3-5 16APSK/16QAM-OFDM 3.2 Gbps RF Signal Direct-Processing Transmitter and Receiver Transmission Experiments using WINDS Satellite

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The National Institute of Information and Communications Technology (NICT) has experimented using a 1,244 Mbps high-speed burst modem with single carrier QPSK modulation through the bandwidth of a 1.1 GHz transponder on the Wideband InterNetworking Engineering Test and Demonstration Satellite (WINDS). We developed a 16APSK/16QAM-OFDM 3.2 Gbps RF Signal Direct-Processing Transmitter and Receiver system for even greater broadband transmission. This paper shows that a 4K UHDTV transmission experiment using a WINDS satellite connection through a 10GbE interface was successfully performed by this system.

1 Introduction

NICT is conducting research and development of high-speed satellite communication using WINDS (Wideband InterNetworking engineering test and Demonstration Satellite, also known as “Kizuna”), launched in 2008[1]. In 2010, NICT succeeded in achieving a single carrier transmission rate of 1.2 Gbps by maximizing the 1.1 GHz bandwidth of WINDS’s Ka-band bent-pipe relay mode [2]. Also, we are developing an engineering flight model (EFM) for reconfigurable communication equipment (RCE: software defined radio) [3] using SRAM-based FPGAs (Fig. 1). This is a satellite-equipped transponder whose circuits can be configured by uploaded circuit information from earth after the satellite has been launched into orbit. To make reconfigurable communication equipment more compact and lightweight, we developed a 16APSK RF signal direct-processing transmitter and receiver [4]. We sought to expand on this and achieve broadband transmission using WINDS. Recently in high throughput satellites (HTS) [5][6] such as Inmarsat-5 [7], KA-SAT[8], Viasat-1, and Echostar 17, the total capacity per satellite is several tens to hundreds Gbps [9]. The data rate of each user link will be increased from a few tens Mbps in downlink and a few Mbps in uplink to several Gbps in the near future. This study took on the challenge of the highest data rate of Gbps in the both power- and frequency-band-limited 1.1 GHz bandwidth of WINDS’s Ka-band bent-pipe transponder. The improvement of the group delay distortion and the amplitude distortion as well as the efficient use of the limited bandwidth 16APSK/16QAM-OFDM (16-ary Amplitude and Phase-Shift Keying/16-ary Quadrature Amplitude Modulation-Orthogonal Frequency Division Multiplexing) was adopted. We developed a 16APSK/16QAM-OFDM 3.2 Gbps RF signal direct-processing transmitter and receiver and achieved a 6.12×10^{-3} bit error rate through the WINDS satellite bent-pipe transponder. We added LDPC error correction to this system and succeeded in broadband transmission with a data transfer rate of 3.2 Gbps. Furthermore, we added a 10 GbE interface, connected a multi-channel video codec system, and succeeded in UDP/IP transmission of uncompressed 4K UHDTV [10].

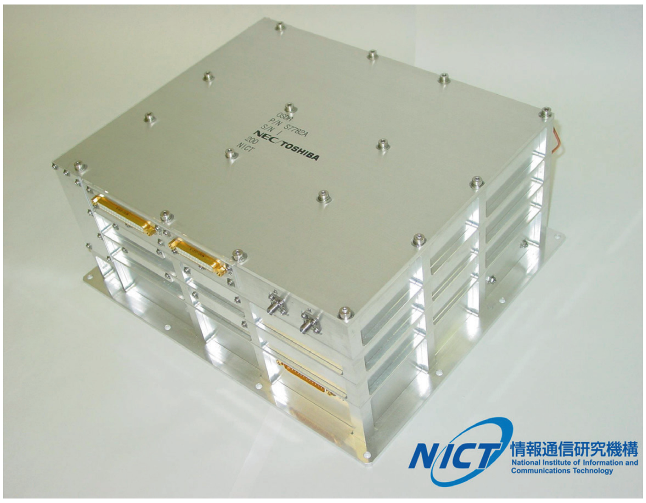


Fig. 1 RCE onboard software defined radio (EFM)

2 16APSK/QAM-OFDM 3.2 Gbps transmitter and receiver

The circuit diagram of the 16APSK/16QAM-OFDM 3.2 Gbps transmitter and receiver system is shown in Fig. 2.

Its specifications are shown in Table 1. Figure 3 shows the modulator and demodulator print wired boards. Figure 4-1 shows the 16APSK signal mapping. Figure 4-2 shows the 16QAM signal mapping. As shown in Fig. 5, the 16APSK/16QAM signal is multiplexed into 16 frequencies (subcarriers: f0-f15) and a data transfer rate of 3.2 Gbps was realized.

