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Simultaneous dual linear polarization transmission technique using digital cross-polarization cancellation for MSS systems

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International Telecommunication Union

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REPORT ITU-R M.2175

Simultaneous dual linear polarization transmission technique using digital cross-polarization cancellation for MSS systems*

(Question ITU-R 83-6/4)

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TABLE OF CONTENTS

Page

1 Introduction 2

2 Adaptive polarization division multiplexing technique using V/H dual linear polarization 4

3 Channel model 6

3.1 Without multi-path components 7

3.2 With multi-path components 7

4 Feasibility of APDM technique 8

5 Considerations on interference among systems using APDM 11

6 Conclusion 11

* When submitting to the Radiocommunication Bureau a satellite network intended to be operated with the technique described in this Report, administrations need to take into account that both orthogonal polarisations have to be included in the submission, in order for them to be appropriately coordinated.

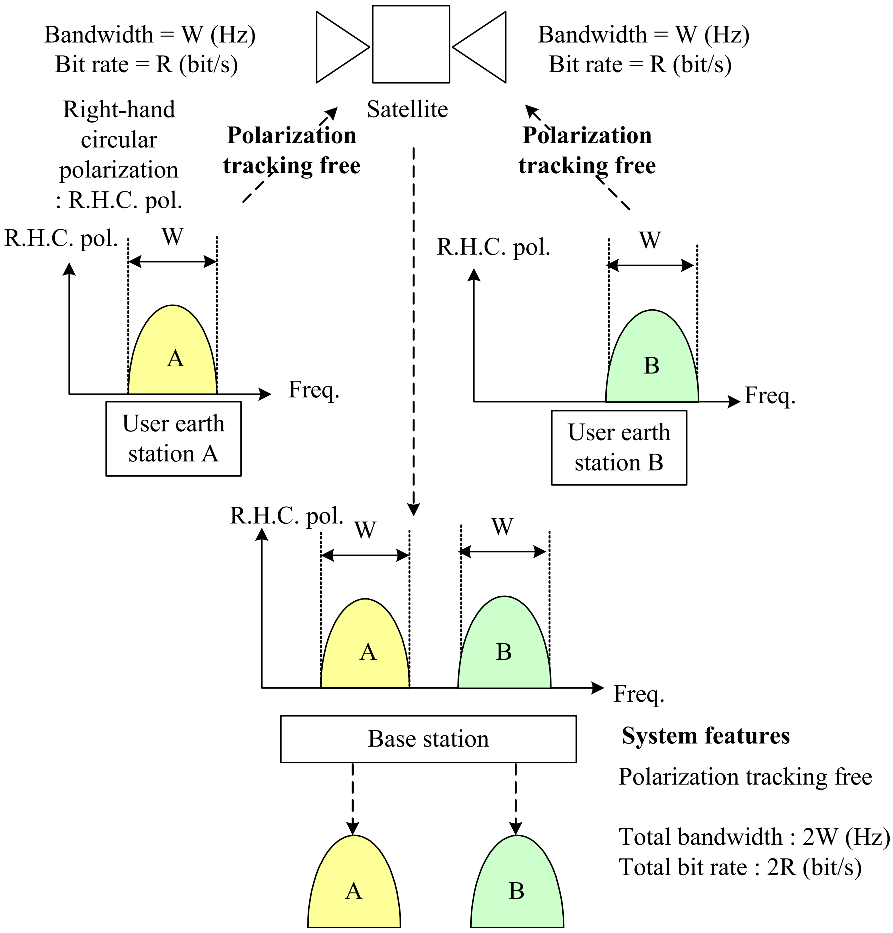
1 Introduction

Mobile-satellite communication services are now being offered all over the world. In order to share the limited frequency bandwidth among many MSS systems, a perpetual requirement is to improve the spectrum utilization efficiency. For this purpose, it is important to consider how to not only share the same frequency bandwidth between different systems but also improve spectrum utilization efficiency within an MSS system.

Figure 1 shows a typical MSS system that employs circular polarization. Circular polarization is mainly adopted due to its polarization-tracking-free nature, which makes it suitable for mobile services. In a typical system, right-hand circular polarization or left-hand circular polarization is selected. If a single user earth station sends at the bit rate of R (bit/s) with bandwidth of W (Hz) and user earth stations A and B make use of the satellite transponder, the total bit rate is 2R with the bandwidth of 2 W in Fig. 1.

