

RECOMMENDATION ITU-R BO.1212

**CALCULATION OF TOTAL INTERFERENCE BETWEEN
GEOSTATIONARY-SATELLITE NETWORKS IN THE
BROADCASTING-SATELLITE SERVICE**

(Questions ITU-R 83/11 and ITU-R 85/11)

(1995)

The ITU Radiocommunication Assembly,

considering

- a) that successful implementation of satellite systems in the World Administrative Radio Conference for the Planning of the Broadcasting-Satellite Service (Geneva, 1977) (WARC BS-77) and the First Session of the World Administrative Radio Conference on the Use of the Geostationary-Satellite Orbit and the Planning of the Space Services Utilizing It (WARC ORB-85) broadcasting-satellite service (BSS) plans is dependent upon accurate calculation of mutual interference between satellite networks;
- b) that geostationary-satellite networks in the BSS operate in the same frequency bands;
- c) that interference between networks in the BSS contributes to noise in the network;
- d) that it is necessary to protect a network in the BSS from interference by other source networks;
- e) that, due to increased orbit occupancy, the detailed estimation of mutual interference between satellite networks, requires more accurate values of polarization discrimination in order to take account of the use of different or identical polarizations by wanted and interfering systems,

recommends

- 1 that to calculate the total interference between two satellite networks considered, the method described in Annex 1 should be used.

ANNEX 1

Calculation of total interference

When evaluating the power produced at a given point by a single satellite (downlink) or at a given satellite location by an earth-station transmitter (up link) the concept of an equivalent gain for each partial link may be employed.

There are two antennas involved in each partial link, and these have both co-polar and cross-polar transmission and reception characteristics. In addition, atmospheric propagation effects, represented principally by co-polar attenuation and cross-polar discrimination, influence the net signal level.

The equivalent gain (as a power ratio) for one partial link can be represented by the following approximation:

$$\begin{aligned}
 G &= G_1 \cos^2 \beta + G_2 \sin^2 \beta \\
 G_1 &= G_{tp} G_{rp} A + G_{tc} G_{rc} A + G_{tp} G_{rc} A X + G_{tc} G_{rp} A X \\
 G_2 &= \left(\sqrt{G_{tp} G_{rc} A} + \sqrt{G_{tc} G_{rp} A} \right)^2 + G_{tp} G_{rp} A X + G_{tc} G_{rc} A X
 \end{aligned} \tag{1}$$

where:

β : for linear polarization, is the relative alignment angle between the received signal polarization plane and the plane of polarization of the receive antenna;

for circular polarization, $\beta = 0^\circ$ is assumed to correspond to co-polar transmission and reception and $\beta = 90^\circ$ is assumed to correspond to mutually cross-polarized transmission and reception;

for cases of differing polarizations (e.g. linearly polarized wanted receive antenna and circularly polarized interfering transmissions, or *vice versa*), $\beta = 45^\circ$

G_{tp} : co-polar gain characteristic of the transmit antenna expressed as a power ratio (Recommendation ITU-R BO.652)

G_{tc} : cross-polar gain characteristic of the transmit antenna expressed as a power ratio

G_{rp} : co-polar gain characteristic of the receive antenna expressed as a power ratio (Recommendation ITU-R BO.652)

G_{rc} : cross-polar gain characteristic of the receive antenna expressed as a power ratio

A : co-polar attenuation on the interfering partial link (as a power ratio ≤ 1)

X : cross-polar discrimination on the interfering partial link (as a power ratio ≤ 1)

$$X = 10^{-0.1[30 \log f - 40 \log (\cos \varepsilon_s) - 20 \log (-10 \log A)]} \quad \text{for } 5^\circ \leq \varepsilon_s \leq 60^\circ$$

where:

f : frequency (GHz)

ε_s : satellite elevation angle as seen from the earth station (degrees).

For $\varepsilon_s > 60^\circ$, use $\varepsilon_s = 60^\circ$ in calculating the value of X .

(See Appendix 1 for derivation of the relative alignment angle, β .)

In the expression for G_1 , power summation of the terms is assumed throughout. Near the main axis of the wanted transmission, a voltage addition of the first two terms may be more appropriate due to phase alignment while away from this axis random effects dictate power addition. However, since the second term is insignificant near this axis the assumption of power addition does not compromise the approximation. Atmospheric depolarization is a random effect thus the last two terms are power summed.