To reduce the effects of inter-symbol interference, which causes distortion in the transmission line, we set 57.14 MHz as the frequency interval and the entire bandwidth (equivalent noise bandwidth) as 940 MHz. To cancel the effects of amplitude and group delay due to the characteristics of the earth station's communication equipment, the satellite circuit, and the satellite's transponder, adjust-

Table 1 Major specifications of 16APSK/16QAM-OFDM 3.2 Gbps RF signal direct-processing transmitter and receiver

	Specification
Modulation:	16APSK-OFDM, GI=2.5ns (radius ratio γ=R2/R1=2.73205), 16QAM-OFDM, GI=2.5ns
Signal Mapping:	DVB-S2 conformity (16APSK) Gray code (16QAM)
Data Rate:	3,200Mbps =50Msps × 4bit/symbol × 16ch
Error Correcting Code:	LDPC code
Interleave:	Interleave between subcarriers (every eight subcarriers)
Randomizer:	Generating polynomial $h(x)=x^8+x^7+x^5+x^3+1$ (CCSDS)
10GbE external interface:	10GbE SFP+ interface Internet Protocol: UDP/IP Bit Rate: 3,200Mbps (after adding error correction)

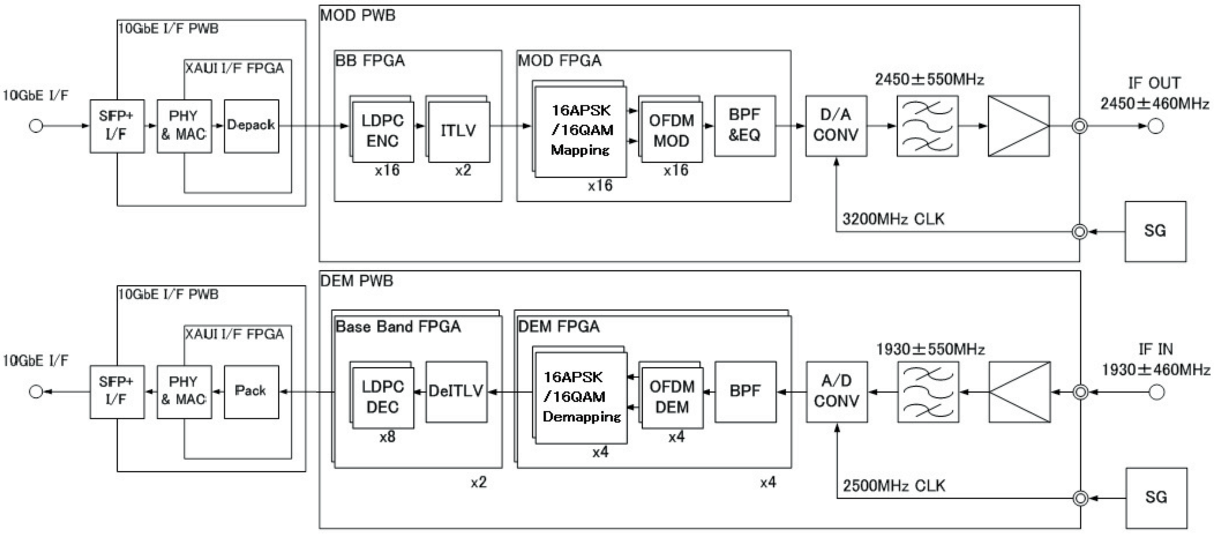
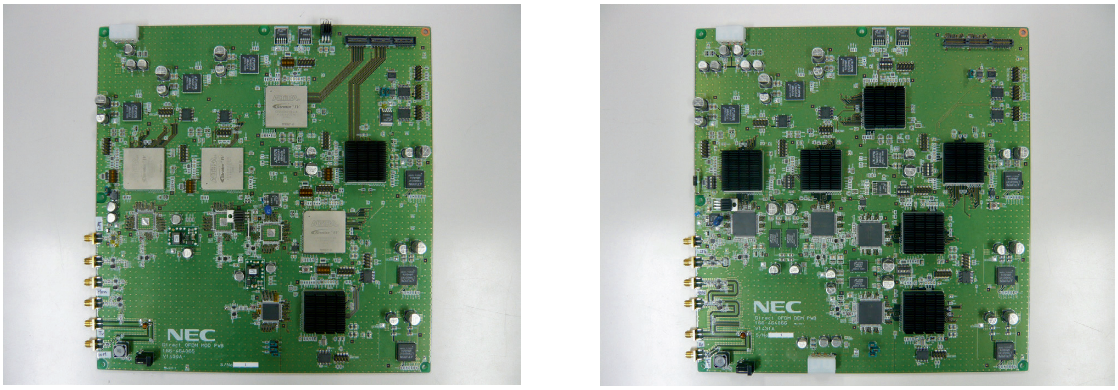


