ANALYSIS ON THE INFLUENCE OF XPD IN DUAL-POLARIZED TRANSMISSION

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ABSTRACT: Dual-polarized transmission is one of the effective methods to transmit such a high speed data thanks to two independent channel leads to the orthogonal feature between RHCP (Right-Hand Circular Polarization) and LHCP (Left-Hand Circular Polarization). However, in practical case, the transmitted signal by RHCP polarized antenna in satellite can be occurred at the output port of LHCP polarized antenna in ground station, vice versa. XPD (Cross-Polarization Discrimination) is the ratio of the signal level at the output of a receiving antenna that is nominally co-polarized to the transmitting antenna to the output of a receiving antenna of the same gain but nominally orthogonally polarized to the transmitting antenna. In this paper, the detailed estimation of XPD within the interface between satellite and ground station is written and the influence of XPD to link performance is also described.

KEY WORDS: Polarization, XPD, RHCP, LHCP

1. INTRODUCTION

It is the worldwide trend that satellite needs to transmit a large amount of data resulted from high resolution of optical camera. Because there is a limitation of contact time in the case of LEO (Low Earth Orbit) satellite, transmission has to be accomplished with high datarate which means the data size to be transmitted in on second. To estimate data for a high resolution and quantization, KOMPSAT-1 can be taken as an example. Figure 1 shows the scanning of EOC (Earth Observing Camera) sensor in KOMPSAT-1.

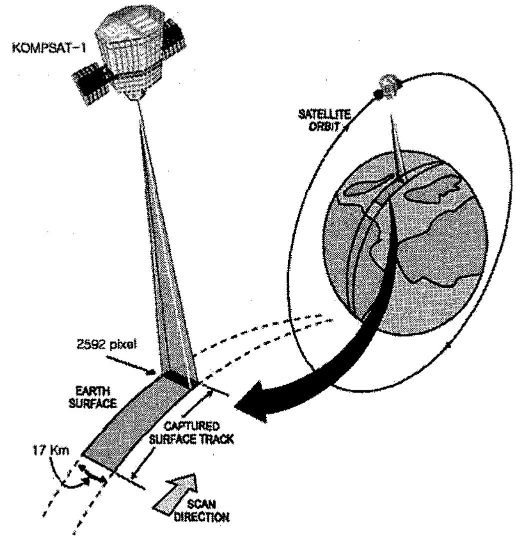

Figure 1 Scan mirroring of EOC sensor in KOMPSAT-1

From the 2592 pixel per swath, 17Km, the resolution is calculated as 6.6m by diving 17Km with 2592 pixel. Because a pixel is quantized as 8 bits, size of source packet is 2605 bytes including 13 bytes of header. The number of packet within one second is estimated by the satellite's speed on ground. The VCDU (Virtual Channel Data Unit) data zone is 212 bytes estimated by subtracting Reed-Solomon check symbols (255/223, virtual fill = 1) and ASM (Attached Sync Marker) form CADU (Channel Access Data Unit) which size is 256 bytes. Table 1 illustrates the data size is about 1.18 Gbps when only the resolution of KOMPSAT-1 is assumed as 1m.

Table 1 Increased data size by 1m of resolution

No	Parameters	Real value	Assumed Value
1	Swath	17Km	17Km
2	Focal Plane Array	2592	17000
3	Resolution (No.1/No.2)	17Km/2592 ≅ 6.6m	17Km/17000 = 1m
4	Quantization	8 bits	8 bits
5	Satellite Speed on Ground	6.8Km	6.8Km
6	Number of EOC source packet per second (No.5/No.3)	6.8Km/6.6m ≅ 1024	6.8Km/1.0m = 6800
7	Generated EOC data per second (source frame length × No.6)	(2592+13)× 1024×8 = 2,667,520×8 = 21,340,160 bits	(17000+13)× 1024×8 = 115,688,400×8 = 925,507,200 Bits
8	Number of CADU per second (No.7/212)	2,667,520 / 212 = 12,583	115,688,400 / 212 = 545,700
9	Total Data Size (No.8 × 256)	12,583 × 256 × 8 = **25.77Mbps**	545,700 × 256 × 8 = **1,117.6Mbps**

When modulation is OQPSK and roll-off factor of RRC (Root-Raised Cosine) filter is 0.5, the required bandwidth is about 885MHz. Unfortunately, the available