In the expression for G_2 , voltage addition of the first two terms is assumed since, near axis, either term could be dominant and phase alignment of these terms would dictate voltage addition. Away from this main axis the third and fourth terms become the dominant contribution; thus, although a power addition of the first two terms is warranted, in this region as for the G_1 discussion, the validity of the assumed model is not unduly compromised by maintaining voltage addition in all regions. Since the transition from voltage addition near axis to power addition off-axis is nebulous, the above expressions, in view of the arguments presented, would appear to be a reasonable compromise between accuracy and simplicity.

Using the equivalent gain concept, the wanted carrier power, C , or the single-entry interfering power, I , on each partial link is simply given by:

$$C \text{ (or } I) = P_T - L_{FS} - L_{CA} + G \quad \text{dBW} \quad (2)$$

where:

P_T : wanted (interfering) transmitting antenna power (dBW)

L_{FS} : free-space loss on the wanted (interfering) link (dB)

L_{CA} : clear-air absorption on the wanted (interfering) link (dB)

G : equivalent gain on the wanted (interfering) link (dB).

The aggregate interference power is obtained by adding the powers so calculated for all interferers. The ratio of the desired signal power to the aggregate interference power is the downlink aggregate carrier-to-interference ratio, C/I . The up-link aggregate interference power and C/I are obtained in a similar way, and the two aggregate values of C/I are then combined to obtain the total aggregate C/I .

If the ratio of the wanted carrier power to the power of an interfering signal, where both powers are calculated using equation (2), is to be evaluated for the worst case, such parameters as satellite station-keeping tolerances, satellite antenna pointing errors, and propagation conditions must be taken into account. The station-keeping and satellite transmit-antenna beam errors which should be included are those which result in the lowest receive level of the wanted signal and the highest receive level of the interfering satellite signal. When the interfering satellite is at a lower elevation angle than the wanted satellite, worst-case interference conditions usually occur during clear-sky operation. Conversely, if the interfering satellite is at a higher elevation angle, worst-case interference usually occurs during heavy rain conditions.

APPENDIX 1

TO ANNEX 1

Derivation of the relative alignment angle β for linear polarization

This Appendix defines the polarization angle of a linearly polarized radiowave and outlines the method for calculating polarization angles and relative alignment angles for both the downlink and feeder link interference cases. Calculation of relative alignment angles are necessary for determining the equivalent gain as defined by equation (1).

1 Definition of principle and cross-polarized components of a linearly polarized radiowave

In general, the polarization of a radiated electromagnetic wave in a given direction is defined to be the curve traced by the instantaneous electric field vector, at a fixed location and at a given frequency, in a plane perpendicular to the direction of propagation as observed along the direction of propagation. When the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain. In practice, polarization of the radiated energy varies with the direction from the centre of the antenna, so that different parts of the pattern may have different polarizations. Polarization may be classified as linear, circular or elliptical. If the vector that describes the electric field at a point in space as a function of time is always directed along a line, the field is said to be linearly polarized. In the most general case, the figure that the electric field traces is an ellipse, and the field is said to be elliptically polarized. Linear and circular polarizations are special cases of elliptical when the ellipse becomes a straight line or a circle, respectively. For the interference calculations, we are interested in the far-field polarization of the antenna where the E-field component in the direction of propagation is negligible so that the net electric field vector can be resolved into two (time-varying) orthogonal components that lie in a plane normal to the outward radial direction of propagation. In the case of linear polarization, the reference directions of these orthogonal components must first be defined before one can define a polarization angle. One of these reference directions is designated as the principle or main polarization component direction while the orthogonal reference direction is designated as the cross-polarization component direction.

Surprisingly, there is no universally accepted definition for these reference directions. Some alternative definitions of principle and cross-polarization component directions are discussed in Arthur C. Ludwig's paper, "The Definition of Cross Polarization", in the IEEE Transactions on Antennas and Propagation, January 1973. In his paper, Ludwig derives expressions for the unit vectors for three different cross-polarization definitions in terms of a spherical antenna pattern coordinate system, which is the coordinate system usually adopted for antenna measurements. We briefly describe these three definitions below. In this Appendix the unit vector $\mathbf{u}_p$ represents the reference direction for the principle polarization component of the electric field vector while $\mathbf{u}_c$ represents the direction of the cross-polarized component. It is helpful to first review the transformation of vectors among rectangular, cylindrical and spherical coordinate systems.

