

RECOMMENDATION ITU-R S.743-1

**THE COORDINATION BETWEEN SATELLITE NETWORKS USING SLIGHTLY INCLINED
GEOSTATIONARY-SATELLITE ORBITS (GSOs) AND BETWEEN SUCH NETWORKS
AND SATELLITE NETWORKS USING NON-INCLINED GSO SATELLITES**

(Question ITU-R 51/4)

(1992-1994)

The ITU Radiocommunication Assembly,

considering

- a) that the definition of a geostationary satellite in the Radio Regulations (RR No. 181) has no indication for a maximum value of the angle of inclination of the orbit of a geostationary satellite;
- b) that station-keeping fuel on geostationary space stations constitutes an appreciable portion of in-orbit mass and tends to be the limiting factor of a geostationary space station's life;
- c) that North-South station-keeping consumes up to 90% of the total fuel;
- d) that, in the absence of North-South station-keeping, the orbit of a geostationary satellite is subject to no more than about 0.9° of orbit change per year, and the inclination will never exceed the natural limit of 15°;
- e) that, on the other hand, the absence of North-South station-keeping may require additional equipment at the earth stations, such as angular tracking, polarization tracking and for digital transmissions also, larger size elastic buffers and more complex synchronization methods;
- f) that the Second Session of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and on the Planning of Space Services Utilizing It (Geneva, 1988) (WARC ORB-88) considered the matter of coordinating slightly inclined geostationary satellite networks, and referred action to the ex-IFRB and the ex-CCIR;
- g) that the ex-IFRB requested the ex-CCIR to study the related problems:
 - the technical aspects of coordination between geostationary satellites and those in inclined geostationary orbits;
 - the technical aspects of coordination between satellites in inclined geostationary orbits;
- h) that there appears to be no intrinsic limitation on the coordination of satellite networks using slightly inclined geostationary orbits;
- j) that the data required by RR Appendices 3 and 4 (WARC ORB-88) include the effects of using slightly inclined geostationary-satellite orbits,

noting that

- a) under co-coverage conditions, the isolation between geostationary-satellite networks with one using a slightly inclined orbit, will be equal to or greater than that between two geostationary-satellite networks (near 0° inclination);
- b) under co-coverage conditions, the isolation between two geostationary-satellite networks using slightly inclined orbits may be either less, or greater, than that between two geostationary-satellite networks near 0° inclination, depending on the relative nodal phase;
- c) under co-coverage conditions, the isolation between two closely spaced geostationary-satellite networks with frequency re-use by dual linear orthogonal polarization, one or both of which use a slightly inclined orbit, may be less than two geostationary-satellite networks, depending on the relative nodal phase;
- d) under non co-coverage conditions, between two geostationary-satellite networks, one or both of which use slightly inclined orbits, the isolation may be less, or greater, than that between two geostationary-satellite networks, depending on a number of factors in addition to the relative nodal phase,

recommends

1. that the coordination of geostationary-satellite networks using slightly inclined geostationary-satellite orbits be performed in accordance with the RR that apply to geostationary-satellite networks based upon the minimum separation between the satellites concerned;
2. that in bands shared with terrestrial services the inclination limit for the application of § 1 may need to be determined by the inter-service sharing considerations (see Note 1); in other bands § 1 may be applied up to the natural inclination limit for satellites launched initially into a geostationary or near-geostationary orbit if N/S station-keeping manoeuvres are not undertaken;
3. that for interference considerations involving the coordination of geostationary-satellite networks using slightly inclined geostationary orbits, the information given in Annex 1 should be utilized;
4. that the relative nodal phase between the orbits be adjusted if practicable, and/or other measures should be used to minimize any deleterious effects (see § 5 of Annex 1);
5. that the following Note should be regarded as part of the Recommendation.

Note 1 – Recommendation ITU-R SF.1008 deals with possible use by space stations in the fixed-satellite service of orbits slightly inclined with respect to the geostationary-satellite orbit in bands shared with the fixed service.

ANNEX 1

1. Introduction

The information contained in this Annex should be used in connection with the coordination of satellite networks using slightly inclined geostationary-satellite orbits (GSO) and between such networks and other satellite networks using non-inclined GSO satellites.

During slightly inclined GSO operation, there are basically three factors which affect the interference between two satellite networks. These are:

- the exocentric angular separation between the coverage areas of the networks as seen from either satellite;
- the exocentric angular width of the coverage areas as seen from either satellite;
- the topocentric angular spacing between the satellites as seen from an earth station of either network.