X-Band frequency bandwidth is about 500 ~ 700MHz due to the allocation of ITU (International Telecommunication Unions) and technical limitation of antenna system. To send a higher speed data than allocated bandwidth, bandwidth-effective method is needed. Dual-polarized transmission is one of the effective methods to transmit such a high speed data thanks to two independent channel leads to the orthogonal feature between RHCP (Right-Hand Circular Polarization) and LHCP (Left-Hand Circular Polarization). However, in practical case, the transmitted data by RHCP polarized antenna in satellite can be occurred at the output port of LHCP polarized antenna in ground station, vice versa. XPD (Cross-Polarization Discrimination) is the ratio of the signal level at the output of a receiving antenna that is nominally co-polarized to the transmitting antenna to the output of a receiving antenna of the same gain but nominally orthogonally polarized to the transmitting antenna. Because the worse XPD leads to the degradation of receiving performance, it is important to know the influence of XPD in the interface between satellite and ground. In this paper, the calculation of XPD performed by dividing satellite, ground and atmosphere was described after showing the theory related to axial ratio of antenna. Finally, link analysis was explained by using link parameters of KOMPSAT-2 except dual-polarized transmission.

2. XPD OF SATELLITE, GROUND AND ATMOSPHERE

Figure 2 shows the meaning of XPD in the case RHCP antenna receives both RHCP and LHCP signal transmitted from satellite antenna. The co-polarized signal, RHCP_CRX and the cross-polarized signal, RHCP_IRX is estimated as following equation, respectively. [1]

$$RHCP\_C_{Rx} = \frac{(1+AR_{Tx}^2)(1+AR_{Rx}^2)+4AR_{Tx}\cdot AR_{Rx}+(1-AR_{Tx}^2)(1-AR_{Rx}^2)Cos(2\Delta\theta)}{2(1+AR_{Tx}^2)(1+AR_{Rx}^2)}$$

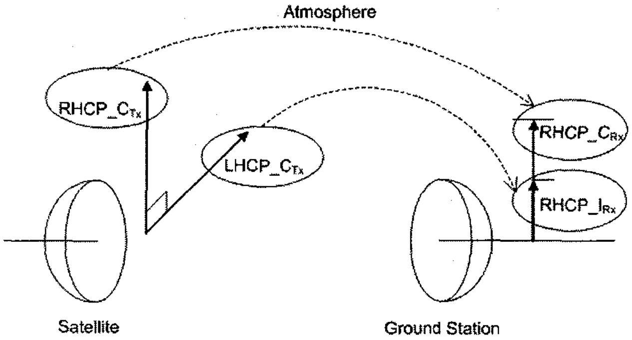

Figure 2 Illustration of XPD

$$RHCP\_I_{Rx} = \frac{(1+AR_{Tx}^2)(1+AR_{Rx}^2)-4AR_{Tx}\cdot AR_{Rx}+(1-AR_{Tx}^2)(1-AR_{Rx}^2)Cos(2\Delta\theta)}{2(1+AR_{Tx}^2)(1+AR_{Rx}^2)}$$

where, AR_{TX} and AR_{RX} is the axial ratio related to the shape of elliptic in satellite antenna and ground antenna, respectively. Δθ means the angle difference between the direction of long axial in satellite antenna and that of long axial in ground antenna. From the above two equation, XPD can be expressed as followings.

$$XPD = \frac{RHCP\_C_{Rx}}{RHCP\_I_{Rx}} = \frac{(1+AR_{Tx}^2)(1+AR_{Rx}^2)+4AR_{Tx}\cdot AR_{Rx}+(1-AR_{Tx}^2)(1-AR_{Rx}^2)Cos(2\Delta\theta)}{(1+AR_{Tx}^2)(1+AR_{Rx}^2)-4AR_{Tx}\cdot AR_{Rx}+(1-AR_{Tx}^2)(1-AR_{Rx}^2)Cos(2\Delta\theta)}$$

Figure 3 show the combination of XPD generated in the interface between satellite and ground station. If all interferences expressed as "I" are considered as independent each other, total XPD from the viewpoint of RHCP are estimated as followings,