1.1 Vector transformation among rectangular, cylindrical and spherical coordinate systems

Figure 1 shows the three coordinate systems and their associated unit vectors. The transformation matrix for transforming a vector $\underline{\mathbf{A}}$ in rectangular components (A_x, A_y, A_z) to cylindrical components (A_ρ, A_ϕ, A_z) is:

$$M_{rc} = \begin{bmatrix} \cos \phi & \sin \phi & 0 \\ -\sin \phi & \cos \phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (3)$$

The transformation matrix for transforming a vector $\underline{\mathbf{A}}$ in cylindrical components (A_ρ, A_ϕ, A_z) to spherical components (A_r, A_θ, A_ϕ) is given by:

$$M_{cs} = \begin{bmatrix} \sin \theta & 0 & \cos \theta \\ \cos \theta & 0 & -\sin \theta \\ 0 & 1 & 0 \end{bmatrix} \quad (4)$$

The transformation matrix for transforming a vector $\underline{\mathbf{A}}$ in rectangular components (A_x, A_y, A_z) to spherical components (A_r, A_θ, A_ϕ) is then:

$$M_{rs} = M_{cs} M_{rc} = \begin{bmatrix} \sin \theta \cos \phi & \sin \theta \sin \phi & \cos \theta \\ \cos \theta \cos \phi & \cos \theta \sin \phi & -\sin \theta \\ -\sin \phi & \cos \phi & 0 \end{bmatrix} \quad (5)$$

so that, in terms of components:

$$\begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix} = \begin{bmatrix} \sin \theta \cos \phi & \sin \theta \sin \phi & \cos \theta \\ \cos \theta \cos \phi & \cos \theta \sin \phi & -\sin \theta \\ -\sin \phi & \cos \phi & 0 \end{bmatrix} \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} \quad (6)$$

Because the matrix is orthogonal, the transformation matrix for transforming from spherical (A_r, A_θ, A_ϕ) to rectangular (A_x, A_y, A_z) components is simply the transposed matrix:

$$M_{sr} = \begin{bmatrix} \sin \theta \cos \phi & \cos \theta \cos \phi & -\sin \phi \\ \sin \theta \sin \phi & \cos \theta \sin \phi & \cos \phi \\ \cos \theta & -\sin \theta & 0 \end{bmatrix} \quad (7)$$

so that:

$$\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} = \begin{bmatrix} \sin \theta \cos \phi & \cos \theta \cos \phi & -\sin \phi \\ \sin \theta \sin \phi & \cos \theta \sin \phi & \cos \phi \\ \cos \theta & -\sin \theta & 0 \end{bmatrix} \begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix} \quad (8)$$

The unit vectors $\mathbf{u}_r$, $\mathbf{u}_\theta$, and $\mathbf{u}_\varphi$ of the spherical coordinate system are in spherical coordinates

$$\mathbf{u}_r = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \quad \mathbf{u}_\theta = \begin{pmatrix} 0 \\ 1 \\ 0 \end{pmatrix} \quad \mathbf{u}_\varphi = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \quad (9)$$

$$\mathbf{u}_r = \begin{bmatrix} \sin \theta \cos \varphi \\ \sin \theta \sin \varphi \\ \cos \theta \end{bmatrix} \quad \mathbf{u}_\theta = \begin{bmatrix} \cos \theta \cos \varphi \\ \cos \theta \sin \varphi \\ -\sin \theta \end{bmatrix} \quad \mathbf{u}_\varphi = \begin{bmatrix} -\sin \varphi \\ \cos \varphi \\ 0 \end{bmatrix} \quad (10)$$

in rectangular coordinates.

1.2 Alternative definitions of principal polarization and cross-polarization reference directions

Ludwig describes three definitions for the cross polarization by deriving unit vector $\mathbf{i}_{ref}$ and $\mathbf{i}_{cross}$ (which we have renamed $\mathbf{u}_p$ and $\mathbf{u}_c$) such that the dot product of the electric field vector $\underline{\mathbf{E}}$ (t, θ, φ) along some direction (θ, φ) in the far-field antenna pattern with these unit vectors defines the principal and cross-polarization components, respectively. In the direction specified by the spherical coordinate angles (θ, φ), the principal and cross-polarization components of the electric field vector are therefore given by:

$$E_p(\theta, \varphi) = \underline{\mathbf{E}} \cdot \mathbf{u}_p \quad E_c(\theta, \varphi) = \underline{\mathbf{E}} \cdot \mathbf{u}_c \quad (11)$$

(Note that, in general, $\underline{\mathbf{E}}$, $\mathbf{u}_p$ and $\mathbf{u}_c$ will themselves vary with θ and φ .)

