

RECOMMENDATION ITU-R S.1555

Aggregate interference levels between closely spaced dual circularly and dual linearly polarized geostationary-satellite networks in the fixed-satellite service operating in the 6/4 GHz frequency bands

(Questions ITU-R 230/4 and 42/4)

(2002)

The ITU Radiocommunication Assembly,

considering

- a) that in the 6/4 GHz frequency bands both dual circular polarization (CP) and dual linear polarization (LP) are used by different operational geostationary-satellite fixed satellite service (FSS) networks, and this situation is likely to continue because of the established infrastructure in those networks;
- b) that such bands are heavily used resulting in the need for co-frequency and co-coverage networks to operate with relatively small orbital spacing;
- c) that the existing ITU-R Recommendations, as well as Appendix 8 to the Radio Regulations (RR), only address the single entry interference between adjacent satellite networks, taking the interfering signal in each polarization at a time;
- d) that it is important during coordination to be able to determine the aggregate effect of adjacent satellite interference arising from the simultaneous use of both orthogonal polarizations in each adjacent satellite network, whether the two networks use the same type of polarization (i.e. both CP or both LP) or whether they use different types of polarization (i.e. one using CP and the other using LP);
- e) that the magnitude of the two orthogonally polarized signals of the interfered with and/or the interfering networks could be equal or unequal,

recommends

1 that, on the basis of the technical information contained in Annexes 1, 2 and 3, the aggregate interference between closely spaced adjacent satellite networks (up to 6° orbital separation) operating in the 6/4 GHz frequency bands using different types of polarization (i.e. CP in one network and LP in the other) should be assumed to be identical to that which would occur if both networks used the same types of polarization (i.e. both LP or both CP), under the following conditions:

- those networks simultaneously use both orthogonal polarizations co-frequency and co-coverage and the magnitude of the two orthogonally polarized signals of the interfered with and the interfering networks are equal; or
- the magnitude of the two orthogonally polarized signals of the interfered with network are unequal, and the magnitude of the two orthogonally polarized signals of the interfering networks are equal;

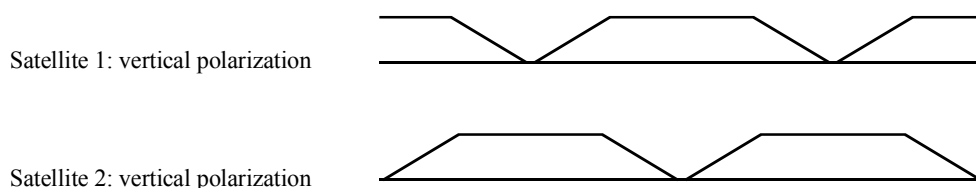
2 that, on the basis of the technical information contained in Annex 3, when the magnitude of the two orthogonally polarized signals of the interfering network are unequal, the aggregate interference between closely spaced adjacent satellite networks (up to 6° orbital separation) operating in the 6/4 GHz frequency bands using different types of polarization (i.e. CP in one network and LP in the other) could be assumed to be identical to that which would occur if both networks used the same types of polarization (i.e. both LP or both CP) under the following conditions:

- these networks simultaneously use both orthogonal polarizations co-frequency and co-coverage;
- an additional reduction of the magnitude of the two downlink orthogonally polarized signals of the CP network or an additional reduction of the magnitude of the downlink signal having the highest magnitude of the CP network should be applied.

3 that the technical information contained in Annex 1 should be used to determine the additional reduction of the magnitude of the two orthogonally polarized signals of the CP network when those networks simultaneously use both orthogonal polarizations co-frequency and co-coverage, and the magnitude of the two orthogonally polarized signals of the interfering networks are unequal.

NOTE 1 – When the desired network uses dual LPs with equal magnitudes for the two orthogonal polarized signals and the adjacent network uses dual polarizations with a large difference between the magnitudes for the two orthogonal polarized signals (e.g. greater than 10 dB), the interference environment would differ depending on whether the adjacent satellite uses CP or LP. When LP is used the interference caused to the desired network would be primarily to one polarization (i.e. vertical or horizontal). When CP is used the interference caused to the desired network would be to both polarizations but at a reduced power level compared to the interference from a network using LP.