Fig. 2 16APSK/16QAM-OFDM 3.2 Gbps RF signal direct-processing transmitter and receiver circuit configuration


MOD PWB

DEMOD PWB

Fig. 3 16APSK/16QAM-OFDM 3.2 Gbps RF signal direct-processing modulator/demodulator print wired boards

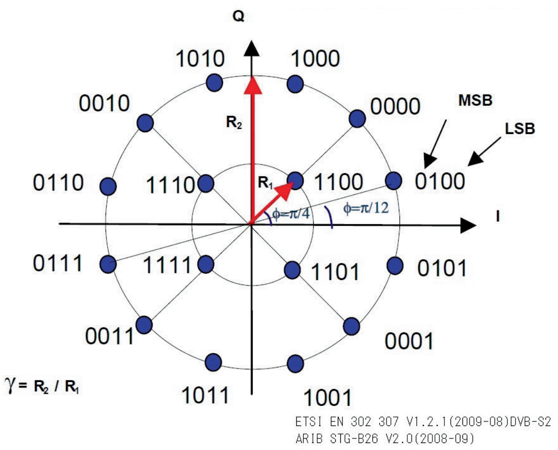


Fig. 4-1 16APSK signal mapping

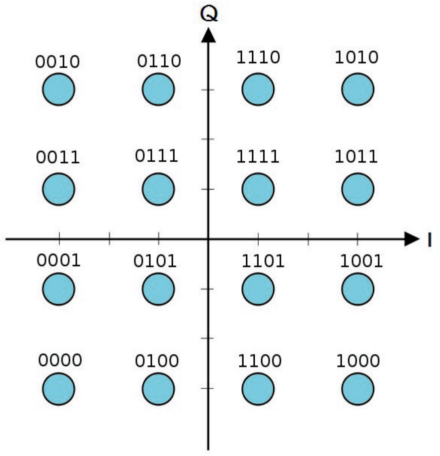


Fig. 4-2 16QAM signal mapping

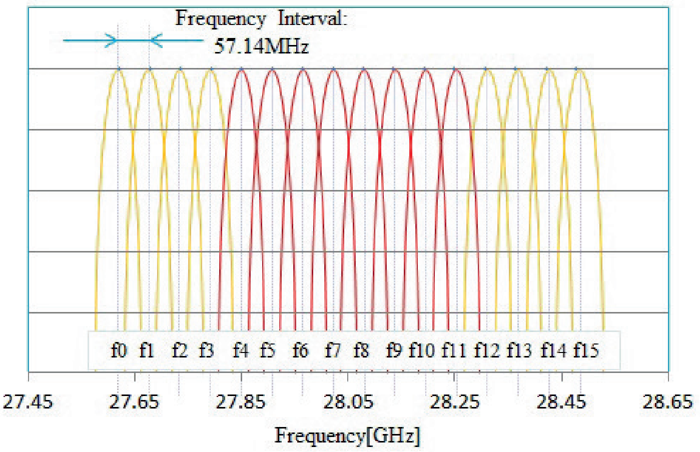


Fig. 5 QFDM frequency arrangement

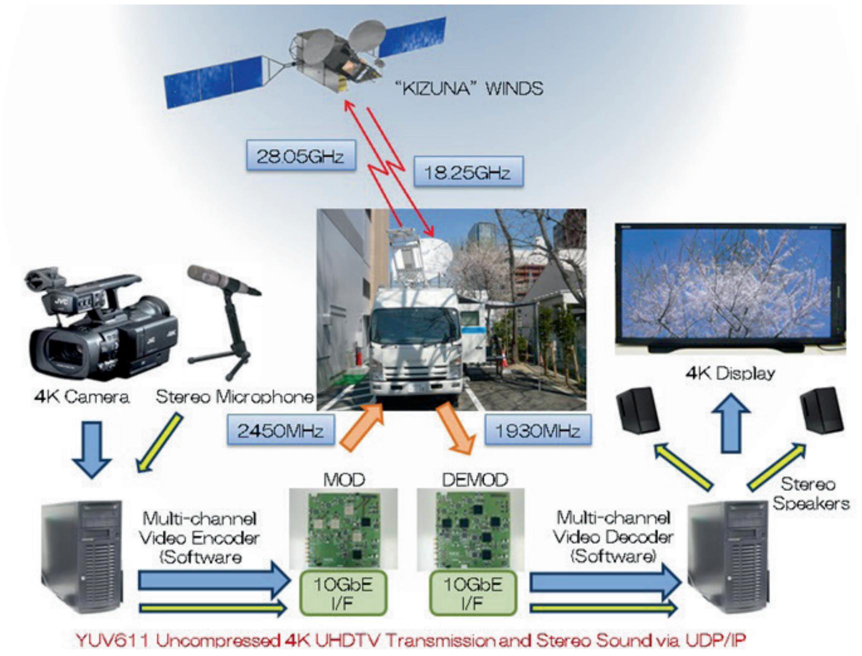


Fig. 6 WINDS satellite experiment block diagram

ment of the equalizer coefficient is required. However, because the frequency bandwidth for each frequency can be narrowed with OFDM, these effects can be reduced.

3 WINDS satellite communication experiment: Uncompressed 4K UHDTV

Figure 6 shows an overview diagram of the WINDS satellite communication experiment. A satellite communication experiment was conducted using a large-scale in-vehicle earth station with a 2.4 m antenna in the earth station. Furthermore, digital clipping by CF (Clip and Filtering) (9 dB Back Off) is being conducted in the FPGA on the earth station transmitting side that prevents excessive