FIGURE 1

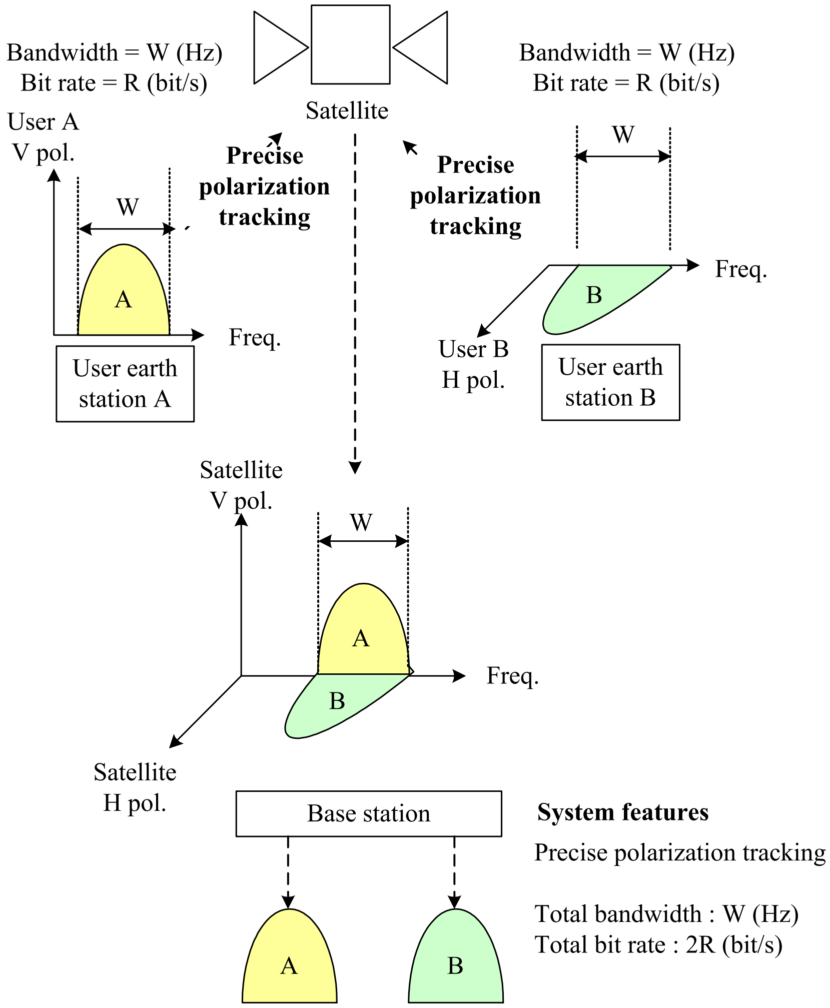
Spectrum utilization in a circular polarization system without polarization tracking



Another MSS system utilizes V/H dual linear polarization. Figure 2 shows an example of spectrum utilization in a V/H dual linear polarization system. Each user earth station communicates using either V or H polarization. In Fig. 2, V polarization is assigned to user earth station A and H polarization is assigned to user earth station B. Since user earth station A and user earth station B share the same frequency bandwidth with different polarization, polarization tracking is required at each user earth station so as to eliminate cross-polarization interference on the other user earth station. In Fig. 2, if each user earth station sends at the bit rate of R with bandwidth of W, the total bit rate, 2R, is achieved with the bandwidth of W.

FIGURE 2

Spectrum utilization in a dual V/H linear polarization system with polarization tracking

