ALMA Memo 625
Proof of Concept of the ALMA WSU Data Transmission System

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1. Introduction

This document describes the results of Proof of Concept (PoC) testing of the ALMA Data Transmission System upgrade (DTS), which is part of the ALMA2030 Wideband Sensitivity Upgrade (WSU) Stage I in the WSU Implementation Plan [1]. The main feature of the DTS is the transmission of the data received from the Digitizer at the antennas to the ingests of the 2nd generation Correlator (ATAC) and 2nd generation TP Spectrometer at the OSF.

2. Requirements

The technical requirements for DTS upgrade are summarized in the below table:

Parameter	Specification	Comment
Max Data rate	1200 Gb/s	
Max Span	80 km	45 km to AOS + 30 km to OSF
Protocol	Gigabit Ethernet	
BER	< 1e-12	w/ FEC

Table 1: Requirements of DTS

Based on the rapid growth of digital coherent communications technology, long-range 400 GbE optical transceivers, QSFP-DD-ZR optical transceivers, are the leading candidates for the transmission equipment used in the DTS. The 400 GbE-ZR transceivers are commercially available devices, which use standard architectures and protocols, and enable long-range transmission over 80 km or more together with optical amplifiers. These features allow to build a simple system and provide good maintainability. Through discussions with the WSU Digitizer and WSU Correlator groups, the baseline design is defined to include the following conditions:

* The DSP/OT board developed by the Digitizer group directly drives the optical transceivers of DTS.

* The maximum data rate is 1200 Gb/s. But the DTS has a capability to transmit 1600 Gb/s by using 4 optical transceivers @ 400 GbE each.
* The ingest of the Correlator consists of a commercially available network switch, which accepts multiple 400 GbE-ZR optical transceivers.
The currently proposed diagram for the DTS is shown as Figure 1.

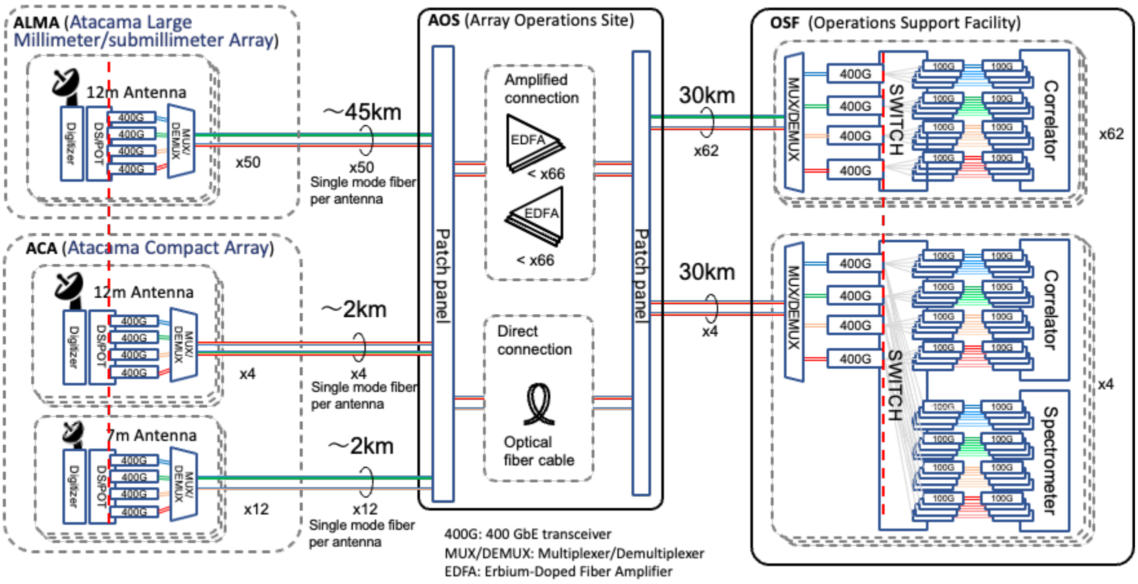

Figure 1: Diagram of the DTS. Note: The DTS is responsible for the data transmission between 400 GbE-ZR transceivers inserted on the DSP/OT boards and the network switches.

