

# Study of Channel Interference Between Two Satellites Employing Orthogonal Polarization

Sang Gyu Lee<sup>1</sup>, Dae Hyung Lee<sup>2</sup>, #Sung Woong Ra<sup>3</sup> and Song Jae Lee<sup>4</sup>

<sup>1</sup>KARI, Korea Aerospace Research Institute

45 Eoeun-Dong, Yuseong, Daejeon, 305-333, Korea, [sglee@kari.re.kr](mailto:sglee@kari.re.kr)

<sup>2,3,4</sup>Chungnam National University, Department of Electronics Engineering

220 Gung-Dong, Yuseong, Daejeon, 305-764, Korea, [dpseo@cnu.ac.kr](mailto:dpseo@cnu.ac.kr)<sup>2</sup>, [swra@cnu.ac.kr](mailto:swra@cnu.ac.kr)<sup>3</sup> and [sjlee@cnu.ac.kr](mailto:sjlee@cnu.ac.kr)<sup>4</sup>

## 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.

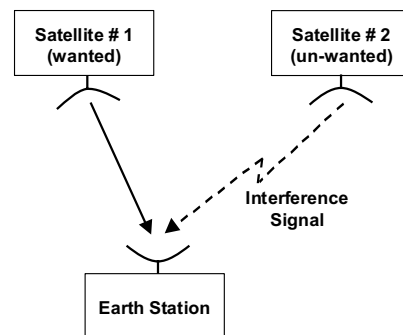


Fig. 1: Channel interference between two satellites

## 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

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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

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

where  $f$ ,  $CPA$ ,  $\tau$ ,  $EL$ ,  $\sigma$  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  $12.8f^{0.19}$  ( $8 \leq f \leq 20$  GHz) and  $22.6$  ( $20 < f \leq 35$  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

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

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

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  $\Gamma$  (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

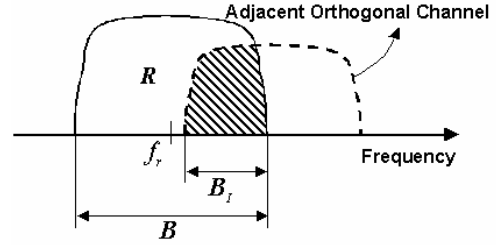


Fig. 2: Spectrum distribution of two orthogonally polarized interfering channels

co-polar attenuation and the other of width  $B_I$  suffering not only the CPA but also the degradation due to depolarization.

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

$$\left( \frac{E_b}{I_o} \right) = \left( \frac{C}{I} \right) + 10 \log_{10} \left( \frac{B}{D} \right) + 10 \log_{10} \left( \frac{B}{B_I} \right) + 10 \log_{10} \left( \frac{C}{C_{adj}} \right) \quad (4)$$

$$= XPD - 10 \log_{10}(\Gamma) + 10 \log_{10} \left( \frac{B}{B_I} \right) + 10 \log_{10} \left( \frac{C}{C_{adj}} \right)$$

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  $\Gamma$  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

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

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

$$\left(\frac{E_b}{N_o}\right) = -10\log_{10}\left[10^{\frac{-(E_b/N_o)_s}{10}} + 10^{\frac{-(E_b/N_o)_I}{10}}\right] \quad (6)$$

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

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

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

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

### 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  $5^\circ$ .

The EIRP of satellite 1 is assumed to be 21 dBW using circular polarization antenna ( $\tau = 45^\circ$ ). Some important parameters for the assumed QPSK channel are:  $f_r = 8,185$  MHz,  $B = 320$  MHz, and  $\Gamma = 1$  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.

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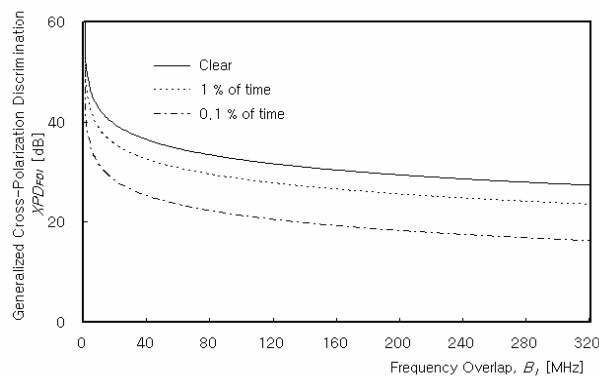


Fig. 3: Generalized XPD as a function of the shared spectral width  $B_I$  (power ratio,  $C/C_{adj} = 1$ )

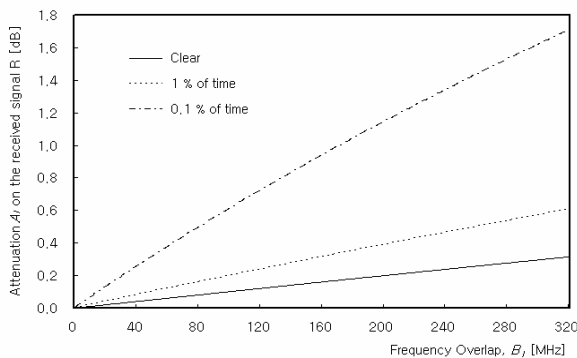


Fig. 4: Effective attenuation  $A_I$  as a function of the shared spectral width  $B_I$  (power ratio,  $C/C_{adj} = 1$ )

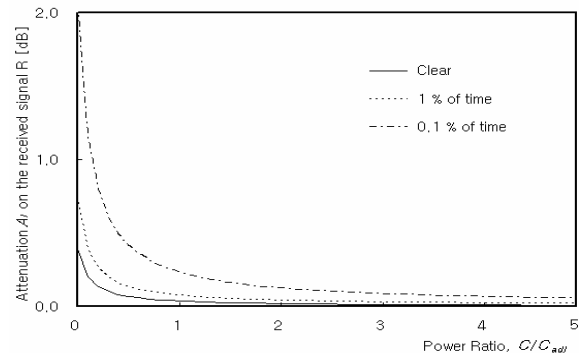


Fig. 5: Effective attenuation  $A_I$  as a function of power ratio ( $B_I = 40$  MHz)