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CALCULATION OF PROBABILITY OF HARMFUL INTERFERENCE BETWEEN SPACE NETWORKS (*C*/*I* RATIOS)

1 Introduction

When an administration cannot successfully complete coordination, the administration can request the Bureau to examine the probability of harmful interference under the provision of No. **11.32A**. For cases when coordination under No. **9.7** cannot be successfully completed, the Bureau uses the single entry carrier-to-interference (*C*/*I*) method[1] as described in Section B3 of Part B of the Rules of Procedure to assess the probability of harmful interference.

In this method, the *C*/*I* calculation is performed following the geometrical considerations of Recommendation ITU-R S.740 and utilizes an adjustment factor that accounts for the amount of interference power to be considered in the calculation. The adjusted *C*/*I* value is then compared to the required *C*/*I* to assess the probability of harmful interference. The required *C*/*I* is derived from an objective *C*/*N* and a K value which generally is 12.2 or 14 dB corresponding to a maximum permissible interference of 6% and 4% of the total noise power respectively.

The single entry *C*/*I* calculation method is also widely used by administrations for interference assessment in the coordination of satellite networks.

2 Carrier-to-noise ratio (*C*/*N*)

A link budget accounts for gains and losses as a signal traverses from one end to the other of the link. It is used in the design of communication links taking into consideration link objectives such as type of services, targeted service areas, transmission rates, link availability and antenna size requirements, among other factors. Therefore, when a satellite filing is submitted with the Bureau, the data in the notices would have been derived from link budgets with desired link objectives that meet a desired carrier-to-noise (*C*/*N*) ratio, which is a measure of the performance of the link.

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[1] WRC-15 adopted Resolution **762** where power flux-density criteria replaces the C/I method for some cases as mentioned in the Resolution.

2.1 Calculating *C*/*N*

The diagram below shows a typical satellite communication link consisting of an uplink and a downlink and the parameters that are required to calculate the *C*/*N* ratio.

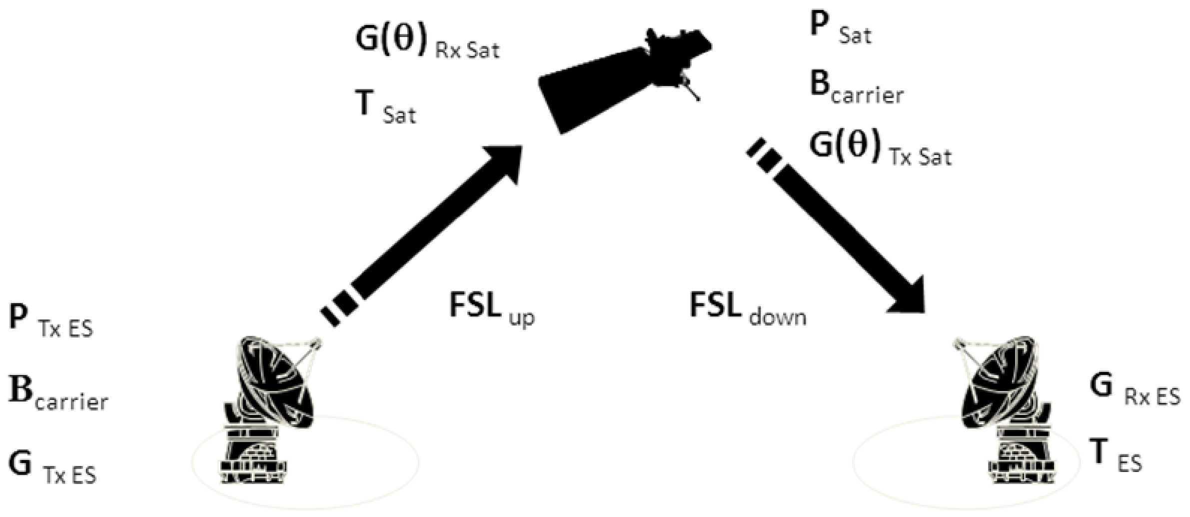

Fig 1. Satellite Communication Link

The carrier-to-noise (*C*/*N*) ratio equation is expressed as follows:

$$(C/N)_{up} = EIRP_{Tx\ ES} - FSL_{up} + (G(\theta)/T)_{RxSat} - B_{carrier} - k \quad (dB) \qquad [1]$$

$$(C/N)_{up} = P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat} - (T_{Sat} + B_{carrier} + k) \quad (dB) \qquad [2]$$

where:

$$C_{up} = P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat} \quad (dBW) \qquad [3]$$