NOTE 2 – When both the desired and the interfering networks use a staggered channelization plan and when these networks transmit high spectral density in the central portion of the occupied bandwidth of the transponder (e.g. analogue TV/FM), an advantage exists in having adjacent satellites using the same polarization type (i.e. dual LP or dual CP). In these conditions, the signal energy in the centre of the channel falls within the guardband of the co-polarized channel of the adjacent network. The example figure below shows the co-polar channelization plans for one of the polarizations on each adjacent satellite. The interference from the adjacent satellite is mitigated by the angular separation of the satellites and additionally by the frequency separation of the carriers due to filtering of the co-polarized channel of the adjacent satellites.



1555-00

ANNEX 1

Interference between closely spaced dual circularly and dual linearly polarized satellite networks operating in the 6/4 GHz frequency bands**Abstract**

This Annex introduces the issue of the aggregate interference between closely spaced adjacent satellite networks (up to 6° orbital separation) operating in the 6/4 GHz frequency bands when these networks use different types of polarization (i.e. CP in one network and LP in the other), and when those networks simultaneously use both orthogonal polarizations co-frequency and co-coverage. It provides the general expression of the equations which were used to perform the analyses.

It includes the main results of an analysis of the impact on the aggregate adjacent satellite interference levels when neighbouring satellites operating in the 6/4 GHz frequency bands use different types of polarization (i.e. LP versus CP) and when the magnitude of the two orthogonally polarized signals of the interfered with and the interfering networks are equal. In addition, it is assumed that the interfering and interfered with networks operate the same type of carriers at the same frequency. It compares the interference levels in these situations with those that exist when the satellite networks use the same type of polarization, either both using dual LP or both using dual CP. It concludes that in this case, for practical values of satellite and earth station cross-polar discrimination (XPD), the absolute worst-case additional interference, relative to the idealized case where both networks use the same type of polarization and are perfectly aligned, is less than approximately 0.5 dB for the downlink and less than approximately 1.5 dB for the uplink. The earth station antenna off-axis co-polar and cross-polar patterns are the main contributors to the interference. The analysis is worst case and uses simple template envelopes to represent the earth station antenna performance. In practice it is extremely unlikely that worst case conditions will occur on co-polar and cross-polar patterns of each of the two polarization transmitted by the earth station antenna simultaneously.

1 Introduction

6/4 GHz satellites operate co-frequency and co-coverage along the geostationary arc with small orbital spacing between adjacent satellites, typically in the range of 2° to 6°. Coordination between these networks often assumes that they operate co-polar to each other, where no polarization isolation is assumed, such as when both networks use dual orthogonal LP or dual orthogonal CP.

Cases arise where some polarization isolation exists between adjacent networks such as when adjacent networks only use opposite senses of the same type of polarization (e.g. vertical polarization (VP) adjacent to horizontal polarization (HP), or right-hand circular (RHC) adjacent to left-hand circular (LHC) polarization)). With the satellite antenna XPD of the order of 30 dB, the earth station antenna off-axis cross-polar gain will be the dominant cross-polarization effect in these cases. It essentially controls the cross-polar interference between two adjacent satellite networks regardless of whether they are operating in LP or in CP.

Another situation can arise in which adjacent satellite networks use different types of polarization – CP in one network and LP in the other. Such situations occur regularly with networks operating in the 6/4 GHz frequency bands where historical choices of polarization (CP versus LP) made decades ago are still maintained in the current operational networks, a situation that is likely to continue in the future due to the considerable infrastructure investment in these networks. The off-axis polarization isolation between networks in these cases has been studied, but only taking account of one polarization at a time¹. Paragraph 2.2.3 of RR Appendix 8 provides guidance to administrations in terms of the isolation between a single CP interfering signal and an LP wanted signal (or vice versa) with a recommended worst-case numerical isolation factor of 1.4 times (= 1.46 dB) as an envelope value for all ranges of orbital separation.

