Study of Channel Interference Between Two Satellites Employing Orthogonal Polarization

Sang Gyu Lee [1], Dae Hyung Lee [2], #Sung Woong Ra [3] and Song Jae Lee [4]
[1]*KARI, Korea Aerospace Research Institute*
45 Eoeun-Dong, Yuseong, Daejeon, 305-333, Korea, sglee@kari.re.kr
[2,3,4]*Chungnam National University, Department of Electronics Engineering*
220 Gung-Dong, Yuseong, Daejeon, 305-764, Korea, dpseo@cnu.ac.kr [2], swra@cnu.ac.kr [3] and sjlee@cnu.ac.kr [4]

Abstract

The depolarization-induced interference between two orthogonally polarized channels belonging to two different satellites is analyzed assuming the two channels with different power spectral density share some of the bandwidth. The equivalent white Gaussian noise generated in the shared spectral region is presumed to spread uniformly over the whole channel bandwidth with an appropriately adjusted noise power spectral density. In this manner we generalized XPD formula and obtained effective signal attenuation due to cross-channel interference between two satellites operating at not far-off center frequencies with orthogonal polarization.

1. INTRODUCTION

In this paper, we present an analysis of the interference between two channels belonging to two separate communication satellites. The channel interference between two satellites may become an important issue soon, as the space becomes more crowded with increasing number of satellites and, at the same time, the demand for high speed data transmission that requires a wider channel bandwidth increases ever more.

Fig. 1 shows a two-satellite interference configuration, in which a satellite channel is interfered by another channel belonging to a different satellite. The most fundamental approaches to minimize the channel interference may be: 1) to reduce the spectral bandwidth shared by the two channels; 2) to reduce the antenna beam overlap between two satellites; 3) to allocate mutually orthogonal polarizations to the satellites involved. In this study, we would consider only the case in which mutually orthogonal polarizations are employed. The configuration employing the same polarization may not be very interesting in practical sense, since in this case the interference between two channels would be always much more severe, requiring either very high gain antennas or much more rigorous bandwidth management, compared to the case employing orthogonal polarizations.

It is believed that not much work has been done regarding the depolarization-induced interference between two-satellite channels. Some relevant works may be the ones reported in [1], [2] and [3]. Arun Kumar Sigh et al. [3] presented some experimental results showing, without detailed analysis, that the depolarization effect could be reduced by offsetting the center frequencies of two channels. One of the most important works regarding the depolarization-induced interference may be the analysis of the dual-polarized frequency reuse systems by Hugues Vasseur [4]. In the dual-polarized systems, however, the two orthogonally polarized channels share the whole bandwidth, rather than a fraction of the bandwidth, and have an equal power level, and thus, the results may not be directly applicable to the two-satellite channel interference problem. Recently Lee et al. [5], [6] have analyzed the depolarization effect in dual-polarized system employing frequency offset between two channels. In their case, the two channels were assumed to share only a fraction of the bandwidth and have an equal power level. In this paper, the approach by Lee et al. would be extended to analyze the more generalized depolarization-induced interference cases, in which two interfering channels have arbitrary power levels as well as arbitrary center frequencies.

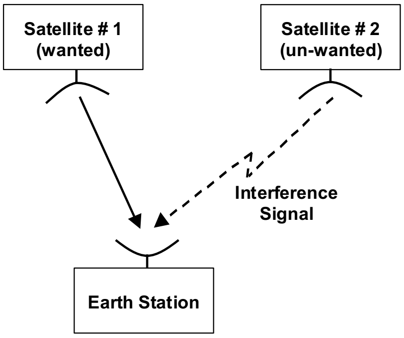

Fig. 1: Channel interference between two satellites

2. DEPOLARIZATION BETWEEN ADJACENT SATELLITES

A. Previous XPD Models

It is well known that even the orthogonally polarized channels suffer the channel interference due to the depolarization effect

---

Some of the results reported in this paper are based on the works of KOMPSAT3 and BK21 program, which are being supported by MOST (Ministry of Science and Technology) and MOE & HRD (Ministry of Education and Human Resources Development) of Korea, respectively.