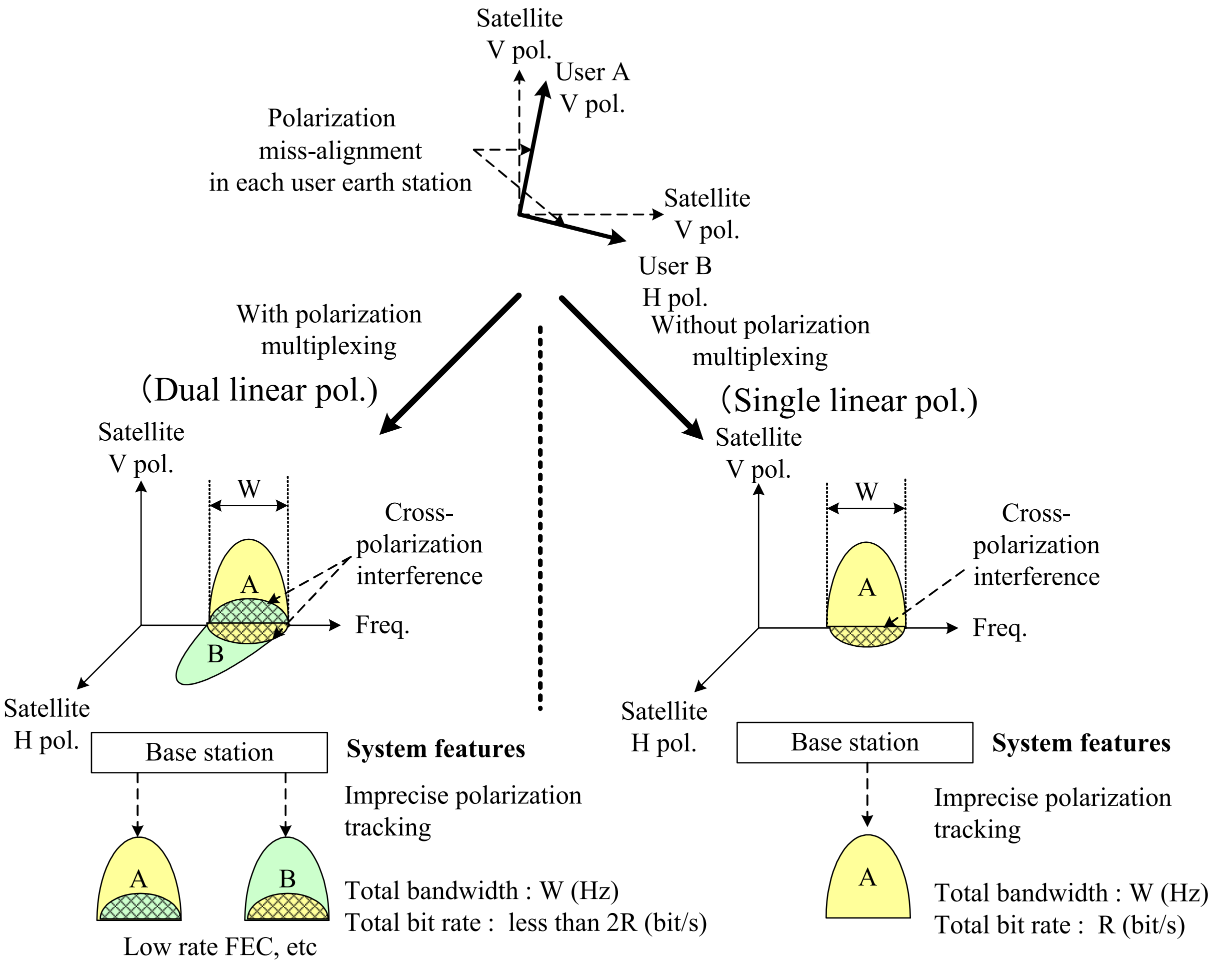


Compared to dual linear polarization, circular polarization excels in terms of its polarization-tracking-free nature which yields simple user earth stations. However, linear polarization offers double the spectrum utilization efficiency; 2R/W (bit/s/Hz) compared to 2R/2W (bit/s/Hz). This means that dual linear polarization makes better use of spectrum resources than circular polarization.

It is true that dual linear polarization is attractive from the viewpoint of spectrum utilization efficiency. However, in practice, accurate polarization tracking is difficult to realize, especially for mobile user earth stations with low-profile antennas. Figure 3 shows the degradation in spectrum utilization efficiency that occurs when the mobile user earth station experiences polarization misalignment. As shown, to handle this misalignment, the spectrum utilization efficiency of both user earth station A and user earth station B should be reduced to hold communication quality steady in the face of cross-polarization interference between user earth stations. Figure 3 also shows one solution to the problem of mutual interference: single linear polarization. This approach does not employ polarization multiplexing and so avoids the mutual interference between user earth stations. Its weakness is that it fails to increase the spectrum utilization efficiency.

FIGURE 3

Degradation in spectrum utilization efficiency due to imprecise polarization tracking