3. Proof of Concept

The PoC was performed from July 4, 2023 to July 5, 2023 in collaboration with the Photonic Network Laboratory of the National Institute of Information and Communications Technology (NICT). The 400 GbE-ZR transceivers, FIM38900/120 (QSFP56-DD-400ZR) from Fujitsu Optical Components, and the network tester, Anritsu MT1040A, were employed in the PoC.

3.1 Field test using the 90-km deployed optical fiber link in Tokyo

A system was established simulating the currently proposed DTS as shown in Figure 2 including a booster EDFA and in-line EDFA and tested in the 90-km round-trip optical fiber link in Tokyo. The optical fiber link is a part of the testbed provided by NICT for R&D of Information and Communications Technologies [2]. The optical fiber link consists of a dark fiber made up of different commercially available optical fiber links for communications, with a length and optical signal loss of 45 km and approximately -15 dB at 1550 nm, respectively. Two 400 GbE-ZR modules, with wavelengths set around 1550 nm, were combined with two other transponders to simulate the four colors WSU system. The two active 400 GbE-ZRs were driven by independent network testers. Figure 3 shows the spectrum after the 90-km transmission, just before the reception by the 400 GbE-ZRs. The field test was performed for two hours. The results are shown in Figure 4, recorded by the network testers. As shown in Figure 4 (d), the mean bit error rate (BER) before forward error correction (FEC) was approximately 2e-3. The numbers of uncorrected frames were zero as shown in Figure 4 (c). It shows that the actual BER after FEC was zero and all data were transmitted without any gaps. It was confirmed by these results that the simulated DTS worked as anticipated in the 90-km optical fiber link.

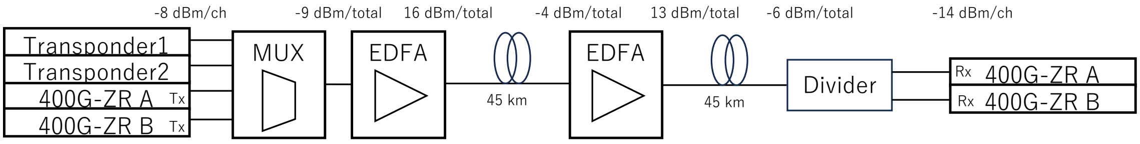

Figure 2: Diagram for the field test

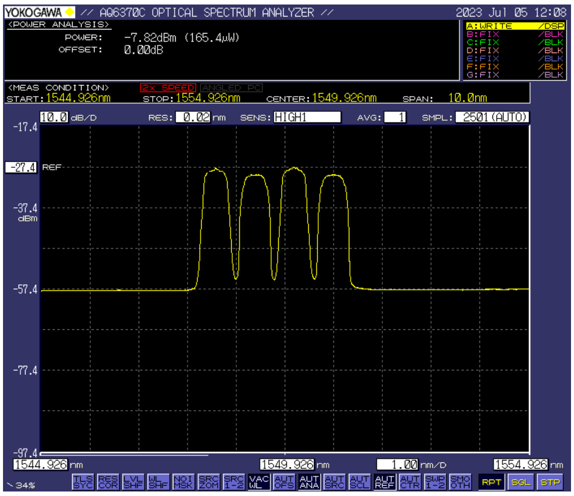

Figure 3: Spectrum after the 90-km link for the reception by the 400 GbE-ZR optical transceivers. First and third spectral lines from the left correspond to the 400G-ZR transceivers.