Figure 2 illustrates the polarization patterns corresponding to the three definitions for the case in which the antenna is transmitting horizontal polarization along its main beam axis.

In the first definition, the reference unit vector $\mathbf{u}_p$ is simply taken to be one of the rectangular basis vectors of the antenna pattern coordinate system while $\mathbf{u}_c$ is another one of the basis unit vectors. For example, we can define:

$$\mathbf{u}_p = \mathbf{y}_a \quad \mathbf{u}_c = \mathbf{x}_a \quad (12)$$

where $\mathbf{y}_a$ and $\mathbf{x}_a$ are unit vectors in the positive y and x directions.

From the transformation matrices above the spherical coordinate components of these vectors are given by:

$$\mathbf{u}_p = \mathbf{y}_a = \sin \theta \cdot \sin \varphi \cdot \mathbf{u}_r + \cos \theta \cdot \sin \varphi \cdot \mathbf{u}_\theta + \cos \varphi \cdot \mathbf{u}_\varphi \quad (13)$$

$$\mathbf{u}_c = \mathbf{x}_a = \sin \theta \cdot \cos \varphi \cdot \mathbf{u}_r + \cos \theta \cdot \cos \varphi \cdot \mathbf{u}_\theta - \sin \varphi \cdot \mathbf{u}_\varphi \quad (14)$$

Ludwig notes that this definition leads to inaccuracies, since in practice, the polarization of the radiated field does vary with direction from the centre of the antenna and that the far-field of the antenna is not planar, but tangent to a spherical surface. Ludwig's second and third definitions of polarization therefore involve unit vectors which are tangent to a sphere. In his second definition, the principle polarization direction is chosen to be one of the spherical coordinate unit vectors while the cross-polarization direction is chosen to be one of the other spherical unit vectors. For example, we can choose:

$$\mathbf{u}_p = \mathbf{u}_\varphi \quad \mathbf{u}_c = \mathbf{u}_\theta \quad (15)$$

In Ludwig's third definition, the principal and cross-polarization component directions are defined according to how one usually measures the polarization pattern of an antenna. The standard measurement method is described in Fig. 3. The

probe polarization angle β (angle between $\mathbf{u}_\varphi$ and $\mathbf{u}_p$) is measured from $\mathbf{u}_\varphi$ towards $\mathbf{u}_\theta$. In the case where the transmitted field is linear horizontal polarization (i.e. in the +y direction) along the boresight ($\theta = 0^\circ$), β turns out to be equal to φ . Therefore the principal and cross-polarization components in the direction (θ, φ) are given by:

$$E_p(t) = \underline{\mathbf{E}}(t) \cdot \mathbf{u}_p \quad E_c(t) = \underline{\mathbf{E}}(t) \cdot \mathbf{u}_c \quad (16)$$

so that the electric field $\underline{\mathbf{E}}(t)$, in that direction can be expressed as:

$$\underline{\mathbf{E}}(t) = E_p(t) \cdot \mathbf{u}_p + E_c(t) \cdot \mathbf{u}_c = E_{pm} \cdot \cos(\omega t) \cdot \mathbf{u}_p + E_{cm} \cdot \cos(\omega t + \delta) \cdot \mathbf{u}_c \quad (17)$$

This is the general expression for an elliptically polarized wave. Note that in order for $\underline{\mathbf{E}}(t)$ to be linearly polarized the time phase δ between the two orthogonal linear components must be zero (or an integer multiple of π). The amplitudes of the components E_{pm} and E_{cm} however, need not be equal.