2 Adaptive polarization division multiplexing technique using V/H dual linear polarization

The adaptive polarization division multiplexing (APDM) technique realizes a polarization-tracking-free MSS system with dual V/H linear polarization transmission. This technique offers improved spectrum utilization efficiency with a simple satellite tracking antenna. Figure 4 shows the concept of APDM. Each signal is divided into two blocks and conveyed independently using V or H linear polarization. The two signals are polarization multiplexed at the antenna of each user earth station. In Fig. 4, user earth station A sends at the bit rate of R with bandwidth of W. Therefore, user earth station A's signal is divided into two independent blocks, A1 and A2 (each W/2), and they are polarization multiplexed in the user earth station A. The signal of user earth station B is divided into B1 and B2 (each W/2) similarly. Note that the APDM station dispenses with polarization tracking. Therefore, the polarization states of user earth station A and user earth station B are not aligned to those of the satellite as shown in Fig. 4. Thus, cross-polarization interference occurs between A1 and A2, and between B1 and B2 in the receiver. To counter this interference, a digital cross-polarization interference canceller is implemented in the user earth station's receiver as shown in Fig. 5. Figure 6 shows an example of the configurations of APDM transmitter and receiver. For realizing APDM, each transmitter must have a V/H dual modulator/frequency converter with high-power amplifier. Each receiver, on the other hand, needs to have a V/H dual low noise amplifier/frequency converter/demodulator with interference canceller. In Fig. 6, since modulator, demodulator and interference canceller are realized by digital circuits, they can be compactly implemented as integrated circuits. The major differences from the earth stations without APDM are the additional RF components, shown by the hatching in Fig. 6, that transmit/receive V/H dual polarized signals simultaneously.

This polarization division multiplexing with digital cross-polarization interference cancellation realizes polarization-tracking-free MSS systems using V/H dual linear polarization and facilitates broadband mobile-satellite communications services by achieving better spectrum utilization efficiency.

FIGURE 4

Spectrum utilization in a dual V/H linear polarization system with APDM technique