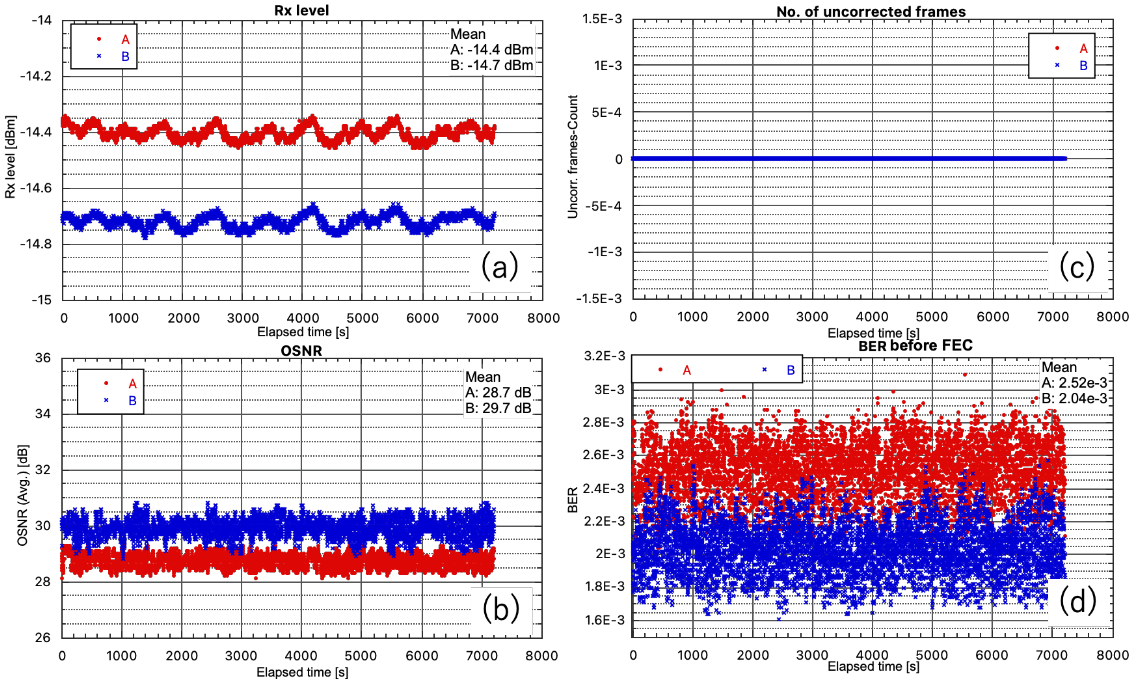

Figure 4: Parameters of reception signals. (a) Rx level, (b) Optical Signal to Noise Ratio (OSNR), (c) Number of uncorrected frames, (d) Bit Error Rate (BER) before Forward Error Correction (FEC).

3.2 The 11-m VLBI antenna

As shown during the design phase of the CLOA, coherent optical systems are sensitive to perturbations of the optical path, such as bending or twisting, and this may have an impact on the 400 GbE-ZR transceivers because they are based on digital coherent optics. Since the ALMA antenna rotates, the optical fibers deployed along the antenna may cause variations of the Rx level and polarization state for example. As a result, it may increase the BER during ALMA operations. To clarify if such a problem occurs or not, we tested the 400 GbE-ZR modules using the 11-m VLBI antenna at NICT (Figure 5). Optical fibers are installed for the reception-signal transmission between the antenna cabin and a control building where an A/D sampler is installed. Its length is approximately 40 m. In the test, the 80-m round-trip link was established by using two optical fibers connected into a loop. The data transmission was performed as shown in Figure 6 and the BER, Rx level variation and so on were monitored while the antenna rotated at the maximum speed of approximately 3 degrees/second. The movements were a) elevation only, b) azimuth only, and c) both elevation and azimuth changed with the maximum speed in the test, over the full range of motion. Figure 7 shows the variations in the Rx level and number of uncorrected frames during the azimuth angle movement from 0 to 360 degrees. While the Rx level showed the variation by 0.4 dB, the number of uncorrected frames was kept to zero. It means that the BER after FEC was zero.

We confirmed that stable data transmission was possible without any lack of data using the 400 GbE-ZR transceiver.

