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Theoretical Interpretation of Interference Arising Between Closely Spaced Dual Polarized Geostationary Satellites

Won Jun Choi[1], Dong-Won Lee[1], Jong Won Eun[2], and Jae-Hyun Lee[3*], *Member*, *KIICE*

[1]Environmental Satellite Center, National Institute of Environmental Research, Incheon 22689, Korea
[2]Satellite Technology- Information Technology Convergence R&D Center, Namseoul University Cheonan, 31020, Korea
[3]Department of Radio and Information Communications Engineering, Chungnam National University, Daejeon 34134, Korea

Abstract

The interference between closely placed co-coverage satellites was analyzed. In general, a satellite network may use different orthogonal polarizations and frequencies to increase the throughput of a satellite. However, when orthogonal linear polarization (horizontal polarization and vertical polarization) or orthogonal circular polarization (left-handed circular polarization and right-handed circular polarization) is used, the signal from one polarization sense to another may be coupled, resulting in cross-polarization interference. This signal-coupling arises due to the finite value of the cross-polarization discrimination of the earth station. In this study, field equations were used to analyze the interference between adjacent satellites using co-frequency. The level of interference was compared to that when two adjacent satellites used the same polarization. The simulation results show that the interference mainly depends on the off-axis co-polar pattern and the cross-polar pattern of the earth station antenna.

Index Terms: Adjacent satellite interference, Cross polar discrimination, Dual polarization, Depolarization

I. INTRODUCTION

The demand for satellite services has been steadily increasing. The number of GEO satellites has increased rapidly with the flourishing satellite service market. Currently, there are more than 550 geostationary satellites [1]. To accommodate more geostationary satellites, the orbital separation must be reduced to a maximum of 0.5°. Owing to this small orbital separation, the burden on communication links may, in some cases, be dominated by adjacent satellite interference. As a result, interference from adjacent satellites will become increasingly severe if the adjacent satellites are not properly controlled. The use of dual orthogonal polarization can effectively double satellite capacity. Polarization is a property applied to transverse waves; it specifies the geometric orientation of the propagated wave.

This capacity increase is sensitive to system imperfections, such as a poor antenna axis ratio. These imperfections attenuate and/or phase-shift the received signal, resulting in depolarization. If a satellite antenna cross-polar determination (XPD) of approximately 30 dB is used, the effect of the antenna off-axis cross-polarization gain of the earth station will be more dominating [2-4]. The cross-polarization interference between two adjacent satellite networks is essentially independent of a linear polarization operation or circular polarization. Regarding the use of different polarization types in adjacent satellite networks, another situation can arise.

As shown in Fig. 1, if the interfering satellite network uses both directions of polarization and the desired satellite network uses another type of polarization, the interference due to the combined effect must be calculated. However, when

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***Corresponding Author** Jae-Hyun Lee (E-mail: jeahyun@cnu.ac.kr, Tel: +82-42-821-6870)
Department of Radio and Information Communications Engineering, Chungnam National University, Daejeon, 34134, Korea.

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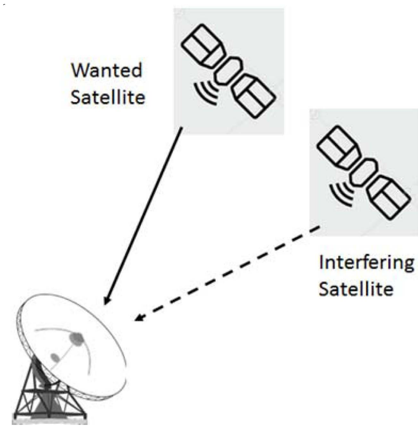

Fig. 1. Downlink ASI from adjacent satellite network.

orthogonal linear polarization (horizontal polarization and vertical polarization) or orthogonal circular polarization (left-hand circularly polarized sense and right-hand circularly polarized sense) is used, the signal from one polarization sense to another may be coupled, resulting in cross-polarization interference. This signal-coupling arises due to the finite value of the cross-polarization discrimination of the earth station. The circular polarization is a polarization state in which, at each point, the electromagnetic field of the wave has a constant magnitude and rotates at a constant rate in a plane perpendicular to the direction of the wave. Linear polarization of electromagnetic radiation confines the electric field vector to a given plane along the propagation direction.