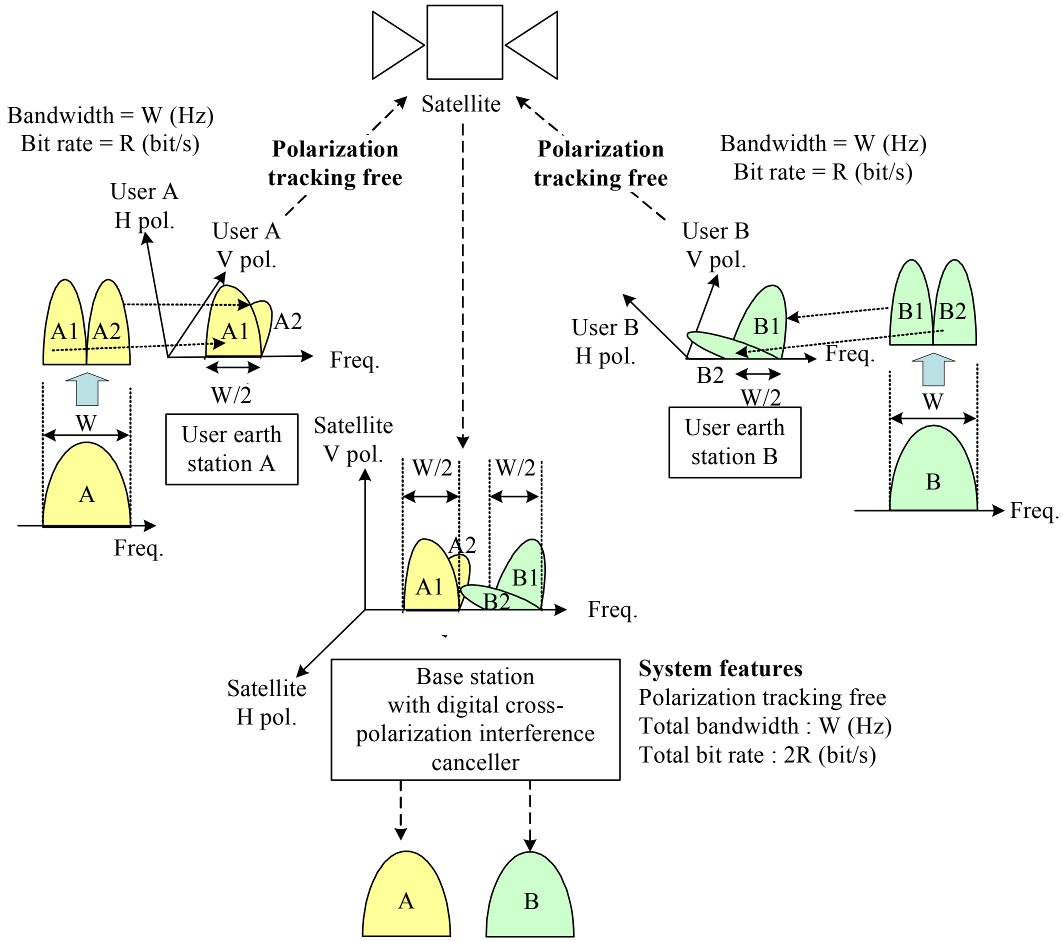


FIGURE 5

APDM cross-polarization interference cancellation in the receiver

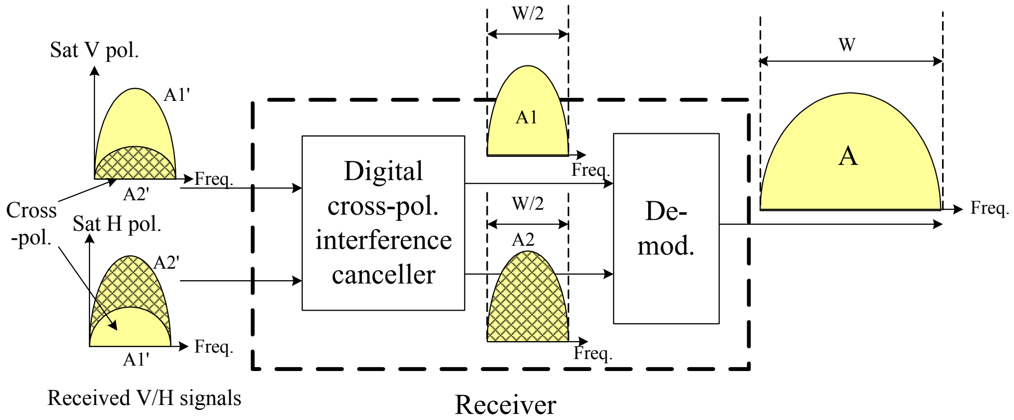
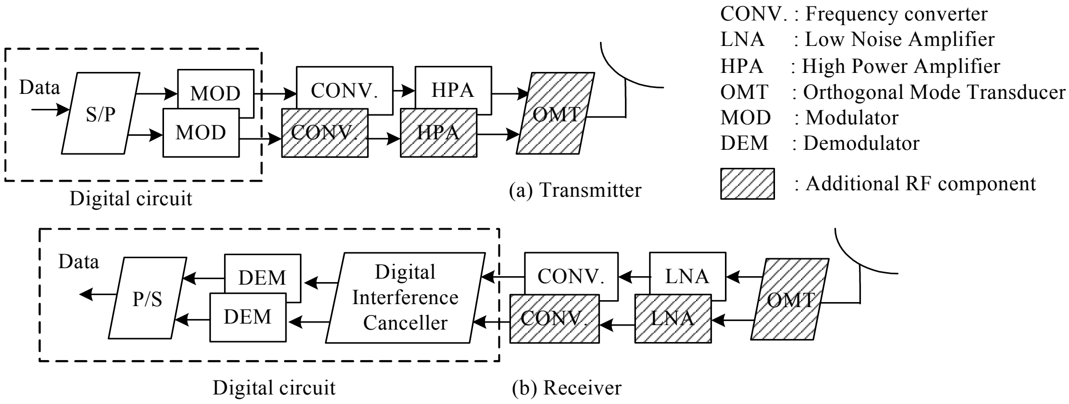


FIGURE 6

Configuration of APDM transmitter and receiver



3 Channel model

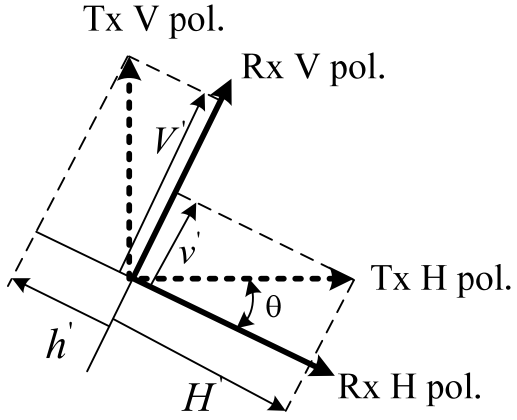
Due to the polarization-tracking-free-nature of APDM, its transmission channel triggers mutual coupling, V to V, H to H, V to H and H to V polarizations. To determine the basic properties of these mutual couplings, we introduce θ which denotes the polarization rotation angle between the transmitter (Tx) and receiver (Rx) as shown in Fig. 7. By using polarization rotation angle θ, XPI (cross-polarization isolation) is defined as:

$$XPI(\text{dB}) = 20\log\left|\frac{v'}{V'}\right| = 20\log\left|\frac{h'}{H'}\right| = 20\log\left|\frac{\sin\theta}{\cos\theta}\right|$$

where v', h' and V', H' denote the amplitude of the cross polarization signal and that of the desired polarization signal, respectively.