The principal and cross-polarization unit vectors, $\mathbf{u}_p$ and $\mathbf{u}_c$ can be expressed in terms of the spherical coordinate unit vectors, $\mathbf{u}_\theta$ and $\mathbf{u}_\varphi$, and the angle $\beta = \varphi$ (when the transmitted field is polarized in the +y direction at $\theta = 0^\circ$) by:

$$\mathbf{u}_p = \sin \varphi \cdot \mathbf{u}_\theta + \cos \varphi \cdot \mathbf{u}_\varphi \quad (18)$$

$$\mathbf{u}_c = \cos \varphi \cdot \mathbf{u}_\theta - \sin \varphi \cdot \mathbf{u}_\varphi \quad (19)$$

Finally, by expressing $\mathbf{u}_\theta$ and $\mathbf{u}_\varphi$ in rectangular coordinates as shown above, $\mathbf{u}_p$ and $\mathbf{u}_c$ can be expressed in terms of the antenna coordinate system's rectangular unit vectors ($\mathbf{x}_a, \mathbf{y}_a, \mathbf{z}_a$) as:

$$\mathbf{u}_p = \sin \varphi \begin{bmatrix} \cos \theta & \cos \varphi \\ \cos \theta & \sin \varphi \\ -\sin \theta \end{bmatrix} + \cos \varphi \begin{bmatrix} -\sin \varphi \\ \cos \varphi \\ 0 \end{bmatrix} = \begin{bmatrix} \cos \theta \cos \varphi \sin \varphi - \sin \varphi \cos \varphi \\ \cos \theta \sin(\varphi)^2 + \cos(\varphi)^2 \\ -\sin \theta \sin \varphi \end{bmatrix} \quad (20)$$

$$= (\cos \theta \cos \varphi \sin \varphi - \sin \varphi \cos \varphi) \cdot \mathbf{x}_a + (\cos \theta \sin(\varphi)^2 + \cos(\varphi)^2) \cdot \mathbf{y}_a - (\sin \theta \sin \varphi) \cdot \mathbf{z}_a$$

$$\mathbf{u}_c = \cos \varphi \begin{bmatrix} \cos \theta & \cos \varphi \\ \cos \theta & \sin \varphi \\ -\sin \theta \end{bmatrix} - \sin \varphi \begin{bmatrix} -\sin \varphi \\ \cos \varphi \\ 0 \end{bmatrix} = \begin{bmatrix} \cos \theta \cos(\varphi)^2 + \sin(\varphi)^2 \\ \cos \theta \cos \varphi \sin \varphi - \sin \varphi \cos \varphi \\ -\sin \theta \cos \varphi \end{bmatrix} \quad (21)$$

$$= (\cos \theta \cos(\varphi)^2 + \sin(\varphi)^2) \cdot \mathbf{x}_a + (\cos \theta \cos \varphi \sin \varphi - \sin \varphi \cos \varphi) \cdot \mathbf{y}_a - (\sin \theta \cos \varphi) \cdot \mathbf{z}_a$$

These are the expressions for the principal and cross-polarization unit vectors for the case of the satellite antenna transmitting a horizontally linearly polarized field parallel to $\mathbf{y}_a$ (i.e. a polarization angle of $\gamma = 0^\circ$). This means that the principal polarization direction $\mathbf{u}_p$ is in the direction of $\mathbf{y}_a$ (which lies in the equatorial plane) on the antenna boresight at $\theta = 0^\circ$ (as can be seen from the above expression for $\mathbf{u}_p$ with $\theta = 0^\circ$). Note that for off-axis angles, $\mathbf{u}_p$ is not parallel to $\mathbf{y}_a$ since their dot product is not equal to one. For the case when the satellite is not transmitting horizontal polarization, the principal and cross-polarization directions are, for a transmitted polarization angle γ , given by:

$$\begin{aligned} \mathbf{u}_p &= \sin(\varphi + \gamma) \cdot \mathbf{u}_\theta + \cos(\varphi + \gamma) \cdot \mathbf{u}_\varphi \\ \mathbf{u}_c &= \cos(\varphi + \gamma) \cdot \mathbf{u}_\theta - \sin(\varphi + \gamma) \cdot \mathbf{u}_\varphi \end{aligned} \quad (22)$$