In this study, the electromagnetic field equations used to evaluate the coupling from a circularly polarized signal to a linearly polarized signal were derived.

II. FIELD EQUATIONS TO EVALUATE INTERFERENCE

Electromagnetic field equations used to evaluate the coupling from a circularly polarized signal to a linearly polarized signal were derived.

The case where a satellite with circular polarization illuminates an earth station with linear polarization is considered. Any sense of polarization can be decomposed into two orthogonal polarizations. At the receiving antenna of the earth station, the incident field is [5].

$$\boldsymbol{E}_R = e_R\left(\frac{\hat{\phi}-j\hat{\theta}}{\sqrt{2}}\right) + e_{RX}\left(\frac{\hat{\phi}+j\hat{\theta}}{\sqrt{2}}\right)e^{j\delta_R}, \quad (1)$$

$$\boldsymbol{E}_L = e_L\left(\frac{\hat{\phi}+j\hat{\theta}}{\sqrt{2}}\right) + e_{LX}\left(\frac{\hat{\phi}-j\hat{\theta}}{\sqrt{2}}\right)e^{j\delta_L}. \quad (2)$$

where E_R is the incident electric field vector for a right-hand circularly polarized (RHCP) signal, E_L is the incident electric field vector for a left-hand circularly polarized (LHCP) signal, e is the amplitude of a field with co-polarization., e_X is the amplitude of a field with cross-polarization, ϕ is the horizontal unit vector at the receiving antenna of an earth station, θ is the vertical unit vector at the receiving antenna of an earth station, δ_R is the unknown RHCP phase difference between a cross-polarization field and a co-polarization field, and δ_L is the unknown LHCP phase difference between a cross-polarization field and a co-polarization field.

The signal dependence on time is expressed by $e^{j\omega t}$. It may be assumed that the signals with different polarizations are not correlated to each other.

Each port in the earth-station receiving antenna with linear polarization may be represented as an effective length [4]:

$$\boldsymbol{l}_h = \sqrt{G}\,\hat{\phi} + \sqrt{G_x}\,\hat{\theta}\,e^{j\delta}, \quad (3)$$

$$\boldsymbol{l}_v = \sqrt{G}\,\hat{\theta} + \sqrt{G_x}\,\hat{\phi}\,e^{j\delta}. \quad (4)$$

where G is the receiving antenna gain with co-polarization, G_x is the receiving antenna gain with cross-polarization, and d is an unknown phase difference between the cross-polarization signal voltage and co-polarization signal voltage received at the port of a linearly polarized antenna. The subscript h indicates a horizontally polarized (HP) signal. The subscript v indicates a vertically polarized (VP) signal.

The open-circuit voltage V_{oc} in the received antenna port may be defined as $V_{oc} = \boldsymbol{E}\cdot\boldsymbol{l}$, where $\boldsymbol{l}$ is the effective length vector, and $\boldsymbol{E}$ is the incident electric field vector [3].

In fact, G, G_x, and d usually differ for the two ports of the receiving antenna, that is, the HP port and the VP port. The interference of the receiving antenna port was analyzed. For the two incident electric fields in (1) and (2), i.e., the RHCP and LHCP signals, the received voltages in the HP (h) and VP (v) receive ports are

$$v_{Rh} = \boldsymbol{E}_R\cdot\boldsymbol{l}_h = \sqrt{\frac{G}{2}}(e_R + e_{RX}e^{j\delta_R}) - j\sqrt{\frac{G_x}{2}}e^{j\delta}(e_R - e_{RX}e^{j\delta_R}), \quad (5)$$