FIGURE 7

Polarization rotation between Tx and Rx



3.1 Without multi-path components

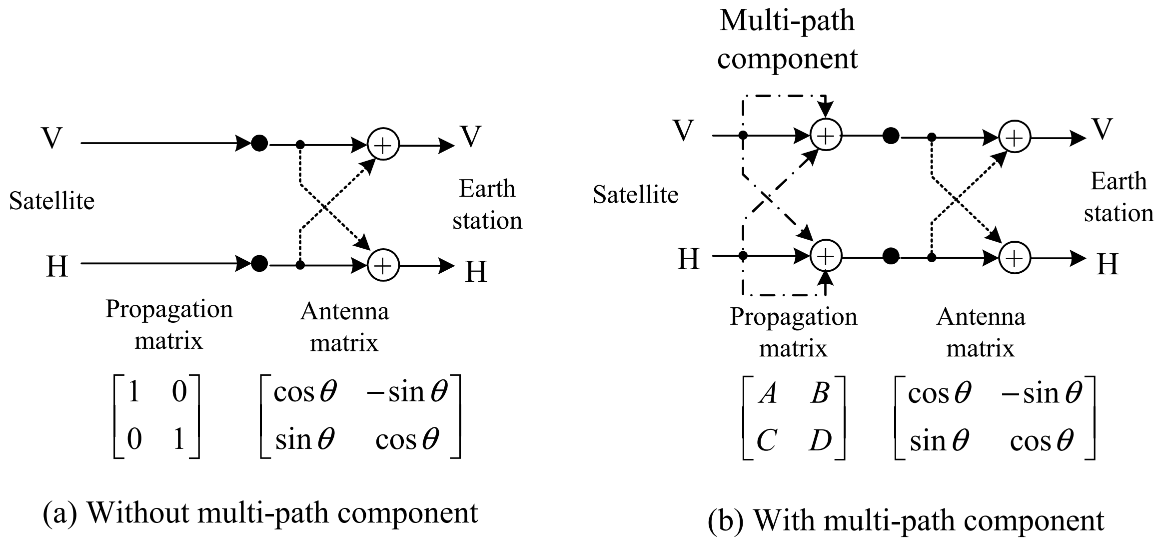
Figure 8 a) shows the channel model without multi-path components. This condition is typically satisfied in bands above 6/4 GHz where most earth stations employ highly directional (pencil-beam) antennas. In general, the channel model is formed as a combination of the propagation path condition and the polarization rotation of the antenna. In other words, it is defined by a channel matrix that is the product of the propagation matrix and the antenna matrix as shown in Fig. 8. If each earth station uses a highly directional antenna, the multi-path component is negligible. As a result, the channel model simply consists of the polarization rotation of the antenna. In this model, cross-polarization cancellation can be carried out without performance degradation.

3.2 With multi-path components

Figure 8 b) shows the channel model with multi-path components. This model is typical in the bands below 6/4 GHz where many of the earth stations employ omni-directional (or broad beam) antennas. Differently from the channel model in § 3.1, the broad directionality of the omni-directional antenna in each earth station means that multi-path signals as well as direct-path signals are received. For example, a multi-path component that originates from the V polarization signal is superposed on its own direct-path component. At the same time, another multi-path component from the V polarization signal is mixed with the H polarization signal. The same situation is true for the multi-path components from the H polarization signal. The resulting propagation matrix is shown in Fig. 8 b), where A, B, C and D are environment-dependent variables. These environment-dependent variables might affect the performance of cross-polarization cancellation.