These factors cause the net antenna discrimination (earth station and satellite antenna) between the two networks to vary in time. In cases where satellite networks have a common service area (co-coverage networks), the earth-station antenna is the basic element providing discrimination between the networks. Where satellite networks have separate service areas (non co-coverage networks), both the earth station and satellite antenna contribute to the discrimination between the networks.

2. Geometric considerations

The geocentric angle, φ_g , between two slightly inclined geostationary satellites with latitudes (γ_1 and γ_2) and longitudes (φ_1 and φ_2) may be determined by:

$$\cos \varphi_g = \cos \gamma_1 \cos \gamma_2 \cos (\varphi_1 - \varphi_2) + \sin \gamma_1 \sin \gamma_2 \quad (1)$$

The latitude γ and longitude excursions $\Delta\varphi$ of a satellite as a function of the orbit inclination angle i and the satellite phase angle position in the orbit $\Delta\gamma$ as measured from the ascending node are:

$$\gamma = \sin^{-1} (\sin i \sin \Delta\gamma) \quad (2)$$

$$\Delta\varphi = \tan^{-1} (\cos i \tan \Delta\gamma) - \Delta\gamma$$

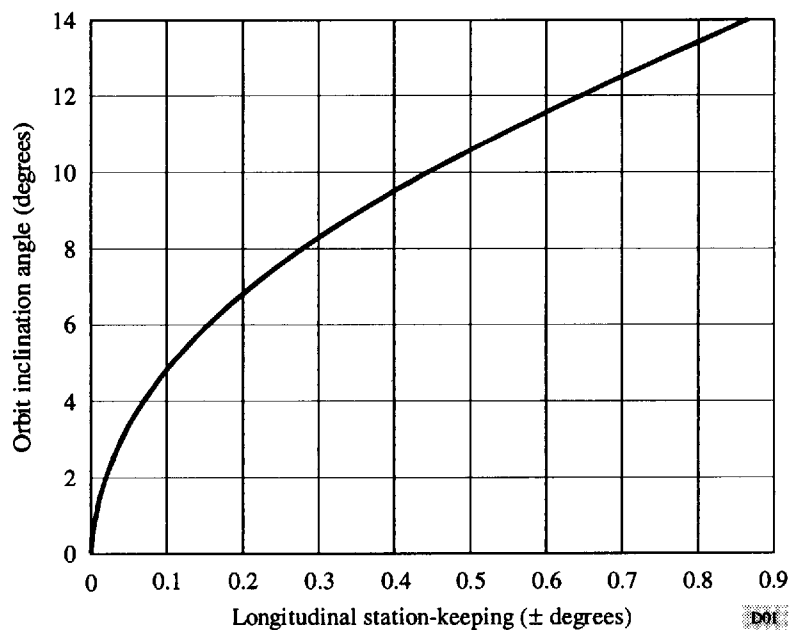
With small angle approximations for $\sin i$ and $\cos i$, equations (2) and (3) become:

$$\gamma = i \sin \Delta\gamma \quad \text{radians} \quad (4)$$

$$\Delta\phi = -0.25 i^2 \sin 2 \Delta\gamma \quad \text{radians} \quad (5)$$

The longitudinal excursions of a satellite in a circular geostationary orbit can be determined from the above equations. Figure 1 shows a plot of the maximum excursions as a function of inclination.

FIGURE 1
Orbit inclination where longitude excursion equals station-keeping



For two satellites having inclinations i_1 and i_2 , designating $\Delta\gamma_0$ as the phase angle difference between the satellite orbit positions ($0 \leq \Delta\gamma_0 \leq 2\pi$) and ϕ_s as the angle between the ascending nodes, the minimum value of the geocentric angular separation ϕ_g may be derived from the preceding equations and is closely approximated by:

$$(\phi_g)_{min} = 0.5 i_1 i_2 \sin \Delta\gamma_0 + \phi_s \quad \text{radians} \quad (6)$$

Equation (6) may be expressed as the ratio of the minimum geocentric angle to the geocentric angle of the nodes:

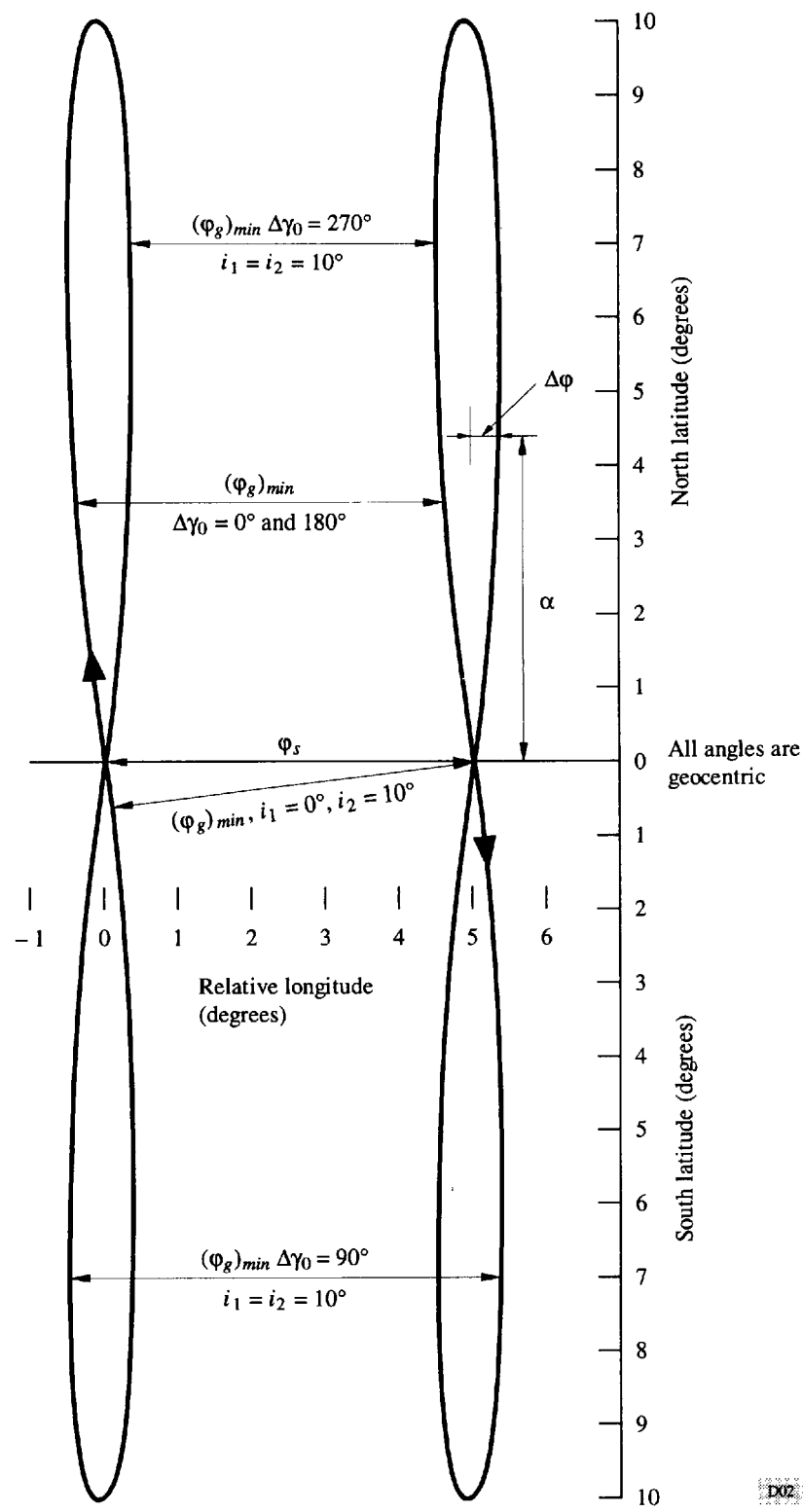
$$(\phi_g)_{min}/\phi_s = 1 + (i_1 i_2 \sin \Delta\gamma_0)/2 \phi_s \quad (7)$$

where i_1 , i_2 and ϕ_s are small compared to 1 rad.

Depending on the phase angle difference between the satellite orbit positions $(\phi_g)_{min}$ can be less than or greater than ϕ_s ; i.e. when $\pi \leq \Delta\gamma_0 \leq 2\pi$ or $0 \leq \Delta\gamma_0 \leq \pi$ respectively (see Fig. 2). If either i_1 or i_2 is zero, then $(\phi_g)_{min} = \phi_s$. The worst phase angle difference is $3\pi/2$ and equation (7) for that value is:

$$(\phi_g)_{min}/\phi_s = 1 - i_1 i_2/2 \phi_s \quad (8)$$

FIGURE 2
Inclined circular geostationary orbit geometry

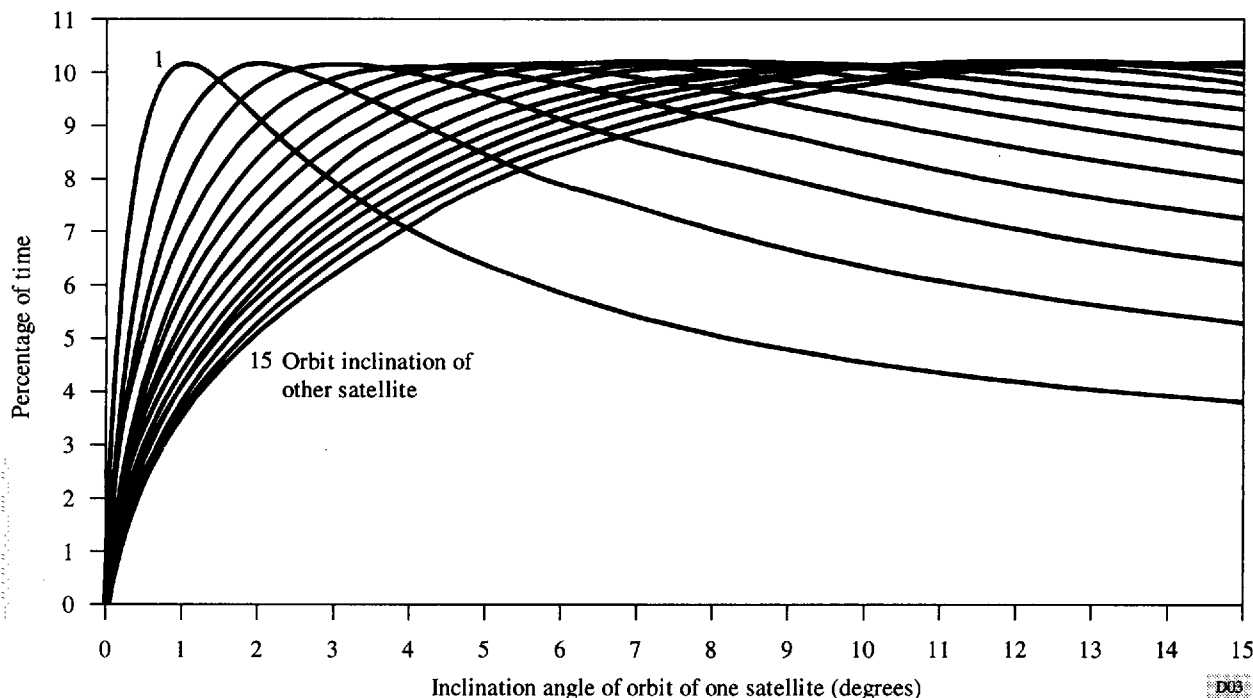


When there is some inclination in the orbit of either of a pair of satellites, the time averaged value of angular spacing is always greater than the nodal spacing φ_s . The portion of time T_1 in which φ_g is less than φ_s under worst-case phase angle conditions is approximately:

$$T_1 = 0.64 \left[(i_1 i_2 \varphi_s) / (i_1^2 + i_2^2) \right]^{0.5} \quad (9)$$

When $i_1 = i_2$, T_1 varies from 1 h twice daily for a φ_s of 2° to about 2.25 h twice daily for a φ_s of 10° for equal inclinations and worst-case phase angle. A plot of equation (9) is shown in Fig. 3 for a φ_s of 3° .

FIGURE 3
Percentage of time that satellite spacing is less than nodal spacing



3. Co-coverage networks

Under co-coverage conditions, little if any satellite antenna discrimination exists so that only the earth-station antennas provide spatial discrimination. For tracking earth stations, the discrimination is a function of the angular spacing between the satellites. Assuming a $-25 \log(\varphi)$ side-lobe envelope slope, equation (7) may be expressed as:

$$\Delta d \leq 25 \log_{10} \left[1 + \frac{i_1 i_2 \sin \Delta \gamma_0}{2 \varphi_s} \right] \quad \text{dB} \quad (10)$$

where Δd is the change in discrimination (dB) with respect to the earth-station antenna discrimination at a nominal spacing of φ_s .

Figure 4 shows the antenna discrimination for $i_1 = 7^\circ$ and $i_2 = 9^\circ$ and a nominal satellite spacing $\varphi_s = 1^\circ$.

As shown in Fig. 4, the nodal phase difference appears to be a critical factor determining the relative earth-station antenna discrimination. Depending on the nodal phase difference, relative earth-station discrimination can be larger or smaller than nominal, reaching a minimum at 270° of nodal phase difference. It is important to note that for either i_1 or i_2 equals zero, the minimum relative discrimination also becomes zero. Practically, this means that the discrimination between a geostationary-satellite network and a slightly inclined geostationary orbit network will always be larger than or equal to the nominal discrimination which would have been achieved if the two networks were geostationary.