input to the satellite. There are also no problems in the analog limit because the point of saturation of the output of the ground transmitter is lower than the point of excessive input to the satellite.

Figure 7 shows the received signal frequency spectrum through the WINDS satellite. Figure 8 shows the I/Q constellation of each of the 16 frequencies when demodulating. Because of differences in the Es/No for each wavelength due to the effects of the transponder's amplitude-frequency characteristics, differences in demodulation characteristics were observed. However, all 16 frequencies were demodulated normally. The bit error rate before correction was 6.12×10^{-3}. A quasi-error-free (BER < 1.0×10^{-11}) line was achieved by applying LDPC error correction. Figure 9 shows the I/Q constellations of the f12 subcarrier of 16APSK and 16QAM when Eb/No is 14.5 dB. 16QAM confirmed that BER before error correction is improved compared to 16APSK. Figure 10 shows the measurement results of 16 APSK-OFDM and 16 QAM-OFDM BER characteristics measured again under a good

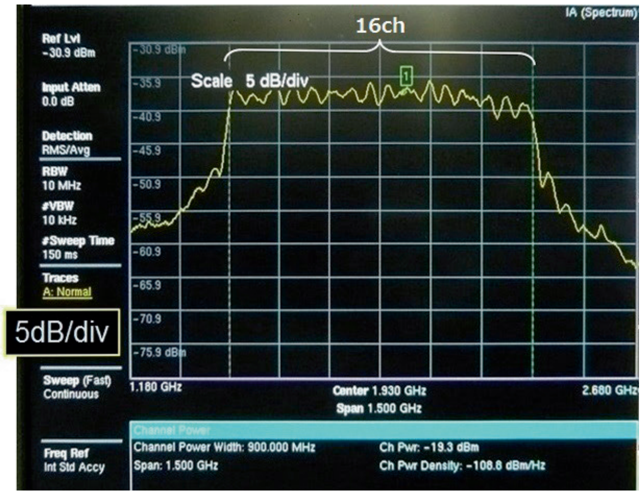


Fig. 7 Received signal frequency spectrum (12 March 2014)