FIGURE 8

Channel models of dual V/H polarization signal transmission



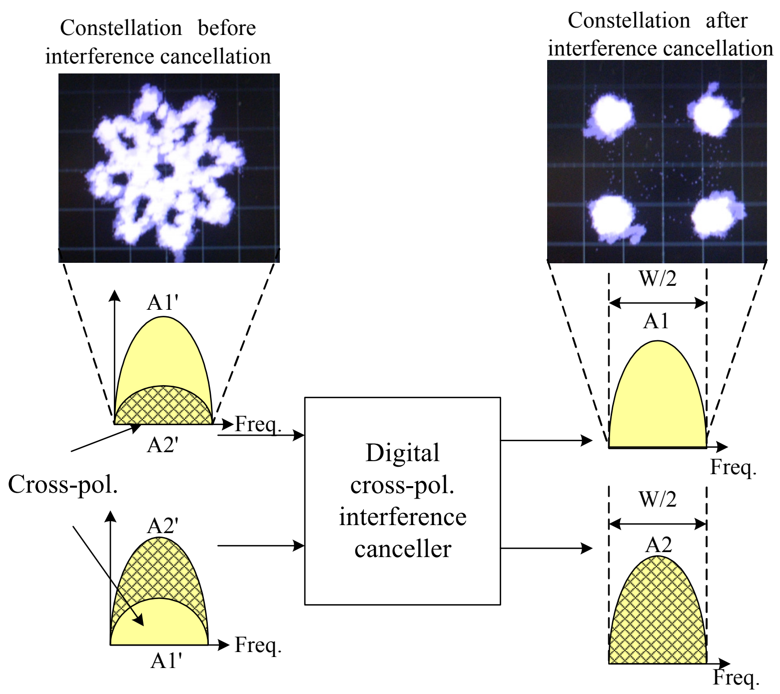
4 Feasibility of APDM technique

To confirm the basic feasibility of cross-polarization interference cancellation technique, an APDM modem module was developed and its performance was measured.

Figure 9 shows the constellation before/after cross-polarization interference cancellation. Various types of interference canceller have been studied in the wireless communications field so far. In Fig. 9, the minimum mean squared error (MMSE) algorithm is used for the canceller. As shown in Fig. 9, cross-polarization interference can be removed by a digital cross-polarization interference canceller.

FIGURE 9

Cross-polarization interference cancellation



To evaluate the overall performance of the APDM technique for polarization-tracking-free broadband communications using Vertical/Horizontal dual linear polarization, several system level satellite experiments were conducted in the 14/12 GHz bands. The experimental parameters are listed in Table 1. In the satellite experiments, an APDM station and a base station were prepared. The APDM station uses dual polarization simultaneously but does not track the polarization status at all. Note that the polarization status of the base station is adjusted to match that of the satellite.

TABLE 1

Signal conditions

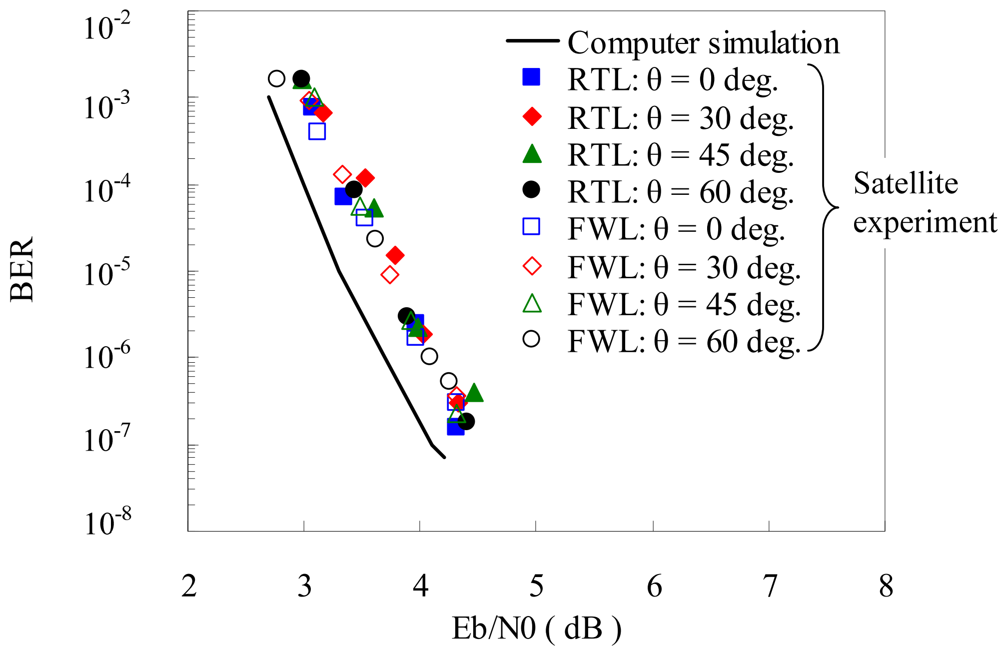
Access method	FDMA
Bit rate	1.28 Mbit/s, 5.12 Mbit/s
Modulation	QPSK
FEC	Turbo product code (R = 0.66)

First, in order to confirm the basic performance of dual polarization use, a dual polarized fixed antenna and satellite modem were prepared for both an APDM station and base station; the bit error ratio (BER) performance of a dual polarized signal was measured in satellite experiments. In the experiments, the polarization angle of the APDM user antenna was rotated manually to emulate a polarization-tracking-free environment with the fixed antenna.

Figure 10 shows the BER performance of the dual polarized signal while the polarization angle was manually rotated. In Fig. 10, RTL denotes the link from the APDM user station to the base station, and FWL the link from the base station to the APDM user station. As shown in Fig. 10, the degradation in required E_b/N_0 was about 0.5 dB with different polarization rotation angles, θ, and no significant performance degradation was measured.