The situation that has not been adequately studied, and which is addressed in this Recommendation, is when the interfering network uses both senses of polarization (either CP or LP) and the wanted network uses the other type of polarization (either LP or CP, respectively). In this case it is important during coordination to calculate the aggregate interference resulting from the combined effect of the two orthogonally polarized signals in the interfering network. In fact, this is the case that exists in practice in most situations with currently operational satellite networks, where both are using dual orthogonal polarization for spectral efficiency reasons.

2 Generic vector equations

This section summarizes the general expressions of the equations that should be used to assess the coupling from the two polarization components of the interfering network into one component of the interfered with network. The equations are provided for each possible case of interference (i.e. CP into LP, LP into CP, LP into LP).

2.1 Interference from circularly polarized into linearly polarized antenna systems

In this section we first derive general expressions for the coupling from the two types of circular polarization into a linearly polarized antenna. Then, we consider the two special cases:

- A dual circularly polarized satellite illuminates a linearly polarized earth station.
- A dual circularly polarized earth station illuminates a linearly polarized satellite.

The incident field at the location of the receive antenna is, for each polarization of the circularly polarized transmit antenna:

$$\begin{aligned} \mathbf{e}_R &= e_R \left[\frac{\mathbf{h} - j\mathbf{v}}{\sqrt{2}} \right] + e_{RX} \left[\frac{\mathbf{h} + j\mathbf{v}}{\sqrt{2}} \right] e^{j\delta_R} \\ \mathbf{e}_L &= e_L \left[\frac{\mathbf{h} + j\mathbf{v}}{\sqrt{2}} \right] + e_{LX} \left[\frac{\mathbf{h} - j\mathbf{v}}{\sqrt{2}} \right] e^{j\delta_L} \end{aligned} \quad (1)$$

¹ See ex-CCIR Reports 555 and 1141 and Recommendation ITU-R S.736.

where:

- $\mathbf{e}_R, \mathbf{e}_L$: incident electric field vectors for the right-hand and the left-hand circularly polarized signals
- e_R, e_{RX} : co-polarized and the cross-polarized field amplitudes of the right-hand circularly polarized signal
- e_L, e_{LX} : co-polarized and the cross-polarized field amplitudes of the left-hand circularly polarized signal
- $\mathbf{h}, \mathbf{v}$: horizontal and vertical unit vectors at the location of the receive antenna
- δ_R, δ_L : unknown phases of the cross-polarized field relative to the co-polarized field for the right-hand and the left-hand circularly polarized signals².

Each port of the linearly polarized receive antenna can be characterized by an effective length³, i.e. for the HP and the VP:

$$\begin{aligned}\mathbf{h}_h &= \sqrt{g} \mathbf{h} + \sqrt{g_x} \mathbf{v} e^{j\delta} \\ \mathbf{h}_v &= \sqrt{g} \mathbf{v} + \sqrt{g_x} \mathbf{h} e^{j\delta}\end{aligned}\quad (2)$$

where:

- g, g_x : proportional to the co-polar and the cross-polar gain of the receive antenna
- $\mathbf{h}, \mathbf{v}$: horizontal and vertical unit vectors at the location of the receive antenna
- δ : unknown phase of the cross-polarization voltage relative to the co-polarization voltage received in a port of the linearly polarized antenna.

The actual values of g, g_x and δ will in general be different for the two receive antenna ports, although the worst-case interference (based on using the gain masks and the appropriate value for δ) will be the same for both antenna ports. The analysis here is of the aggregate interference for one receive antenna port at a time. The received voltages for the two incident signals in equation (1) in the horizontal polarization receive port are therefore:

$$\begin{aligned}v_{Rh} &= \mathbf{h}_h \cdot \mathbf{e}_R \\ &= \sqrt{\frac{g}{2}} e_R + \sqrt{\frac{g}{2}} e_{RX} e^{j\delta_R} - j\sqrt{\frac{g_x}{2}} e_R e^{j\delta} + j\sqrt{\frac{g_x}{2}} e_{RX} e^{j(\delta + \delta_R)}\end{aligned}\quad (3)$$

$$\begin{aligned}v_{Lh} &= \mathbf{h}_h \cdot \mathbf{e}_L \\ &= \sqrt{\frac{g}{2}} e_L + \sqrt{\frac{g}{2}} e_{LX} e^{j\delta_L} + j\sqrt{\frac{g_x}{2}} e_L e^{j\delta} - j\sqrt{\frac{g_x}{2}} e_{LX} e^{j(\delta + \delta_L)}\end{aligned}\quad (4)$$