caused by hydrometeors such as rain drops or ice particles in the RF signal transmission path. The degree of the depolarization is often specified by cross-polarization discrimination (XPD), which is defined by the ratio of the received co-polar signal to the received cross-polar signal and corresponds to the ratio of carrier-to-cross-polarization interference, i.e., *C/I*. There have been many works to estimate XPD theoretically or empirically [7], [8], [9], [10]. Probably the most well-known formula for XPD may be the one recommended by ITU [8], which, in the time period of no more than p % of the time, is expressed by

$$\begin{aligned} XPD = \{&30\log(f) - V(f)\log(CPA) \\ &-10\log[1-0.484(1+\cos 4\tau)] \\ &-40\log[\cos(EL)] + 0.0052\sigma^2\} \\ &\times\{1-[0.3+0.1\log(p)]\div 2\} \end{aligned} \tag{1}$$

where f, CPA, τ, EL, σ and p are operating frequency, co-polar attenuation [11], polarization factor, elevation angle, effective standard deviation of the raindrop canting angle, % of time at the frequency (f), respectively, and $V(f)$ is frequency dependent values of $12.8f^{0.19}$ ($8 \le f \le 20$ GHz) and 22.6 ($20 < f \le 35$ GHz). It is noted that the XPD formula given in (1) is for two orthogonally polarized single frequency sinusoidal signals of an equal power.

The co-polar signal components resulting from the depolarization of the cross-polar signals were often considered as a white Gaussian noise (*AWGN*), which causes an extra signal attenuation in addition to the co-polar attenuation (*CPA*) [4], [12]. The depolarization-induced attenuation A_{XP} in dual-polarized systems can be related to the reduction in E_b/N_o (expressed in decibels), i.e. the energy per bit to single-sided noise power spectral density as

$$\frac{E_b}{N_o} = \left(\frac{E_b}{N_o}\right)_{nom} - CPA - A_{XP} \tag{2}$$

$$A_{XP} = 10\log_{10}\left\{ 1 + \Gamma 10^{\left[(E_b/N_o)_{nom} - CPA - XPD\right]/10} \right\} \tag{3}$$

where $(E_b/N_o)_{nom}$ denotes the E_b/N_o obtained under nominal condition, in which no particular intermittent propagation impairments exist, and Γ (expressed in bits/sec/Hz) is the spectral efficiency of channel involved.

B. Generalization of XPD

Fig. 2 depicts the reference channel of channel R of bandwidth B, center frequency f_r, power spectral density C, which is interfered by an adjacent satellite channel with orthogonal polarization and power spectral density C_{adj}. In the figure, B_I denotes the width of spectral band shared by two channels. It is noted that the channel R consists of two types of spectral regions, one of width $(B - B_I)$ suffering only the co-polar attenuation and the other of width B_I suffering not only the CPA but also the degradation due to depolarization.

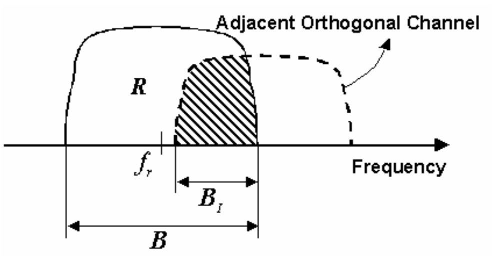

Fig. 2: Spectrum distribution of two orthogonally polarized interfering channels

In the dual-polarized system in which the whole bandwidth of the co-polar channel is shared by the cross-polar channel, the depolarization-induced interference would occur over the whole bandwidth. The equivalent noise due to depolarization-induced interference may be considered as an additive white Gaussian noise (*AWGN*) with a single sided power spectral density of I_o [4], [12]. In our case, however, the depolarization-induced interference would occur only over the shared spectral region of width B_I. For the sake of convenience, however, we presume that the equivalent channel interference noise spreads uniformly over the whole bandwidth of B. It is noted, however, that the uniform spreading of the interference noise over the whole bandwidth should be compensated by scaling down appropriately the intensity of equivalent interference noise. In this study, the equivalent depolarization-induced interference noise is scaled down from I_o to $(B_I/B)(C_{adj}/C)I_o$, assuming that firstly the interference noise generated in the shared spectral region is proportional to the power spectral density of the interfering cross-polar signal C_{adj} and secondly the generated noise spreads uniformly over the whole bandwidth. This *AWGN*-like depolarization-induced noise would then be simply added to the inherent system noise N_o. Thus, the overall ratio of the energy per bit to single-sided noise power spectral density would be reduced to $E_b/[N_o+(B_I/B)(C_{adj}/C)I_o]$. The reduction in the ratio of the energy-per-bit to the depolarization-induced interference power spectral density may be expressed in dB scale by