$$v_{Lh} = \boldsymbol{E}_L\cdot\boldsymbol{l}_h = \sqrt{\frac{G}{2}}(e_L + e_{LX}e^{j\delta_L}) + j\sqrt{\frac{G_x}{2}}e^{j\delta}(e_L - e_{LX}e^{j\delta_L}), \quad (6)$$

$$v_{Rv} = \boldsymbol{E}_R\cdot\boldsymbol{l}_v = -j\sqrt{\frac{G}{2}}(e_R - e_{RX}e^{j\delta_R}) + \sqrt{\frac{G_x}{2}}e^{j\delta}(e_R + e_{RX}e^{j\delta_R}), \quad (7)$$

$$v_{Lv} = \boldsymbol{E}_L\cdot\boldsymbol{l}_v = j\sqrt{\frac{G}{2}}(e_L - e_{LX}e^{j\delta_L}) + \sqrt{\frac{G_x}{2}}e^{j\delta}(e_L + e_{LX}e^{j\delta_L}), \quad (8)$$

where $v_{Rh(v)}$ is the voltage received horizontally (vertically) at the earth station from the satellite RHCP signal, and $v_{Lh(v)}$ is the voltage received horizontally (vertically) at the earth station from the satellite LHCP signal.

The received signal power in the HP port depends on the sum of the squares of the voltage magnitudes.

$$|v_{Rh}|^2 + |v_{Lh}|^2 = (G/2)(e_R^2 + e_L^2 + e_{RX}^2 + e_{LX}^2) + (G_x/2)(e_R^2 + e_L^2) + G(e_R e_{RX} \cos \delta_R + e_L e_{LX} \cos \delta_L) + \sqrt{GG_x}(e_R^2 - e_L^2) \sin \delta - 2\sqrt{GG_x}(e_R e_{RX} \sin \delta_R - e_L e_{LX} \sin \delta_L) \cos \delta \tag{9}$$

The product of the cross-polarization of both antennas will be the smallest when considering the actual cross-polarization performance. Thus, some terms by the squares of the voltage magnitudes are extremely small to the extent that they can be ignored. The power in the horizontal polarization receiving port depends on (9).

Similarly, the power of the port receiving the vertical polarization is proportional to

$$|v_{Rv}|^2 + |v_{Lv}|^2 = (G/2)(e_R^2 + e_L^2 + e_{RX}^2 + e_{LX}^2) + (G_x/2)(e_R^2 + e_L^2) - G(e_R e_{RX} \cos \delta_R + e_L e_{LX} \cos \delta_L) - \sqrt{GG_x}(e_R^2 - e_L^2) \sin \delta - .2\sqrt{GG_x}(e_R e_{RX} \sin \delta_R - e_L e_{LX} \sin \delta_L) \cos \delta \ . \tag{10}$$

III. DOWNLINK ANALYSIS

This analysis is based on processing the electric field at the output port of the antenna receiving the dual polarizations, representing the incident electric signal in terms of dual orthogonal polarization components. It is assumed that the magnitudes of the dual orthogonally polarized interfering signals are the same. The analysis considers the relative effect of different polarization senses on adjacent satellites compared to when two satellites use the same polarization senses. The reference situation is when all adjacent satellites use linear polarization for comparison. The satellite downlink, in which a satellite with circular polarization interferes with an earth station with linear polarization, is analyzed as follows.

To analyze the effect of a satellite with circular polarization on an earth station with linear polarization, the following conditions are assumed.

1) For each polarization, the electric signal amplitude is assumed to be the same, that is, $e_R = e_L = e$. A difference in the co-polarization levels of the satellite may be undesirable as it may create interference. The cross-polarization interference (XPI) cancelation of the earth station occurs if the dual polarization signals are transmitted from a single satellite or co-located satellites. Otherwise, this would be a significant downlink contribution for d = ±90 °.