$P_{Tx\ ES}$ = transmitting earth station power (dBW)

$G_{Tx\ ES}$ = transmitting earth station gain (dBi)

FSL_{up} = free-space loss in the uplink (dB)

$G(\theta)_{Rxsat}$ = receiving satellite gain towards the transmitting earth station (dBi)

T_{Sat} = satellite receiving system noise temperature (dBK)

$B_{carrier}$ = carrier bandwidth (dBHz)

k = Boltzmann's constant = −228.6 (dBJ/K)

$$(C/N)_{down} = EIRP_{sat} - FSL_{down} + (G/T)_{RxES} - B_{carrier} - k \quad (dBW) \qquad [4]$$

$$(C/N)_{down} = P_{Sat} + G(\theta)_{TxSat} - FSL_{down} + G_{RxES} - (T_{ES} + B_{carrier} + k) \quad (dBW) \qquad [5]$$

where:

$$C_{down} = P_{Sat} + G(\theta)_{TxSat} - FSL_{down} + G_{RxES} \qquad [6]$$

P_{Sat} = transmitting satellite power (dBW)

$G(\theta)_{TxSat}$ = transmitting satellite gain towards the receiving earth station (dBi)

FSL_{down} = free-space loss in the downlink (dB) (see eq. [7])

G_{RxES} = receiving gain of the earth station (dBi)

T_{ES} = receiving earth station system noise temperature (dBK)

$B_{carrier}$ = carrier bandwidth (dBHz)

k = Boltzmann's constant = –228.6 (dBJ/K)

2.2 Free-space transmission loss

Free-space transmission loss (FSL) is the power loss resulting from the spreading of the signal in space and can be derived as follows:

$$FSL = 20(\log f + \log d) + 32.45 \quad \text{(dB)} \qquad [7]$$

where:

f: frequency (MHz)

d: distance (km)

The distance *d* between an earth station and a geostationary satellite is given by the equation:

$$d = 42\,644\sqrt{1 - 0.2954\cos\psi} \qquad \text{km} \qquad [8]$$

where:

$$\cos\psi = \cos\zeta \times \cos\beta \qquad [9]$$

where:

ζ : latitude of the earth station

β : difference in longitude between the satellite and the earth station.

NOTE – If $\cos\psi < 0.151$, the satellite is below the horizontal plane.

The distance d_S between two geostationary satellites is determined as follows (relevant for FSL calculation of a signal travelling from one geostationary satellite to another):

$$d_S = 84\,332\sin\frac{\theta_g}{2} \qquad \text{km} \qquad [10]$$

where:

θ_g: geocentric angular separation.

3 Carrier-to-interference calculations

3.1 *C/I* uplink

The diagram below shows an uplink interference scenario where an earth station communicating with a satellite causes interference to the adjacent satellite.