The $\mathbf{x}_a, \mathbf{y}_a, \mathbf{z}_a$ components are thus:

$$\begin{aligned} \mathbf{u}_p(\gamma) &= \sin(\varphi + \gamma) \begin{bmatrix} \cos \theta & \cos \varphi \\ \cos \theta & \sin \varphi \\ -\sin \theta \end{bmatrix} + \cos(\varphi + \gamma) \begin{bmatrix} -\sin \varphi \\ \cos \varphi \\ 0 \end{bmatrix} \\ &= \begin{bmatrix} \cos \theta \cos \varphi \sin(\varphi + \gamma) - \sin \varphi \cos(\varphi + \gamma) \\ \cos \theta \sin \varphi \sin(\varphi + \gamma) + \cos \varphi \cos(\varphi + \gamma) \\ -\sin \theta \sin(\varphi + \gamma) \end{bmatrix} \end{aligned} \quad (23)$$

$$\begin{aligned}
 \mathbf{u}_c(\gamma) &= \cos(\varphi + \gamma) \begin{bmatrix} \cos \theta \cos \varphi \\ \cos \theta \sin \varphi \\ -\sin \theta \end{bmatrix} - \sin(\varphi + \gamma) \begin{bmatrix} -\sin \varphi \\ \cos \varphi \\ 0 \end{bmatrix} \\
 &= \begin{bmatrix} \cos \theta \cos \varphi \cos(\varphi + \gamma) + \sin \varphi \sin(\varphi + \gamma) \\ \cos \theta \sin \varphi \cos(\varphi + \gamma) - \cos \varphi \sin(\varphi + \gamma) \\ -\sin \theta \cos(\varphi + \gamma) \end{bmatrix}
 \end{aligned} \tag{24}$$

This last definition for the polarization reference directions will be the one assumed in the analyses for the reasons cited in Ludwig's paper.

2 Coordinate system descriptions and transformation matrices

In performing polarization angle calculations, four types of Cartesian orthonormal coordinate systems will be considered. These are shown in Fig. 4. They are the boresight point coordinate system (denoted $\mathbf{R}_b$), the earth station coordinate system ($\mathbf{R}_p$), the satellite antenna coordinate system ($\mathbf{R}_a$), and the Earth-centred coordinate system ($\mathbf{R}_g$). For purposes of interference calculations, we can think of systems $\mathbf{R}_b$, $\mathbf{R}_p$, and $\mathbf{R}_a$ together as comprising the “wanted” satellite system. In a similar way, if an “interfering” satellite system is present, it will have its own satellite ($\mathbf{R}_{a2}$) earth station ($\mathbf{R}_{p2}$) and boresight point ($\mathbf{R}_{b2}$), so that the systems $\mathbf{R}_{b2}$, $\mathbf{R}_{p2}$, and $\mathbf{R}_{a2}$ together comprise the “interfering” satellite system. The Earth-centred system $\mathbf{R}_g$ serves as an intermediate system for transforming between any pair of previous systems. In this section, we therefore develop the transformation matrices for transforming a vector from the Earth-centred system $\mathbf{R}_g$ to each of these other systems. Determining these transformation matrices is fundamental to the calculations, since once they are obtained, computation of the polarization angles and relative alignment angles becomes a trivial matter. To aid in understanding the method, an example calculation is performed.

2.1 Symbol notation

Symbol definitions and arbitrarily chosen values for the example calculation are as follows:

GSO radius (earth radii):	$k = 6.61072$
Wanted earth station latitude (degrees):	$\psi_p = 20$
Wanted earth station longitude (degrees):	$\lambda_p = -80$
Wanted satellite boresight point latitude (degrees):	$\psi_b = 10$
Wanted satellite boresight point longitude (degrees):	$\lambda_b = -90$
Wanted satellite longitude (degrees):	$\lambda_a = -100$
Interfering earth station latitude (degrees):	$\psi_{p2} = 45$
Interfering earth station longitude (degrees):	$\lambda_{p2} = -115$
Interfering satellite boresight point latitude (degrees):	$\psi_{b2} = 35$
Interfering satellite boresight point longitude (degrees):	$\lambda_{b2} = -85$
Interfering satellite longitude (degrees):	$\lambda_{a2} = -110$

For notational clarity, unit vectors will be ***bolded in italics***, vectors with magnitudes other than one will be **bolded and underlined**, coordinate vectors which represent the coordinates of a point in 3-D space will be simply underlined, and transformation matrices for transforming between coordinate systems will be **CAPITALIZED AND BOLDED**. The unit of distance is assumed to be one earth radius (6 378.153 km).

NOTE – In order to render the symbolic notation clearer, specific characters have, exceptionally, been used and it is possible that, depending upon the computer hardware and software used, these same characters may be different to those which appear in the printed text.