2) The cross-polarization component of a satellite may be defined by cross-polar discrimination (XPD), i.e., $e_{RX} = e_{LX} = e/\sqrt{XPD}$. XPD is the difference between the co-polarization gain and the cross-polarization gain of an antenna. It is unrealistic to assume that cross-polarization peaks occur at the same location and same frequency for the two circular polarization orientations of the satellite. With a satellite antenna XPD of approximately 30 dB, the antenna off-axis cross-polarization gain of an earth station dominates the cross-polarization effect [6].

3) G and Gx denote the co-polarization and cross-polarization gains of an earth station antenna, respectively. Typically, the value of Gx will be in the range of 19 – 25 log(q) and that of G will be 10 dB higher than Gx [7].

Typically, the satellite XPD is approximately 27 – 30 dB and, the XPD of an earth station near the main beam can be assumed to be 10 dB. It will decrease as the beam moves away from the main beam. Therefore, the cross-polarization of the earth station contributes more to the total adjacent satellite interference (ASI) than to the satellite cross-polarization.

Substituting these assumptions with (9) and (10) gives an expression for the received power at the two ports of the antenna of the earth station as a function of the phase differences δ_R, δ_L, and δ. These phase differences can significantly affect the interference. The interference for the phase difference is limited, as follows:

$$|v_R|^2 + |v_L|^2_{\frac{worst}{best} case} = (G + G_x)e^2 \pm 2\sqrt{\frac{G(G+4G_x)}{XPD}} e^2 + \frac{G}{XPD} e^2 \ . \tag{11}$$

In the worst case, the upper sign "+" is applied and, in the best case, the lower sign "-" is applied. The mean interference is the sum of the first and third terms on the right-hand side of Equation (11). For the HP port, the worst-case interference occurs near $\delta_R \approx 0^o \approx \delta_L$, and the best case interference occurs near $\delta_R \approx 180^o \approx \delta_L$. For the VP port, it is the opposite; i.e., the worst-case interference occurs near $\delta_R \approx 180^o \approx \delta_L$, and the best case interference occurs near $\delta_R \approx 0^o \approx \delta_L$. The reason is that in the worst case, e and e_X are added but, in the best case, e and e_X are subtracted. Equation (11) shows that, on average, there is no degradation compared to a linearly polarized system and if one polarization at the receiving port is degraded, the performance at the other port is better than the average case.

IV. RESULTS AND DISCUSSION

A CP system interfering with an LP system was simulated. The worst-case downlink interference comparing an adjacent CP system interfered by an LP system with another LP system interfered by an LP system is shown as a function of the antenna XPD in satellite for various off-axis cross polarizations of the earth station in Fig. 2.

If the satellite antenna XPD is approximately 30 dB, regardless of the operating mode of the LP or CP, the interference of cross-polarization from two adjacent satellite networks essentially depends on the antenna off-axis cross-polar gain of the earth station. For a low level of satellite cross-polarization, the worst-case downlink interference is negligible.

For a perfect cross-polarization alignment, the power received by an LP earth station from a dual LP satellite is proportional to

$$|v_H|^2 + |v_V|^2{}_{\frac{worst\ case}{best\ case}}$$

$$= (G + G_x)e^2 \pm 4\sqrt{\frac{GG_x}{XPD}}e^2 + \frac{G}{XPD}e^2. \qquad (12)$$

The division of (9) by (10) is shown in Fig. 2. The result — i.e., interference — can be written as

Interference

$$\text{Interference} = \frac{(1/2)(1 + G_x/G + 1/XPD)\sqrt{XPD} + \sqrt{1 + 4G_x/G}}{(1/2)(1 + G_x/G + 1/XPD)\sqrt{XPD} + \sqrt{4G_x/G}}, \qquad (13)$$

where G_x/G is the ratio of the cross-polar gain to the co-polarization gain of an earth station antenna. G_x/G was calculated using only the relative values of G and G_x.