² As in most antenna analyses, simple carriers with the time factor $e^{j\omega t}$ are assumed. The carrier and the signal in one polarization are assumed to be uncorrelated with the carrier and the signal in the other polarization.

³ The concept of “effective length” applied originally to dipole antennas and linear polarization. It has over the years been extended to general polarization states and more general antennas. The effective length of an antenna may be defined as a complex vector so that the received open-circuit voltage is the scalar product of effective length vector $\mathbf{h}$ and the incident electric field vector $\mathbf{e}$, i.e. $v_{oc} = \mathbf{h} \cdot \mathbf{e}$.

The power received in the horizontal polarization port is proportional to the sum of the voltages squared assuming that the two signals are uncorrelated. The last term on the right-hand sides of equations (3) and (4) is the product of the cross-polarization of the two antennas and will therefore be the smallest for practical cross-polar performance values. As a result some of the terms resulting from the squaring of equations (3) and (4) are so small that they can be ignored, and these are the ones involving the product of the last term with any other terms except the first. By simplifying in this way the power in the horizontal polarization receive port is proportional to:

$$\begin{aligned} |v_{Rh}|^2 + |v_{Lh}|^2 = & \frac{g}{2} (e_R^2 + e_L^2 + e_{RX}^2 + e_{LX}^2) + \frac{g_x}{2} (e_R^2 + e_L^2) + \\ & g(e_R e_{RX} \cos \delta_R + e_L e_{LX} \cos \delta_L) + \sqrt{gg_x} (e_R^2 - e_L^2) \sin \delta - \\ & 2\sqrt{gg_x} (e_R e_{RX} \sin \delta_R - e_L e_{LX} \sin \delta_L) \cos \delta \end{aligned} \quad (5)$$

Similarly, the power in the vertical polarization receive port is proportional to:

$$\begin{aligned} |v_{Rv}|^2 + |v_{Lv}|^2 = & \frac{g}{2} (e_R^2 + e_L^2 + e_{RX}^2 + e_{LX}^2) + \frac{g_x}{2} (e_R^2 + e_L^2) - \\ & g(e_R e_{RX} \cos \delta_R + e_L e_{LX} \cos \delta_L) - \sqrt{gg_x} (e_R^2 - e_L^2) \sin \delta - \\ & 2\sqrt{gg_x} (e_R e_{RX} \sin \delta_R - e_L e_{LX} \sin \delta_L) \cos \delta \end{aligned} \quad (6)$$

2.2 Interference from linearly polarized into circularly polarized antenna systems

This section investigates the opposite scenario of that of the previous section. We derive general expressions for the coupling from two orthogonal linear polarizations into a circularly polarized antenna and consider the two special cases:

- A dual linearly polarized satellite illuminates a circularly polarized earth station.
- A dual linearly polarized earth station illuminates a circularly polarized satellite.

The incident field at the location of the receive antenna is for each polarization of the linearly polarized transmit antenna:

$$\begin{aligned} \mathbf{e}_H &= e_H \mathbf{h} + e_{HX} \mathbf{v} e^{j\delta_H} \\ \mathbf{e}_V &= e_V \mathbf{v} + e_{VX} \mathbf{h} e^{j\delta_V} \end{aligned} \quad (7)$$

where:

- $\mathbf{e}_H, \mathbf{e}_V$: incident electric field vectors for the horizontally and vertically polarized signals
- e_H, e_{HX} : co-polarized and the cross-polarized field amplitudes of the horizontally polarized signal
- e_V, e_{VX} : co-polarized and the cross-polarized field amplitudes of the vertically polarized signal
- $\mathbf{h}, \mathbf{v}$: horizontal and vertical unit vectors at the location of the receive antenna
- δ_H, δ_V : unknown phases of the cross-polarized field relative to the co-polarized field for the vertically and the horizontally polarized signals.