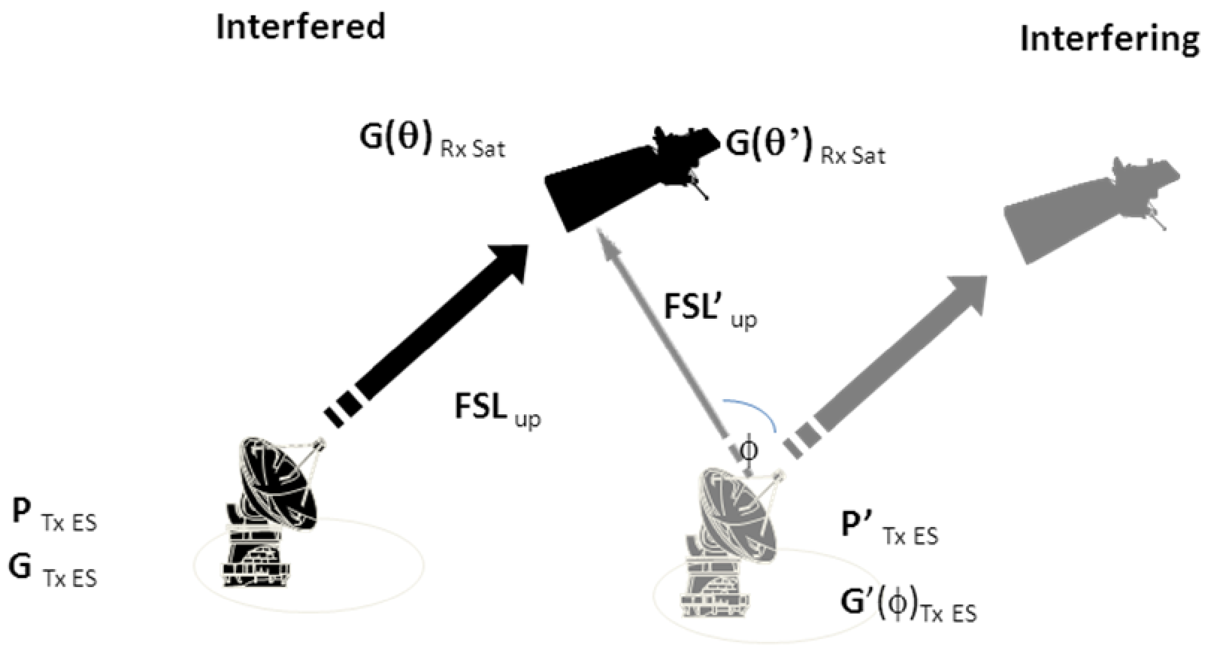

Fig 2. Uplink Interference Scenario

The carrier-to-interference (*C/I*) in the uplink is derived as follows:

From eq. [3]

$$C_{up} = P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat}$$

$$I_{up} = P'_{Tx\ ES} + G'(\phi)_{Tx\ ES} - FSL'_{up} + G(\theta')_{RxSat} \qquad [11]$$

where:

$P'_{Tx\ ES}$ = interfering transmitting earth station power

$G'(\phi)_{Tx\ ES}$ = sidelobe gain of the interfering transmitting earth station in the direction of the interfered space station

and:

ϕ = topocentric angular separation between the interfered and interfering satellite at the interfering transmitting earth station

FSL'_{up} = free-space loss of the interfering transmitting earth station

$G(\theta')_{RxSat}$ = receiving gain of the interfered space station towards the direction of the interfering earth station.

Therefore:

$$(C/I)_{up} = (P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat}) - (P'_{Tx\ ES} + G'(\phi)_{Tx\ ES} - FSL'_{up} + G(\theta')_{RxSat}) \qquad [12]$$

3.2 *C/I* downlink

The diagram below shows a downlink interference scenario where a satellite communicating with an earth station causes interference to the receiving earth station of the adjacent satellite.