$$\begin{aligned} \left(\frac{E_b}{I_o}\right) &= \left(\frac{C}{I}\right) + 10\log_{10}\left(\frac{B}{D}\right) + 10\log_{10}\left(\frac{B}{B_I}\right) + 10\log_{10}\left(\frac{C}{C_{adj}}\right) \\ &= XPD - 10\log_{10}(\Gamma) + 10\log_{10}\left(\frac{B}{B_I}\right) + 10\log_{10}\left(\frac{C}{C_{adj}}\right) \end{aligned} \tag{4}$$

where D (expressed in bits/second) is the binary transmission rate, *C/I*, the carrier-to-interference power ratio is replaced by XPD, and (C/C_{adj}) denotes power ratio, i.e., the ratio of the reference channel power to the interfering channel power. We note, in (4), that Γ is a constant while the third term

$10\log_{10}(B/B_I)$ and the fourth term $10\log_{10}(C/C_{adj})$ depends sensitively on the degree of the spectral overlap of the channel and the power level of the interfering channel, respectively. Thus, the terms, $10\log_{10}(B/B_I)$ and $10\log_{10}(C/C_{adj})$ may be interpreted as the improvement factors of XPD over that in dual-polarized system, which are related to the width of the shared bandwidth and to the power level of the interfering channel, respectively.

From the above reasoning, we may introduce a generalized form of XPD denoted by XPD_{FOI}, which is defined by

$$XPD_{FOI} = XPD + 10\log_{10}\left(\frac{B}{B_I}\right) + 10\log_{10}\left(\frac{C}{C_{adj}}\right) \qquad (5)$$

where XPD corresponds to value of XPD in dual-polarized system in which the bandwidth is completely shared by the interfering channel, and therefore it should be evaluated, for instance, by (1).

C. Signal Attenuation Due To Channel Interference

If we let (E_b/N_o) be the ratio of the energy-per-bit to overall noise, including the depolarization-induced interference noise, for the received signal of channel R, it may be expressed by

$$\left(\frac{E_b}{N_o}\right) = -10\log_{10}[10^{\frac{-\left(\frac{E_b}{N_o}\right)_S}{10}} + 10^{\frac{-\left(\frac{E_b}{I_o}\right)}{10}}] \qquad (6)$$

where $(E_b/N_o)_S$ denotes the E_b/N_o ratio for the single-polarized system of width B in the R-channel that is affected by only co-polar attenuation (CPA) and may be expressed by $[(E_b/N_o)_{nom} - CPA]$. Therefore, (6) may be then expressed, as similarly as in (2), by

$$\left(\frac{E_b}{N_o}\right) = \left(\frac{E_b}{N_o}\right)_{nom} - CPA - A_I \qquad (7)$$

where A_I denotes the effective attenuation in received signal R due to depolarization-induced channel interference, which is incurred additionally over CPA in the single channel systems. Thus, inserting (4) into (6), we obtain A_I given by

$$A_I = 10\log_{10}\left\{\ 1 + \Gamma \cdot 10^{[(E_b/N_o)_{nom} - CPA - XPD_{FOI}\ ]/10}\right\}. \qquad (8)$$

3. SIMULATION AND RESULTS

For the simulation, we assumed the two orthogonally polarized satellites in Fig. 1 are located adjacent to each other; the reference channel R belongs to satellite 1 and interfering channel belongs satellite 2. The design for the channel R is assumed as a typical X-band downlink for Earth Exploration Satellites Service (EESS) [13] with nominal orbit of 685 km heights and instantaneous elevation angle of 5°. The EIRP of satellite 1 is assumed to be 21 dBW using circular polarization antenna (τ = 45°). Some important parameters for the assumed QPSK channel are: f_r = 8,185 MHz, B = 320 MHz, and Γ = 1 bits/sec/Hz with 320 Mbps data transmission rate.