The RHC and LHC polarization ports of the receive antenna are characterized by the effective lengths:

$$\begin{aligned}\mathbf{h}_r &= \sqrt{g} \frac{\mathbf{h} + j\mathbf{v}}{\sqrt{2}} + \sqrt{g_x} \frac{\mathbf{h} - j\mathbf{v}}{\sqrt{2}} e^{j\delta} \\ \mathbf{h}_l &= \sqrt{g} \frac{\mathbf{h} - j\mathbf{v}}{\sqrt{2}} + \sqrt{g_x} \frac{\mathbf{h} + j\mathbf{v}}{\sqrt{2}} e^{j\delta}\end{aligned}\quad (8)$$

where:

g, g_x : proportional to the co-polar and the cross-polar gain of the receive antenna

$\mathbf{h}, \mathbf{v}$: horizontal and vertical unit vectors at the location of the receive antenna

δ : unknown phase of the cross-polarization voltage relative to the co-polarization voltage received in a port of the circularly polarized antenna.

The received voltages for the two incident signals in equation (7) in the RHC polarization receive port are:

$$\begin{aligned}v_{Hr} &= \mathbf{h}_r \cdot \mathbf{e}_H \\ &= \sqrt{\frac{g}{2}} e_H + j\sqrt{\frac{g}{2}} e_{HX} e^{j\delta_H} + \sqrt{\frac{g_x}{2}} e_H e^{j\delta} - j\sqrt{\frac{g_x}{2}} e_{HX} e^{j(\delta + \delta_H)}\end{aligned}\quad (9)$$

$$\begin{aligned}v_{Vr} &= \mathbf{h}_r \cdot \mathbf{e}_V \\ &= j\sqrt{\frac{g}{2}} e_V + \sqrt{\frac{g}{2}} e_{VX} e^{j\delta_V} - j\sqrt{\frac{g_x}{2}} e_V e^{j\delta} + \sqrt{\frac{g_x}{2}} e_{VX} e^{j(\delta + \delta_V)}\end{aligned}\quad (10)$$

The power received in the RHC polarization port is proportional to the sum of the voltages squared (neglecting cross-polarization terms of an order higher than two):

$$\begin{aligned}|v_{Hr}|^2 + |v_{Vr}|^2 &= \frac{g}{2} (e_H^2 + e_V^2 + e_{HX}^2 + e_{VX}^2) + \frac{g_x}{2} (e_H^2 + e_V^2) - \\ &\quad g(e_H e_{HX} \sin \delta_H - e_V e_{VX} \sin \delta_V) + \sqrt{gg_x} (e_H^2 - e_V^2) \cos \delta + \\ &\quad 2\sqrt{gg_x} (e_H e_{HX} \cos \delta_H + e_V e_{VX} \cos \delta_V) \sin \delta\end{aligned}\quad (11)$$

Similarly, the power in the LHC polarization receive port is proportional to:

$$\begin{aligned}|v_{Hl}|^2 + |v_{Vl}|^2 &= \frac{g}{2} (e_H^2 + e_V^2 + e_{HX}^2 + e_{VX}^2) + \frac{g_x}{2} (e_H^2 + e_V^2) + \\ &\quad g(e_H e_{HX} \sin \delta_H - e_V e_{VX} \sin \delta_V) + \sqrt{gg_x} (e_H^2 - e_V^2) \cos \delta - \\ &\quad 2\sqrt{gg_x} (e_H e_{HX} \cos \delta_H + e_V e_{VX} \cos \delta_V) \sin \delta\end{aligned}\quad (12)$$

2.3 Interference from linearly polarized into linearly polarized antenna systems

In this section we consider the interference between two dual linearly polarized systems that may have different polarization alignment angles⁴. We derive expressions for:

- A dual linearly polarized satellite that illuminates a linearly polarized earth station.
- A dual linearly polarized earth station that illuminates a linearly polarized satellite.