FIGURE 10

BER performance of dual polarized signal at the fixed antenna with manual polarization rotation (θ)



Next, to evaluate the performance of APDM in a more practical situation, a dual polarized auto-tracking satellite directional antenna was developed. Its BER performance was measured while rolling the dual polarized antenna mechanically by a ship motion simulator as if it were mounted on a ship. Table 2 shows the motion parameters that were used by the ship motion simulator. In the experiments, two kinds of ship motion were created. The parameters in Table 2 (a) simulate the motion of a large ship (7,300 Gross Ton) on small waves and those in Table 2 (b) are for the motion of a small ship (420 Gross Ton) on large waves.

TABLE 2

Simulated ship motion parameters

Motion (a): Large ship

Roll	2° in 13 s
Pitch	1° in 7 s
Yaw	30°

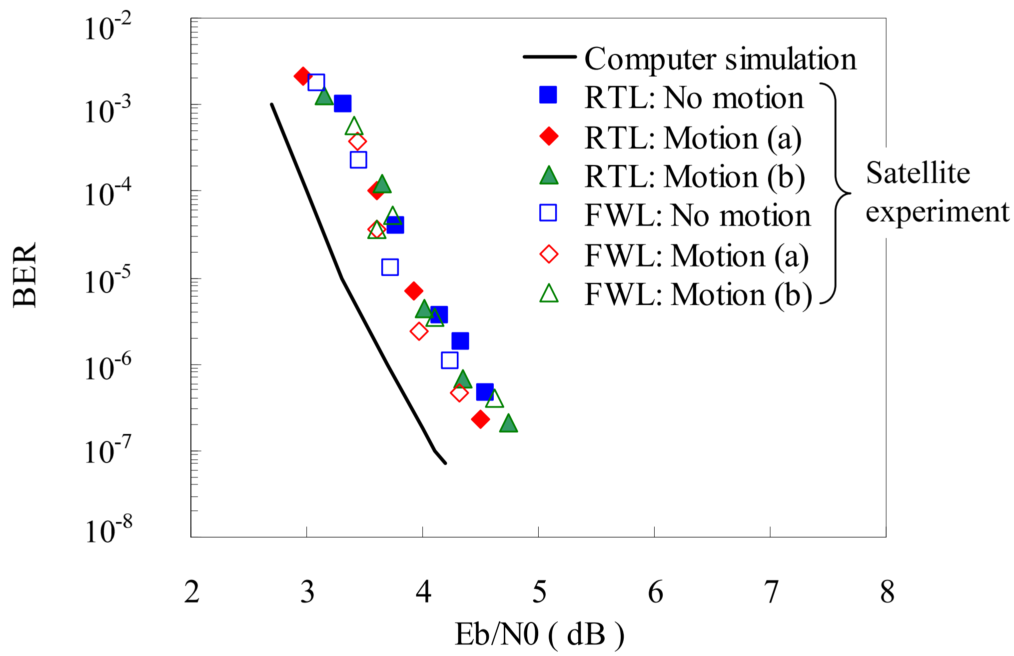
Motion (b): Small ship

Roll	5° in 6 s
Pitch	4° in 5 s
Yaw	5°

Figure 11 shows the BER performance that was measured while rolling the antenna by the ship motion simulator. Figure 11 shows that no significant performance degradation was caused by ship motion in the satellite experiments. This means that dual polarization use with APDM is feasible in MSS systems. From these results, it is concluded that the APDM technique is a practical way of implementing dual polarization use.

FIGURE 11

BER performance of dual polarized signal with dynamic antenna motion



5 Considerations on interference among systems using APDM

MSS systems using APDM are deployed via dual linear polarized satellite transponders that are already being operated. Since APDM earth stations satisfy the same coordination conditions that are imposed on systems operated in the same satellite transponder, no additional coordination is needed.

Among the systems proposing to use APDM, it is assumed that the V/H dual polarization frequency band is divided system by system and a guard band is prepared so as to mitigate interference among systems. This approach is not unique and is a common practice used to avoid interference among systems. Therefore, the use of APDM places no additional burden on the system.

6 Conclusion

To improve the spectrum utilization efficiency when cross-polarization isolation (XPI) is insufficient in the mobile environment, this Report presents a technique of APDM with V/H dual linear polarization. APDM does not induce cross-polarization interference between user earth stations while keeping the spectrum utilization efficiency high through the use of dual polarization.

This technique is anticipated to be further developed and may lead to additions of this Report in the future.