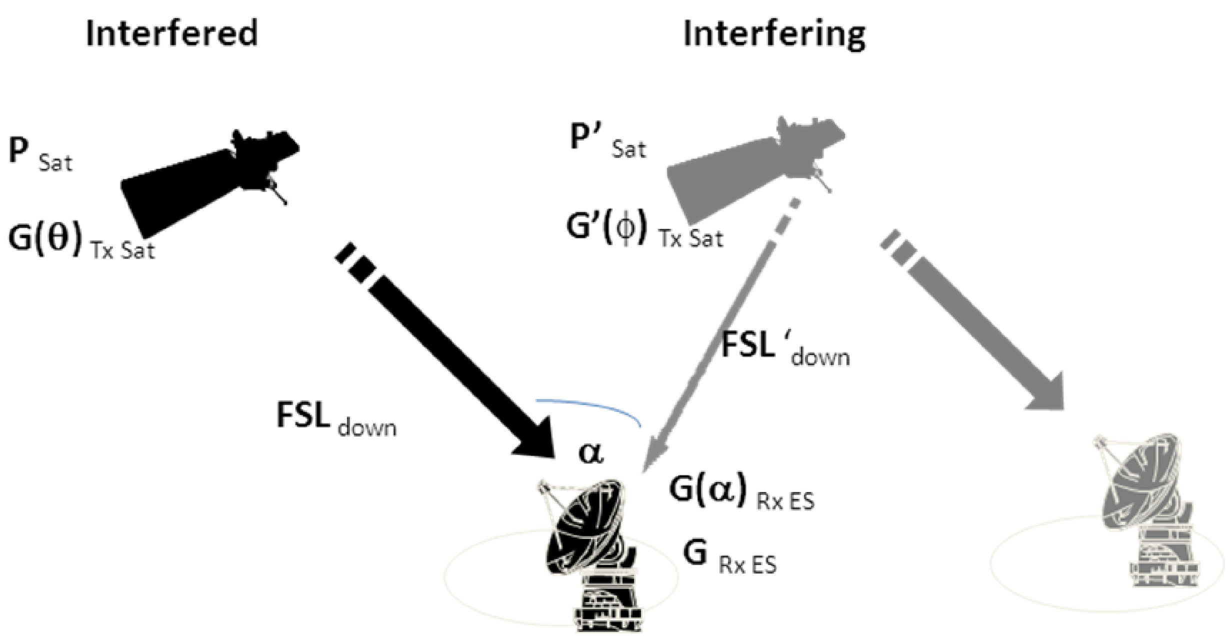

Fig 3. Downlink Interference Scenario

The carrier-to-interference (C/I) in the downlink is derived as follows:

From eq. [6]:

$$C_{down} = P_{Sat} + G(\theta)_{TxSat} - FSL_{down} + G_{RxES}$$

$$I_{down} = P'_{Sat} + G'(\phi)_{TxSat} - FSL'_{down} + G(\alpha)_{RxES} \quad [13]$$

where:

P'_{Sat} = interfering transmitting satellite power

$G'(\phi)_{TxSat}$ = interfering transmitting satellite antenna gain in the direction of the interfered earth station

FSL'_{down} = free-space loss of the interfering transmitting satellite

$G(\alpha)_{RxES}$ = interfered earth station sidelobe gain in the direction of the interfering satellite

where:

α = topocentric angular separation between the interfered and interfering satellite at the interfered receiving earth station

Therefore:

$$(C/I)_{down} = (P_{Sat} + G(\theta)_{TxSat} - FSL_{down} + G_{RxES}) - (P'_{Sat} + G'(\phi)_{TxSat} - FSL'_{down} + G(\alpha)_{RxES}) \quad [14]$$

3.3 Topocentric angular separation

The angular separation subtended by two geostationary satellites at an earth station is referred to as the topocentric angular separation. The topocentric angular separation θ_t can be determined using the equation:

$$\theta_t = \text{arc cos}\left(\frac{d_1^2 + d_2^2 - \left(84\,332\, sin\frac{\theta g}{2}\right)^2}{2d_1 \cdot d_2}\right) \qquad [15]$$

where:

d_1 and d_2 = the distances (km), from the earth station to the two satellites respectively (see eq. [8])

θg = geocentric angular separation in degrees between the two satellites, taking the longitudinal station-keeping tolerances into account

3.4 Antenna patterns

Sidelobe radiation from antennas although undesirable cannot be eliminated. The antenna radiation is characterized by the mainlobe, sidelobes and some transitory regions between the two. There are several radiation envelope reference curves that imitates the antenna radiation pattern mask. The reference pattern of Appendix **8** of the Radio Regulations is shown below as an example:

a) for values of $\frac{D}{\lambda} \geq 100$ (maximum gain ≥ 48 dB approximately):

$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\ \varphi\right)^2$ for $0 < \varphi < \varphi_m$

$G(\varphi) = G_1$ for $\varphi_m \leq \varphi < \varphi_r$

$G(\varphi) = 32 - 25 \log \varphi$ for $\varphi_r \leq \varphi < 48°$

$G(\varphi) = -10$ for $48° \leq \varphi \leq 180°$

where:

D: antenna diameter, λ: wavelength } expressed in the same unit

φ: off-axis angle of the antenna, in degrees

G_1: gain of the first sidelobe = $2 + 15 \log \frac{D}{\lambda}$

(In cases where $\frac{D}{\lambda}$ is not given, it may be estimated from the expression $20 \log \frac{D}{\lambda} \approx G_{max} - 7.7$, where G_{max} is the main lobe antenna gain (dB).)