The incident field at the location of the receive antenna is, for each polarization of the linearly polarized transmit antenna,

$$\begin{aligned} \mathbf{e}_H &= e_H (\cos \psi \mathbf{h} + \sin \psi \mathbf{v}) + e_{HX} (-\sin \psi \mathbf{h} + \cos \psi \mathbf{v}) e^{j\delta_H} \\ \mathbf{e}_V &= e_V (-\sin \psi \mathbf{h} + \cos \psi \mathbf{v}) + e_{VX} (\cos \psi \mathbf{h} + \sin \psi \mathbf{v}) e^{j\delta_V} \end{aligned} \quad (13)$$

where:

- $\mathbf{e}_H, \mathbf{e}_V$: incident electric field vectors for the horizontally and vertically polarized signals
- e_H, e_{HX} : co-polarized and the cross-polarized field amplitudes of the horizontally polarized signal
- e_V, e_{VX} : co-polarized and the cross-polarized field amplitudes of the vertically polarized signal
- $\mathbf{h}, \mathbf{v}$: horizontal and vertical unit vectors at the location of the receive antenna
- ψ : differential polarization angle between the transmit and the receive antenna
- δ_H, δ_V : unknown phases of the cross-polarized field relative to the co-polarized field for the vertically and the horizontally polarized signals.

Equation (2) characterizes the properties of the receive antenna HP and VP ports. The received voltages for the two incident signals in equation (13) in the horizontal polarization receive port are:

$$\begin{aligned} v_{Hh} &= \mathbf{h}_h \cdot \mathbf{e}_H \\ &= \sqrt{g} e_H \cos \psi - \sqrt{g} e_{HX} \sin \psi e^{j\delta_H} + \sqrt{g_x} e_H \sin \psi e^{j\delta} + \sqrt{g_x} e_{HX} \cos \psi e^{j(\delta + \delta_H)} \end{aligned} \quad (14)$$

$$\begin{aligned} v_{Vh} &= \mathbf{h}_h \cdot \mathbf{e}_V \\ &= -\sqrt{g} e_V \sin \psi + \sqrt{g} e_{VX} \cos \psi e^{j\delta_V} + \sqrt{g_x} e_V \cos \psi e^{j\delta} + \sqrt{g_x} e_{VX} \sin \psi e^{j(\delta + \delta_V)} \end{aligned} \quad (15)$$

The power received in the HP port is proportional to the sum of the voltages squared (neglecting cross-polarization products of order higher than two),

⁴ Satellites with the same polarization alignment, e.g. as defined by the equatorial plane, but operating from different positions along the geostationary arc, will appear to have slightly different polarization orientations at an earth station. For segments of the geostationary arc less than about $\pm 6^\circ$, the polarization alignment difference from the central satellite will be less than about 1° .

$$\begin{aligned}
|v_{Hh}|^2 + |v_{Vh}|^2 = & g(e_H^2 \cos^2 \psi + e_V^2 \sin^2 \psi + e_{HX}^2 \sin^2 \psi + e_{VX}^2 \cos^2 \psi) + g_x(e_H^2 \sin^2 \psi + e_V^2 \cos^2 \psi) - \\
& g \sin 2\psi(e_H e_{HX} \cos \delta_H + e_V e_{VX} \cos \delta_V) + \sqrt{gg_x} \sin 2\psi(e_H^2 - e_V^2) \cos \delta + \\
& 2\sqrt{gg_x} \cos^2 \psi(e_H e_{HX} \cos(\delta + \delta_H) + e_V e_{VX} \cos(\delta - \delta_V)) - \\
& 2\sqrt{gg_x} \sin^2 \psi(e_H e_{HX} \cos(\delta - \delta_H) + e_V e_{VX} \cos(\delta + \delta_V))
\end{aligned} \tag{16}$$

