the simplified approach is less complex to implement. For small antenna apertures typically used in BSS systems (i.e. ≤1.8 m) both approaches may be used to assess the Sun interference into a GSO BSS link with an error of less than 0.1 dB.