$\varphi_m = \frac{20\,\lambda}{D} \sqrt{G_{max} - G_1}$ degrees

$\varphi_r = 15.85 \left(\frac{D}{\lambda}\right)^{-0.6}$ degrees

b) for values of $\frac{D}{\lambda} < 100$[4] (maximum gain < 48 dB approximately):

$G(\varphi) = G_{max} - 2.5 \times 10^{-3} \left(\frac{D}{\lambda}\ \varphi\right)^2$ for $0 < \varphi < \varphi_m$

$G(\varphi) = G_1$ for $\varphi_m \leq \varphi < 100 \frac{\lambda}{D}$

$G(\varphi) = 52 - 10 \log \frac{D}{\lambda} - 25 \log \varphi$ for $100 \frac{\lambda}{D} \leq \varphi < 48°$

$G(\varphi) = 10 - 10 \log \frac{D}{\lambda}$ for $48° \leq \varphi \leq 180°$

Other antenna reference patterns can be found in the following references:

- Annex 3 of Appendix **7** of the Radio Regulations
- ITU-R S.580-6
- ITU-R S.465-6
- ITU-R BO.1900
- ITU-R M.694-1
- ITU-R BO.1213-1
- ITU-R BO.1295.

4 Adjustment factor

The amount of interfering carrier power to be considered in the wanted carrier can be obtained by taking the ratio of the wanted carrier bandwidth and interfering carrier bandwidth. This is known as the adjustment factor. As its term suggests the C/I calculations as per expressions [12] and [14] are adjusted using the adjustment factor to account for the amount of interfering carrier power to be considered.

In noise like interference digital carriers, if the desired carrier bandwidth is smaller than the interfering carrier bandwidth, only a portion of the power of the interfering carrier is considered in the C/I calculation. Alternatively, if the desired carrier bandwidth is larger than the interfering carrier bandwidth, the effect of multiple interfering carriers affecting a desired carrier is considered.

In the case of interfering analogue carriers, if the interfering power spectrum is not known, calculation of interference can be made with the approximation that the power spectral density of the interfering carrier is constant over the bandwidth of the desired carrier. The equivalent bandwidth (BW_{eqi}) can then be computed as follows:

$$BWeqi = \text{Total peak power / Maximum power density}$$

In a non-co-frequency interfering situation from a TV-FM carrier into another TV-FM carrier, the protection ratio masks defined in the Rules of Procedure relating to § 3.5.1 and § 3.8 of Annex 5 to Appendix **30** are used.

The three methods of accounting for interference power can be summarized in the table below:

TABLE 1

Adjustment factor cases

<table>
<tr><th>Wanted
Interfering</th><th>Digital</th><th>Analogue (other than TV/FM)</th><th>Other</th><th>TV/FM</th></tr>
<tr><td>Digital</td><td colspan="4">METHOD 1: Wanted bandwidth (BW) to interfering BW overlapping ratio adjustment</td></tr>
<tr><td rowspan="2">TV/FM</td><td colspan="3" rowspan="4">METHOD 2:
Wanted BW to interfering equivalent BW overlapping ratio adjustment</td><td>METHOD 1: Co-freq.</td></tr>
<tr><td>METHOD 3: Non co-freq.
(relative protection ratio)</td></tr>
<tr><td>Analogue (other than TV/FM)</td><td rowspan="2">METHOD 2</td></tr>
<tr><td>Other</td></tr>
</table>

5 Finding the *C*/*I* requirement

The single entry interference (SEI) protection criteria for digital and non-TV analogue carriers is represented by a *C*/*N* objective with a k value of either 12.2 or 14 dB which can be summarized as follows:

<table>
<tr><th>Interfering carrier type
Desired carrier type</th><th>Digital</th><th>Analogue (other than TV-FM)</th></tr>
<tr><td>Analogue (TV-FM)</td><td colspan="2">C/N + 14 (dB)</td></tr>
<tr><td>Digital</td><td colspan="2">C/N + 12.2 (dB)</td></tr>
<tr><td>Analogue (other than TV-FM)</td><td colspan="2">C/N + 12.2 (dB)</td></tr>
<tr><td>Other</td><td colspan="2">C/N + 14 (dB)</td></tr>
</table>

In the case of interfering carrier type analogue TV-FM or carrier type other than digital and non-TV-FM, the protection criteria can be summarized as follows:

Interfering carrier type / Desired carrier type	Analogue (TV-FM) or other
Analogue (TV-FM)	$C/N + 14$ (dB)
Digital	If $BW_w \leq BW_{eqi}$ then $C/N + 5.5 + 3.5{*}\log(BW_w)$ (dB)
	else if $BW_w > BW_{eqi}$ then $C/N + 12.2$ (dB)
Analogue (other than TV-FM)	$11.4 + 2{*}\log(BW_w)$ (dB)
Other	$11.4 + 2{*}\log(BW_w)$ (dB)

where:

BW_w: necessary bandwidth of wanted carrier (MHz)

BW_{eqi}: equivalent bandwidth of interfering carrier (MHz)

C/N: carrier-to-noise ratio (dB)

In Section B3 of Part B of the Rules of Procedure, the carrier types are categorized using the class of emission (Annex 2 item C.7.a of Appendix **4**):

– Analogue (TV-FM):

When the Class of Emission (item C.7.a of Annex 2 to Appendix **4**) is defined with “F” for the first character and with “F” or “W” for the third character.

– Analogue (other than TV-FM):

When the first character of the Class of Emission is “F” and the third character is anything other than “F” or “W”.

– Digital:

When the first character of the Class of Emission is “G”.

– Other:

When the first character of the Class of Emission is anything other than “F” or “G”.

6 Additional margin

Table 2 of Recommendation ITU-R S.741-2 defines “*C/N* ” as a “ratio (dB) of carrier to total noise power which includes all internal system noise and interference from other systems”. No. **1.174** defines the equivalent satellite link noise temperature as “total observed noise at the output of the satellite link excluding the noise due to interference coming from satellite links using other satellites and from terrestrial systems”.

Therefore, to comply with this definition, an additional margin of 0.46 dB for cases involving wanted analogue TV emissions and 1.87 dB for other wanted emissions is added to the margins calculated on the basis of the internal system noise values provided by administrations in the *C/I* calculation method in the Rules of Procedure. These margins are elaborated in Attachment 2 of Section B3 of the Rules of Procedure.

7 Choosing the worst-case locations

In order to obtain the worst-case *C*/*I*, the earth station locations can be chosen as follows:

Uplink

The wanted earth station is located at the edge of the service area of the wanted receiving beam. The interfering earth station is located within the service area of the interfering receiving beam and at the point in which the highest gain is obtained from the wanted receiving beam.

Downlink

The wanted earth station is located at the edge of the service area of the wanted transmitting beam and at the point in which the highest gain is obtained from the interfering transmitting beam.

8 Assumptions for simplification of calculations

As the difference in the topocentric angle and geocentric angle values are small, a fairly accurate *C*/*I* result can be obtained by using geocentric angles instead of topocentric angles in the calculations. In addition, the difference in the free space loss from signals travelling in different paths but sharing the same frequency bands are small. With these assumptions, the *C*/*I* equations of eqs. [12] and [14] can be simplified as follows:

From. Eq. [12]:

$$(C/I)_{up} = (P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat}) - (P'_{Tx\ ES} + G'(\phi)_{Tx\ ES} - FSL'_{up} + G(\theta')_{RxSat})$$

Replacing ϕ with ϕ_g and assuming $FSL_{up} = FSL'_{up}$:

$$(C/I)_{up} = (P_{Tx\ ES} + G_{Tx\ ES} - FSL_{up} + G(\theta)_{RxSat}) - (P'_{Tx\ ES} + G'(\phi_g)_{Tx\ ES} - FSL'_{up} + G(\theta')_{RxSat})$$

$$(C/I)_{up} = (P_{Tx\ ES} + G_{Tx\ ES} + G(\theta)_{RxSat}) - (P'_{Tx\ ES} + G'(\phi_g)_{Tx\ ES} + G(\theta')_{RxSat})$$

where:

ϕ_g = geocentric angular separation between the interfered and interfering satellite at the interfering transmitting earth station

Similarly in the downlink, a fairly accurate *C*/*I* calculation result can be obtained with the following equation:

$$(C/I)_{down} = (P_{Sat} + G(\theta)_{TxSat} + G_{RxES}) - (P'_{Sat} + G'(\phi)_{TxSat} + G(\alpha_g)_{RxES}) \quad [14]$$

where:

α_g = geocentric angular separation between the interfered and interfering satellite at the interfered receiving earth station.

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