With those data assumed, $(E_b/N_o)_{nom}$ for satellite 1 was calculated to be 16.16 dB. Fig. 3 shows XPD_{FOI} evaluated as a function of the shared spectral width B_I, which is calculated using the XPD values evaluated by (1) and ITU-R CPA model at region K [11], assuming that two-channels have the same power level. It is noted in Fig. 3 that XPD_{FOI} becomes infinity when two channels are completely separated ($B_I = 0$). And, as expected, XPD_{FOI} becomes equal to the XPD when the channel R is completely shared by the interfering channel ($B_I = B$). For example, when B_I = 320 MHz = B, both XPD and XPD_{FOI} were calculated to have the same values of 27.39 dB, 23.42 dB and 16.12 dB, for clear weather, 1 % of time and 0.1 % of time, respectively.

Fig. 4 shows the effective attenuation A_I of received signal R, due to depolarization, when the two-channels have the same power level, i.e., power ratio (C/C_{adj}) = 1. In the calculation, we assumed that $(E_b/N_o)_{nom2}$, i.e. E_b/N_o obtained under nominal condition for satellite 2 is the same as $(E_b/N_o)_{nom}$ of 16.16 dB.

Fig. 5 shows A_I of received signal R as a function of the power ratio (C/C_{adj}) with B_I of 40 MHz. And the result clearly shows that the performance of reference channel degrades rapidly as the power level of interfering channel increases over that of the reference channel R.

4. CONCLUSIONS

We have analyzed the effect of depolarization-induced interference between two orthogonally polarized channels belonging to different satellites and obtained a generalized XPD formula, which is applicable to the cases in which two interfering channels have different power levels and center frequencies. The generalized XPD formula would be useful to evaluate E_b/N_o of the received signal, which is essential for link-budget analysis.

In addition, the results from this study may find some important usage in managing effectively the limited satellite communication resources [14], especially in terms of orbit and spectrum.

REFERENCES

[1] A. D. Panagopoulos and J. D. Kanellopoulos, “Optimum Utilization of the Channel Capacity of a Dual Polarized Satellite Link Suffering from Interference Due to Atmospheric Precipitation,” XXVIIth URSI General Assembly 2002 EF.P.8 (2175), Maastricht, Netherlands, Aug. 17th ~ 24th, 2002.

[2] J. D. Kanellopoulos and V. K. Katsambas, “Degradation of the carrier-to-interference ratio (C/I) of an earth-space system using frequency re-use due to interference induced by an adjacent dual polarized satellite system,” ICAP 2003, CP491, pp. 816 ~ 819, Mar., 2003.

[3] Arun Kumar Singh, J. K. Hota, A. K. Sisodia and V. K. Garg, “Co-Channel Interference Analysis for Digital Modulation Systems in Co-Located Satellites,” XXVIIIth URSI General Assembly 2005 EC.5 (0640), New Delhi India , Oct. 23rd ~ 29th, 2005.

[4] Hugues Vasseure, “Degradation of Availability Performance in Dual-Polarized Satellite Communications Systems,” IEEE Trans. On Comm. Vol. 48. No3, pp 465 ~ 472, Mar., 2000.

[5] Sang Gyu Lee, Sung Woong Ra and Song Jae Lee, “Depolarization Mitigation using Frequency Offset in the Dual-Polarized X-Band for EESS,” IWSSC06, Sep. 14th, 2006.

[6] Sang Gyu Lee, Sung Woong Ra and Song Jae Lee, “Generalization of XPD formula for Partially Overlapped Dual-Polarized Channels,” IEEE Comm. Letters, Jul., 2006. Submitted.