$$XPD_{TOT} = \frac{RHCP\_C}{RHCP\_I_{TOT}} = \frac{RHCP\_C}{(RHCP\_I1+RHCP\_I2+RHCP\_I3)}$$

$$XPD_{TOT}^{-1} = XPD_{SAT}^{-1} + XPD_{ATMO}^{-1} + XPD_{GROUND}^{-1}$$

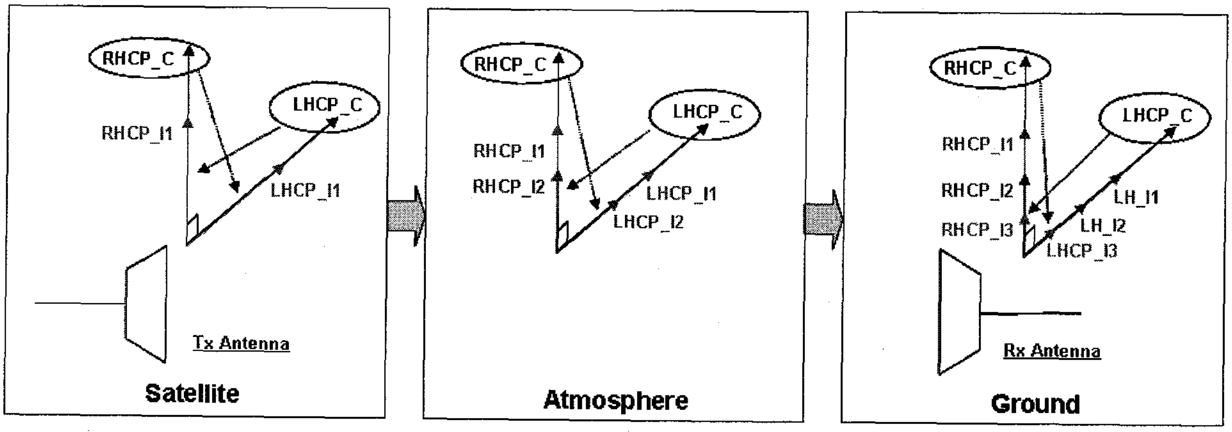

Figure 3 Illustration of XPD in the interface between satellite and ground station

where, XPD_{SAT}, XPD_{ATMO} and XPD_{GROUND} indicates XPD generated by satellite, atmosphere and ground, respectively. Equation for the estimation of XPD generated by satellite and ground can be expressed when axial ratio of counterpart antenna is assumed as ideal, 0 dB.

$$XPD_{SAT} = \frac{(1+AR_{SAT})^2}{(1-AR_{SAT})^2}$$

$$XPD_{GROUND} = \frac{(1+AR_{GROUND})^2}{(1-AR_{GROUND})^2}$$

In the case of XPD_{ATMO} which caused by a non-sphere of water shape in the troposphere, the procedure written in ITU [2] is applied. The procedure comprised of several arithmetic equations induced various statistical backgrounds as followings,

- Frequency-dependent term: $C_F = 30 \log$ (frequency in GHz)
- Rain attenuation-dependent term: $C_A = 12.8\times(\text{frequency})^{0.19}\log(A_P)$, A_P is rain attenuation in dB
- Elevation angle-dependent term, $C_\theta = -40\log(\cos\theta)$
- Raindrop percentage-dependent term: $C_\sigma = 0.0052\sigma^2$, σ takes the value 0°, 5°, 10° and 15° for 1%, 0.1%, 0.01% and 0.001% of the raindrop time.
- $XPD_{RAIN} = C_F - C_A + C_\theta + C_\sigma$
- Ice crystal-dependent term: $C_{ICE} = XPD_{RAIN} \times (0.3+0.1\log(0.01)/2)$
- $XPD_{ATMO} = XPD_{RAIN} - C_{ICE}$

Table 2 shows the XPD_{ATMO} according to rain rate in Deajeon, KOREA.

Table 2 XPD_{ATMO} according to rain rate

Availability (rain rate)	99 % (1.5 mm/h)	99.9 % (12 mm/h)	99.99 % (42 mm/h)
XPD_{ATMO}	26.34 dB	15.583 dB	7.438 dB

3. XPD IN LINK ANALYSIS

In dual-polarized interface with satellite, the (Eb/No) in ground station can be expressed as followings,

$$\frac{E_b}{N_0} = -10\log_{10}\left(10^{-(E_b/N_0)_s/10} + 10^{-(E_b/I_0)/10}\right)$$

where, $(Eb/No)_S$ is single-polarized ratio and I_O is the noise-like co-channel interference power density caused by XPD. (Eb/Io) is the energy-per-bit over co-channel interference power density and it is merely related to the C/I ratio, which is equal to XPD.

$$\frac{E_b}{I_0} = \frac{C}{I} + 10\log_{10}\left(\frac{B}{R}\right) = XPD_{TOT} - 10\log_{10}(\Gamma)$$

where, B is the occupied bandwidth, in hertz, R is the binary transmission rate, in bit/second, and Γ is the spectral efficiency, mainly related to the modulation employed, in bits/second hertz. (Eb/No) can be expressed including spectral efficiency and XPD_{TOT}.

$$\frac{E_b}{N_0} = \left(\frac{E_b}{N_0}\right)_s - 10\log_{10}\left(1+\Gamma 10^{((E_b/N_0)_s - XPD_{TOT})/10}\right)$$

Especially, the latter term can be regarded as the extra degradation incurred by dual-polarized links with respected to single-polarized interface. With assuming the transmission of KOMPSAT-2 as dual-polarization, link analysis was performed. Because the axial ratio of antenna in satellite and ground station was considered as 0.5 and 0.8, respectively, XPD_{SAT} and XPD_{GROUND} is calculated as 30.7 dB and 26.8 dB, respectively. Figure 4 illustrates the relation between elevation angle and XPD_{TOT} according to rain rate.