Similarly, the power in the vertical polarization receive port is proportional to:

$$\begin{aligned}
|v_{Hh}|^2 + |v_{Vh}|^2 = & g(e_H^2 \sin^2 \psi + e_V^2 \cos^2 \psi + e_{HX}^2 \cos^2 \psi + e_{VX}^2 \sin^2 \psi) + g_x(e_H^2 \cos^2 \psi + e_V^2 \sin^2 \psi) - \\
& g \sin 2\psi(e_H e_{HX} \cos \delta_H + e_V e_{VX} \cos \delta_V) + \sqrt{gg_x} \sin 2\psi(e_H^2 - e_V^2) \cos \delta + \\
& 2\sqrt{gg_x} \sin^2 \psi(e_H e_{HX} \cos(\delta + \delta_H) + e_V e_{VX} \cos(\delta - \delta_V)) - \\
& 2\sqrt{gg_x} \cos^2 \psi(e_H e_{HX} \cos(\delta - \delta_H) + e_V e_{VX} \cos(\delta + \delta_V))
\end{aligned} \tag{17}$$

3 Summary of downlink and uplink analysis for dual polarized interfering signals of equal amplitude

The analysis contained in this Annex is based on a rigorous treatment of the field at the output ports of a dual polarized receive antenna (either LP or CP) using a complete representation of the incident signal (either CP or LP, respectively) in terms of their two orthogonally polarized components. This analysis is equally applicable to the uplink and the downlink transmission paths. In this Annex the magnitude of the two orthogonally polarized interfering signals are assumed to be equal.

The analysis uses the generic vector equations given in Section 2 and we present simplified versions for both uplink and downlink. Different combinations of the unknown phase angles, δ_R , δ_L , δ_H , δ_V and δ have been used to derive worst-case, average and best-case results. Separate summary analyses are provided for the uplink and downlink cases of:

- a dual CP network interfering with an LP network
- a dual LP network interfering with an CP network
- a dual LP network interfering with an LP network.

Having addressed the case of a CP network interfering with an LP network, the analysis then deals with the interference in the opposite direction – from an LP network interfering with a CP network.

An important objective of the analysis is to understand the relative impact of the use of different types of polarization in adjacent satellites (CP in one network and LP in the other network) compared to the case where both networks use one type of polarization only (LP in both networks or CP in both networks). Therefore the results are presented in the form of a “ Δ ” compared to the like polarization case. In order to obtain a true comparison, the same analysis approach is used to determine the reference situation where adjacent networks are both operating using LP.

The results of the comparison are given in Section 5 of this Annex. These results show worst-case interference levels that result from particular combinations of the unknown relative phase angles, δ_R , δ_L , δ_H , δ_V and δ . These worst-case interference levels are given relative to the often-assumed situation where the co-polar and cross-polar signals are assumed to be uncorrelated, and therefore

are added in power to determine the aggregate interference level (or average level). The resulting discrepancy between the rigorous worst-case analysis of interference between adjacent LP networks, compared to the simplistic power summation approach, is between 0.05 dB and 0.47 dB. This result should be taken into account when assessing the overall impact of CP networks interfering with adjacent LP networks (and vice versa). The simple power summation approach will provide an average interference level. This average interference is independent of the polarization of the networks. The maximum possible deviation of the worst-case interference from the average interference is slightly larger when the two adjacent networks have different polarization types than when they have the same polarization type.

The conclusions from this analysis are that when the magnitude of the two orthogonally polarized interfering signals is assumed to be equal, the worst-case aggregate downlink interference into an LP system from an adjacent CP system is comparable to that from an adjacent LP system as the interference contributions from the earth station antenna cross-polarization cancel in the earth station antenna receive ports. The worst-case aggregate uplink interference into the LP system from the adjacent CP system is higher than from the adjacent LP system. The interference level depends upon the phase relationship between the co-polarized and the cross-polarized components for the earth station antenna and the satellite antenna. If the interference into the one satellite antenna receive port is increased, the interference into the orthogonal satellite antenna receive port from the same earth station will decrease by a similar amount. Improving the earth station off-axis performance will improve the worst-case aggregate interference. The average interference into dual LP systems from dual CP systems (or vice versa) is identical to the average interference between adjacent dual LP systems or between adjacent dual CP systems.