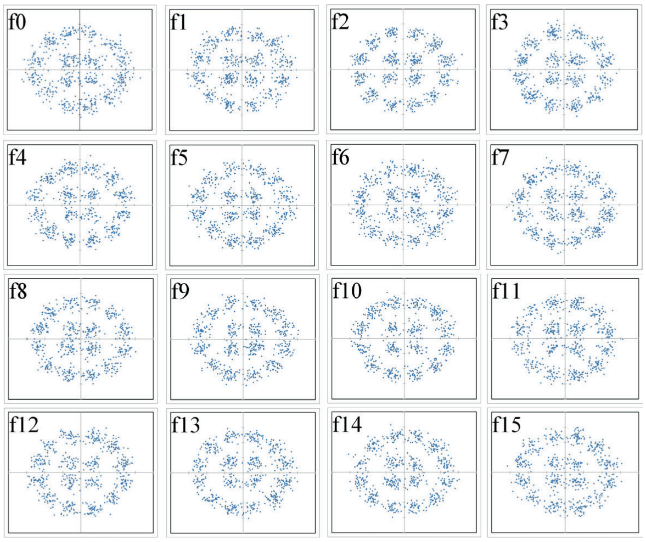
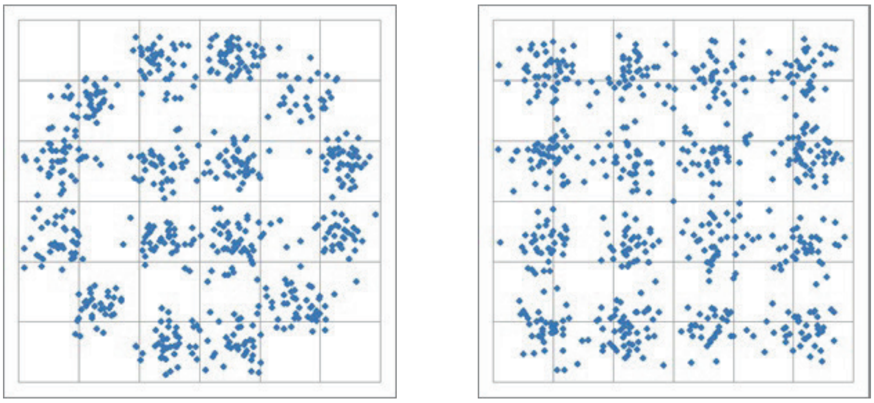


Fig. 8 I/Q constellations (12 March 2014)



16QAM-OFDM(f12) BER=9.82×10^{-3}

16APSK-OFDM(f12) BER=8.30×10^{-3}

Eb/No=14.5[dB]

Fig. 9 f12 I/Q constellations (6 Nov. 2014)

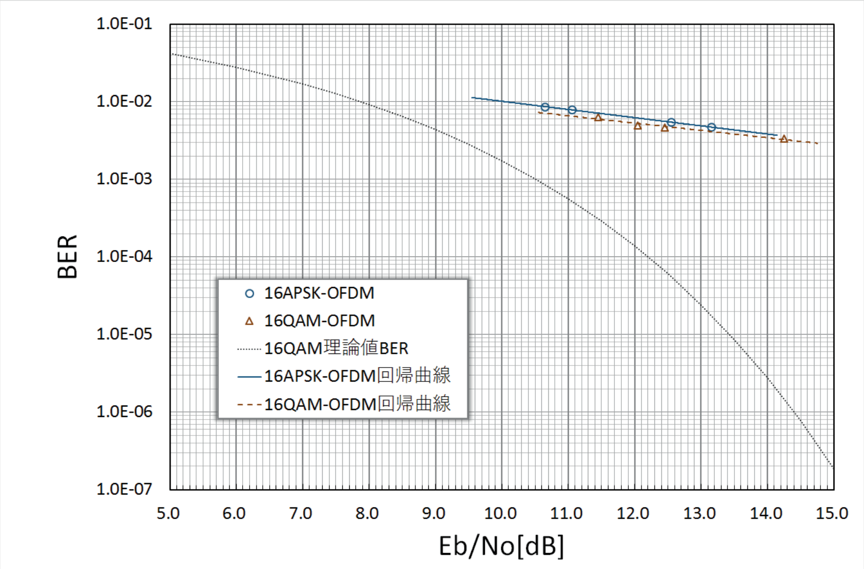


Fig. 10 16APSK/ 16QAM-OFDM BER curve (27 Dec. 2016)

Fig. 11 Transmitted uncompressed 4K UHDTV picture (28 Nov. 2014)

link budget. At the same Eb/No, 16 QAM-OFDM has better BER performance than 16 APSK-OFDM by about 0.9 dB.

For the uncompressed 4K UHDTV's codec system, the "multi-channel video codec system" developed by NICT [11] was used. This codec is entirely software-based, and is realized with ultra-high-speed, multi-channel parallel processing on a multi-core PC. The amount of information was made 4/9 (YUV611) using the method for thinning out chrominance components while leaving the pixel count as-is, yielding a transfer rate of about 2.65 Gbps. Four-channel video (4 high-definition images) were synchronously transmitted. With these achievements, we confirmed that UDP/IP transmission of uncompressed 4K UHDTV took place without packet loss. An example of a transmitted 4K UHDTV picture is shown in Fig. 11.

4 Conclusion

We achieved 3.2 Gbps satellite transmission. Anticipated applications include the field of telemedicine, in which medical information can be accurately transmitted to specialist physicians in remote locations by large-scale in-vehicle earth stations.

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