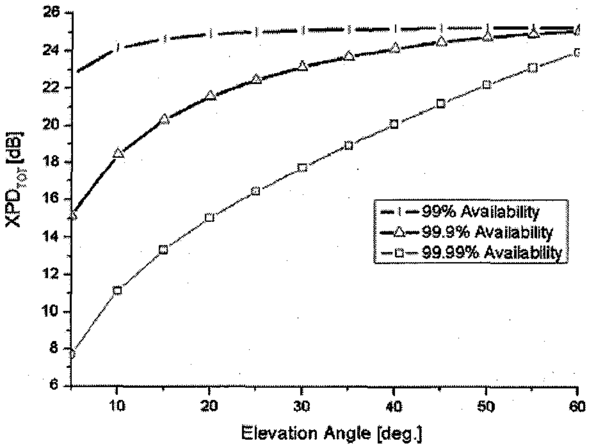

Figure 4 Relation between elevation angle and XPD_{TOT}

It can be found that XPDTOT seems to be influenced by elevation angle in heavy rain whereas XPD is a little of constant in small precipitation. Therefore, the dominant factor in bad weather is XPD_{ATMO} related to elevation angle and rain rate. Furthermore, in the case of high elevation angle and small precipitation, the crucial factor is XPD_{SAT} and XPD_{GROUND}. Figure 5 shows the influence of elevation angle and rain rate over link margin. Due to a degradation of XPDTOT in heavy rain and low elevation angle, the link margin is also less than 3 dB under that condition. Additionally, the reception of data observed by satellite could be accomplished if rain rate is less than 99.9% or 12 mm/h.

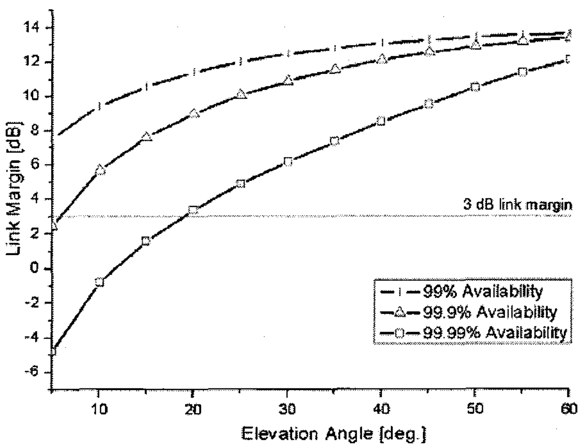

Figure 5 Influence of elevation angle and rain rate over link margin

Figure 6 shows the loss term caused by increased XPD and degradation of link margin in worse axial ratio of ground antenna.

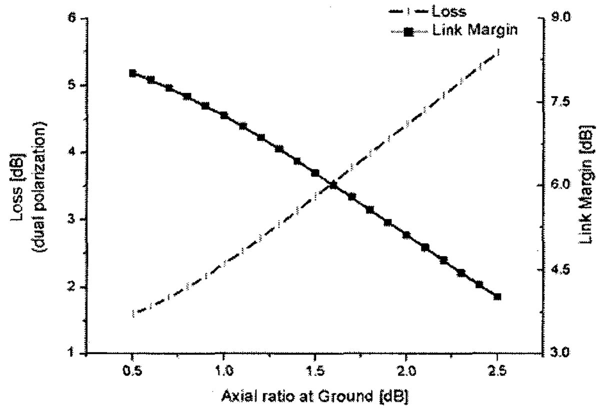

Figure 6 Relation between link performance and axial ratio of antenna in ground station

It can be found that the loss is increased when axial ratio of antenna in ground station is worse. In 99% of precipitation, link margin is more than 3 dB despite of 2.5 dB of axial ratio.

4. CONCLUSION

In this paper, the estimation of XPD was performed by dividing total XPD as XPD in satellite, ground and atmosphere, respectively. After calculating total XPD, link margin is analyzed with considering the added loss by XPD. In the circumstance of heavy rain and high elevation angle, the dominant factor of total XPD was atmosphere XPD and link margin is less than 3dB when the precipitation is more than 42mm/h. Furthermore, link margin is more than 3 dB despite of bad axial ratio of ground antenna when the precipitation is less than 1.5 mm/h.

5. REFERENCE

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[2] Propagation data and prediction methods for the design of earth-space telecommunication systems, Geneva, Switzerland, ITU-R Rec. 618-7, pp. 21-22