The aggregate downlink and uplink interference into a CP system from an adjacent LP system is identical to the interference into an LP system from an adjacent CP system.

3.1 CP satellite into LP earth station

We assume:

- a) The signal amplitude for each polarization is the same, i.e. $e_R = e_L = e^*$.
- b) The satellite cross-polarization is defined by the XPD, i.e. $e_{RX} = e_{LX} = e/\sqrt{xpd}$ **. XPD is the difference between co-polar and cross-polar gain values of an antenna. In general it is expressed in dB, although in the equations of this note the lower case xpd indicates a linear power ratio.

* An imbalance between the co-polarization levels from the satellite may be undesirable as it may generate some interference – see the fourth term of equations (5) and (6). However, the first dominant term will be small in the unbalanced case due to the factor, 1/2. The cancellation of the dominant earth station cross-polarization contribution seems to be unique for the downlink interference case. The cancellation takes place if the two polarizations are transmitted from a single satellite or from co-located satellites. Otherwise, this contribution would be a significant downlink contribution for $\delta = \pm 90^\circ$.

** It is a very pessimistic assumption that the cross-polarization peaks occur at the same location and frequency for both hands of CP from the satellite. This point is discussed further in Section 5 of this Annex.

- c) The earth station antenna co-polarization and cross-polarization gain are defined by the gain envelopes G and G_x . Typical values for the G_x envelope would be $19 - 25 \log(\theta)$ which is 10 dB lower than the typical G envelope of $29 - 25 \log(\theta)$. The lower case g and g_x indicate the corresponding numerical values.

The satellite XPD is typically in the order of 27-30 dB while the off-axis earth station XPD close to the main beam can be assumed to be 10 dB. Far away from the main beam, it will be less. Thus, the earth station cross-polarization would be expected to contribute more to the overall adjacent satellite interference than the satellite cross-polarization.

Substitution of these assumptions into equations (5) and (6) provides expressions for the power received by the two earth station antenna ports as functions of the phase differences δ_R , δ_L and δ . These unknown phase differences are generally not considered in the antenna design. However, they are significant for the aggregate interference. Here we only bound the interference for any phase differences and provide the worst-case and the best-case interference:

$$|v_R|^2 + |v_L|^2_{\text{worst/best case}} = (g + g_x)e^2 \pm 2\sqrt{\frac{g(g + 4g_x)}{xpd}} e^2 + \frac{g}{xpd} e^2 \quad (18)$$

The upper sign applies for the worst case and the lower sign for the best case. The average interference is the sum of the first and the third terms of equation (18). The worst-case interference occurs for the HP port for the phase angles δ , δ_R and δ_L close to 0. Similarly, the best case occurs for the phase angles δ , δ_R and δ_L close to 180°. These two conditions are the best case and the worst case, respectively, for the vertical polarization port. It is significant to note:

- In average there is no degradation compared to LP systems.
- If one receive polarization port is degraded, the performance of the other port will be better than in the average case.

3.2 CP earth station into LP satellite

We assume:

- The signal amplitude for each polarization is the same, i.e. $e_R = e_L = e$.
- The satellite cross-polarization is defined by the XPD. If the co-polar satellite antenna gain is g_{sat} , the cross-polar satellite antenna gain $g_{sat, x} = g_{sat}/xpd$.
- The earth station antenna co-polarization and cross-polarization gain are defined by the gain envelopes G and G_x . Then, the earth station cross-polarization is $e_{RX} = e_{LX} = e\sqrt{g_x/g}$.

The worst-case and the best-case interference are for the uplink case:

$$|v_R|^2 + |v_L|^2_{\text{worst/best case}} = (g + g_x)e^2 \pm 2\sqrt{\frac{g g_x (xpd + 4)}{xpd}} e^2 + \frac{g}{xpd} e^2 \quad (19)$$

The worst-case interference occurs for the horizontal polarization port for δ , δ_L and δ_R close to 0 as in the downlink case. Since the satellite XPD in general will be large, the worst-case degradation will be larger in the downlink case than in the uplink case.