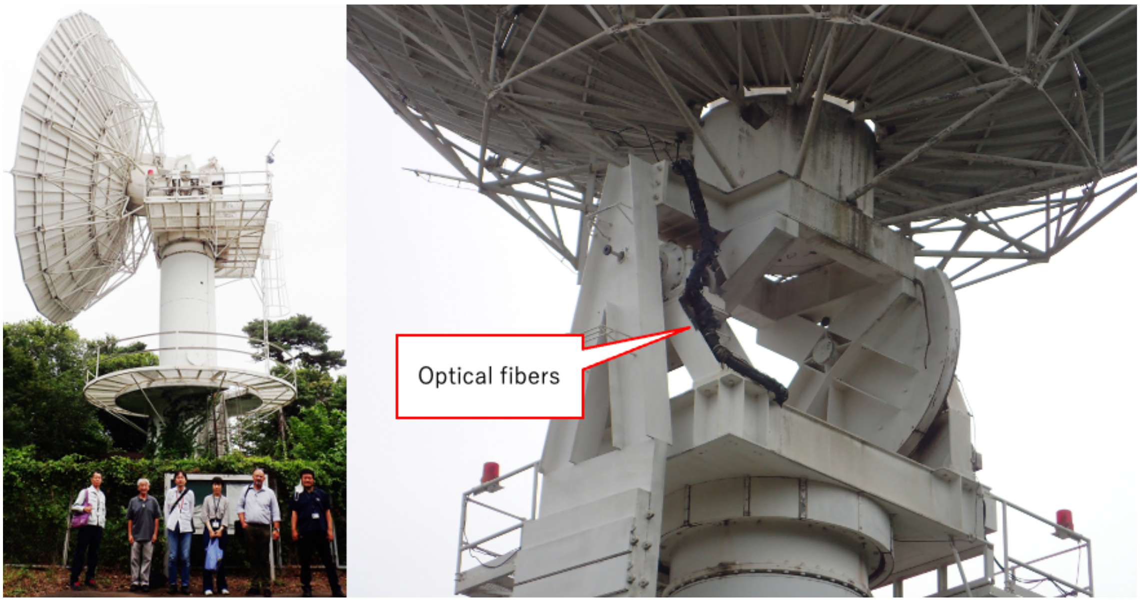

Figure 5: 11-m VLBI antenna at NICT.

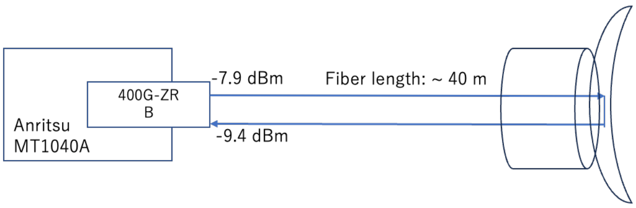

Figure 6: Diagram of the test with the 11-m VLBI antenna

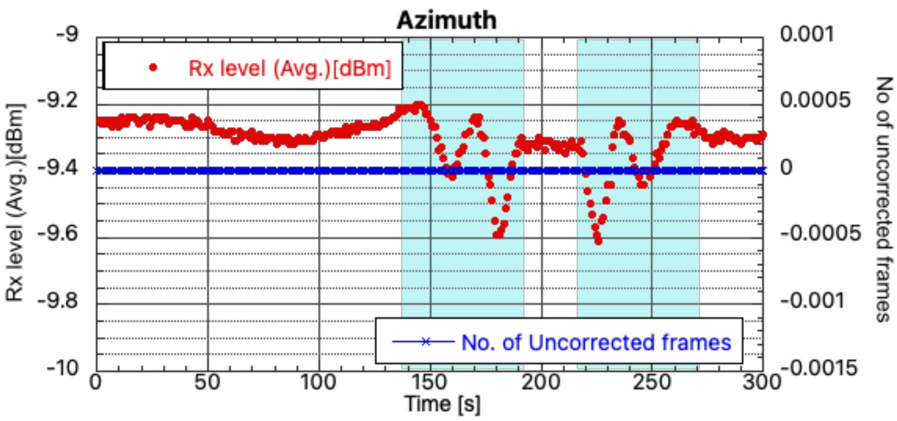

Figure 7: Variation of Rx level and number of uncorrected frames. The azimuth angle changed twice from 0 to 360 degrees during the periods shaded in light blue.

4. Conclusion

We confirmed that the proposed system configuration for the WSU DTS satisfied the technical requirements using standard off-the-shelf parts on a 90-km dedicated optical fiber link. Additionally, we verified that error-free data transmission on a moving telescope using 400 GbE-ZR optical transceivers was possible thanks to FEC while an 11-m VLBI antenna moved in azimuth and elevation.

Acknowledgement

We would like to thank the Space-Time Standards Laboratory of NICT for their technical and fruitful corporation.

References

[1] ALMA2030 Wideband Sensitivity Upgrade Implementation Plan, ALMA-10.00.00.00-3001-1-PLA.

[2] JGN High Speed R&D Network Testbed, https://testbed.nict.go.jp/jgn/english/index.html .