If the cross-polarization peak coincides with the co-polarization peak for both polarization senses of the earth station, downlink interference will occur in the worst case. In other words, the co-polarization interference and cross-polarization interference will be totaled in-phase at the polarization port of the satellite antenna. Moreover, the average interference of an LP system by a CP system is equal to the interference of an LP system by an LP system. The antenna may physically constrain the phase relationship between the cross-polarization and co-polarization of the earth station; i.e., the cross-polarization produced at the reflector edge is generally in quadrature to the co-polarization. Because the cross-polarization by diffraction at the reflector edge usually provides a peak at the co-polarization nulls, the cross-polarization peaks barely occur at the location of the cavity polarization peak.

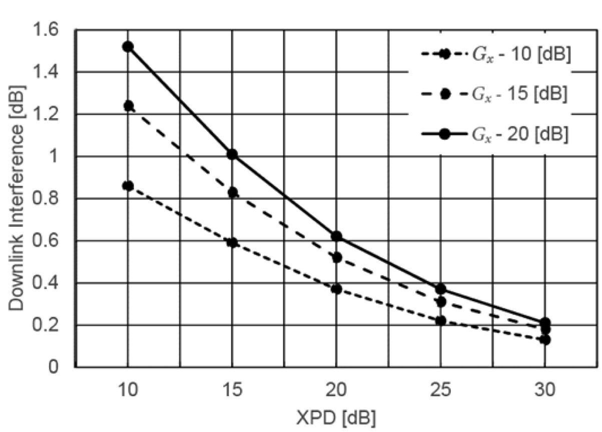

Fig. 2. Worst-case downlink interference levels of an LP system by an adjacent CP system.

V. CONCLUSIONS

If the magnitude of the interfering signal is equal to the magnitude of the interfering signal orthogonal to it, the difference between the worst-case downlink interference from the adjacent CP system to the LP system and the interference from the adjacent LP system to the LP system can be neglected. The interference due to cross-polarization of the earth station antenna is canceled out at the earth station antenna polarization port.

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Won Jun Choi
received the M.S. degree from the department of atmospheric science in Yonsei University in Korea in 2004.
He is currently a researcher at the National Institute of Environmental Research (NIER) in Incheon, Korea, since 2005. He is working on the overall project for air quality monitoring using Geostationary Environment Monitoring Spectrometer (GEMS) and on building segments of GEMS from the beginning of GEMS.
He has contributed to drafting an air quality monitoring plan using space technologies in the environmental field.
Currently, he is working for establishment network in Asian region to validate GEMS data.

Dong-Won Lee
received the Ph.D. degree from the department of environmental science & engineering in Kyung Hee University in Korea. He is currently a researcher at the National Institute of Environmental Research (NIER) in Incheon, Korea. He also performed air quality measurements.
He is currently the director of the environmental satellite center in NIER. His research interests are GEMS operation, verification, utilization, and research.

Jong Won Eun
started working at NASA's Marshall Space Flight Center in the U.S., as a satellite communication systems engineer after completing his M. S. and Ph.D. degrees in physics from Utah State University in 1982 and 1987, respectively. He joined the ETRI (Electronics and Telecommunications Research Institute), Daejon, Korea in 1989.
He was a professor at the department of Information and Communication Engineering at Namseoul University, Cheonan, Korea from Feb. 1998 to Sep. 2009. He has been working as a director general of the Satellite-Information Convergence Research Center at Namseoul University since Mar. 1998.
His research interests are signal processing for satellite communications and next generation environmental monitoring satellite systems.

Jae-Hyun Lee
received the B.S. degree in electronic engineering from Inha University, Incheon, Korea, in 1982. He received the M.S. and Ph.D. degrees in electrical and electronic engineering from KAIST, Seoul, Korea, in 1985 and 1993, respectively.
From 1991 to 2001, he worked as a Senior Researcher with the Satellite Research Division, ETRI (Electronics and Telecommunications Research Institute), Daejeon, Korea. Since 2001, he has been a professor at the Department of Radio and Information Communications Engineering, Chungnam National University, Daejeon, Korea.
His research interests are electromagnetic compatibility, system and microwave passive components for satellite, and microwave signal processing devices.