[7] Max M. J. L. van de Kamp, “Separation of Simultaneous Rain and Ice Depolarization,” IEEE Trans. on Antennas and Propagation Vol. 52, No. 2, pp 513 ~ 523, Feb., 2004.

[8] ITU-R P.618-8, “Propagation Data and Prediction Methods Required for the Design of Earth-Space Telecommunications Systems,” 2003.

[9] W. L. Stutzman and D. L. Runyon, “The Relation of Rain-Induced Cross-Polarization Discrimination to Attenuation for 10 to 30 GHz Earth-Space Radio Links,” IEEE Trans. on Antennas and Propagation Vol. AP-32, No. 7, pp 705 ~ 710, Jul., 1984.

[10] Max M. J. L. van de Kamp, “Depolarization due to Rain: the XPD-CPA Relation,” International Journal of Satellite Communications Vol. 19, pp. 285 ~ 301, 2001.

[11] ITU-R PN.838-2, “Specific attenuation model for rain for use in prediction methods,” 2003.

[12] C. Weil and R. Jakoby, “Impact of depolarization on dual-polarized Ka-band Satellite Systems,” AR98_36 pp. 91 ~ 95, Annual Report, Darmstadt Univ. of Tech., 1998.

[13] SFCG Rec. 14-3 R7, “Use of the 8025 - 8400 MHz Band by Earth Exploration Satellites,” Oct., 2005.

[14] Luca Simone Ronga, “Transmission and Resource Management Techniques for New Satellite Service: a COST272 Perspective,” PM5-076 of COST280 2nd International Workshop, ESTEC in Noordwijk, Holland, May. 26th ~ 28th, 2003.

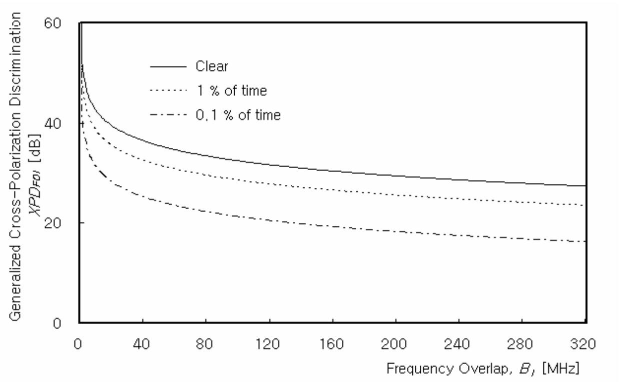

Fig. 3: Generalized XPD as a function of the shared spectral width B_I (power ratio, C/C_{adj} =1)

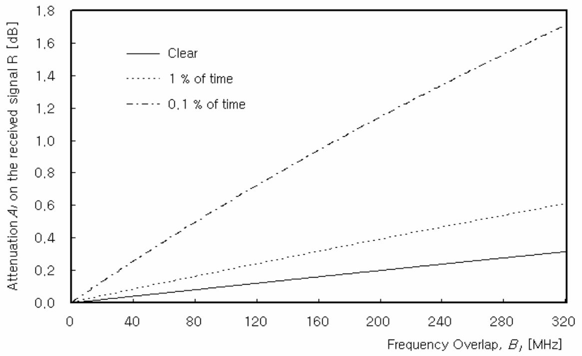

Fig. 4: Effective attenuation A_I as a function of the shared spectral width B_I (power ratio, C/C_{adj} =1)

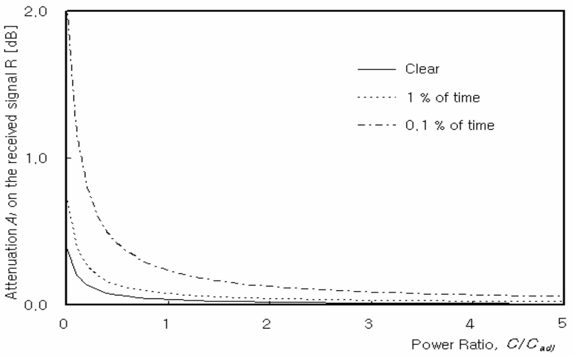

Fig. 5: Effective attenuation A_I as a function of power ratio (B_I = 40 MHz)