Development of Communication Subsystem for the WINDS

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The Wideband InterNetworking engineering test and Demonstration Satellite (WINDS) is an experimental communications satellite, and planned to be launched in 2007. The WINDS communication subsystem has two operating modes, an ATM-based baseband switching mode and a wideband through-repeater mode. Nine units of QPSK multi-rate demodulators (1.5, 6, 24, 51 Mbps) are installed for up-link TDMA receivers at the input of the ATM-based baseband switch (ABS). Three channels for 155.52-Mbps QPSK modulators have been installed at the output of the ABS. In the vent-pipe mode, WINDS works as a transponder with a 1.1-GHz bandwidth. Users can transmit parallel 622-Mbps QPSK signals or a single 1.2-Gbps QPSK signal by using the 1.1GHz-transponder as a bent-pipe connection.

Nomenclature

WINDS	=	wideband inter-networking engineering test and demonstration satellite
ATM	=	asynchronous transfer mode
ABS	=	ATM baseband switch subsystem
FMBA	=	fixed multi-beam antenna
APAA	=	active phased array antenna
MPA	=	multi-port amplifier
DDEM	=	digital demodulator unit
EM	=	engineering model
PFM	=	proto-flight model
TPC	=	turbo product code
BER	=	bit error rate

I. Introduction

THE Japan Aerospace Exploration Agency (JAXA) and National Institute of Information and Communications Technology (NICT) have been cooperating closely in the developing new satellite communication missions. NICT has been conducting research and development on on-board processing technology for a future high-data-rate communication satellite such as the "Gigabit Satellite Project" [1]. The Ministry of Internal Affairs and Communications (MIC) has been advocating the pursuit of "Space Internet" technology since 2000. The aim of this technology is to develop a space-based Internet infrastructure. JAXA has also proposed the "i-Space" initiative in to

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utilize a space infrastructure to achieve high-speed internetworking [2]. Considering the very rapid expansion of the Internet, NICT and JAXA have recognized the importance of space-based network technology to expand worldwide Internet connectivity. JAXA plans to launch a Wideband Inter-Networking engineering test and Demonstration Satellite "WINDS". NICT is in charge of developing a high throughput on-board ATM baseband switching subsystem (ABS) as part of the mission payload of WINDS.

This paper describes an overview of the WINDS communication subsystem and the development status of the earth stations for the WINDS communication experiments.

II. Overview of WINDS

WINDS is an experimental communication satellite that is tentatively planned to be launched in 2007. This satellite has been designed for fixed satellite services in conjunction with the Internet to solve the "digital divide" problem. The concept behind the WINDS project is outlined in Fig. 1.

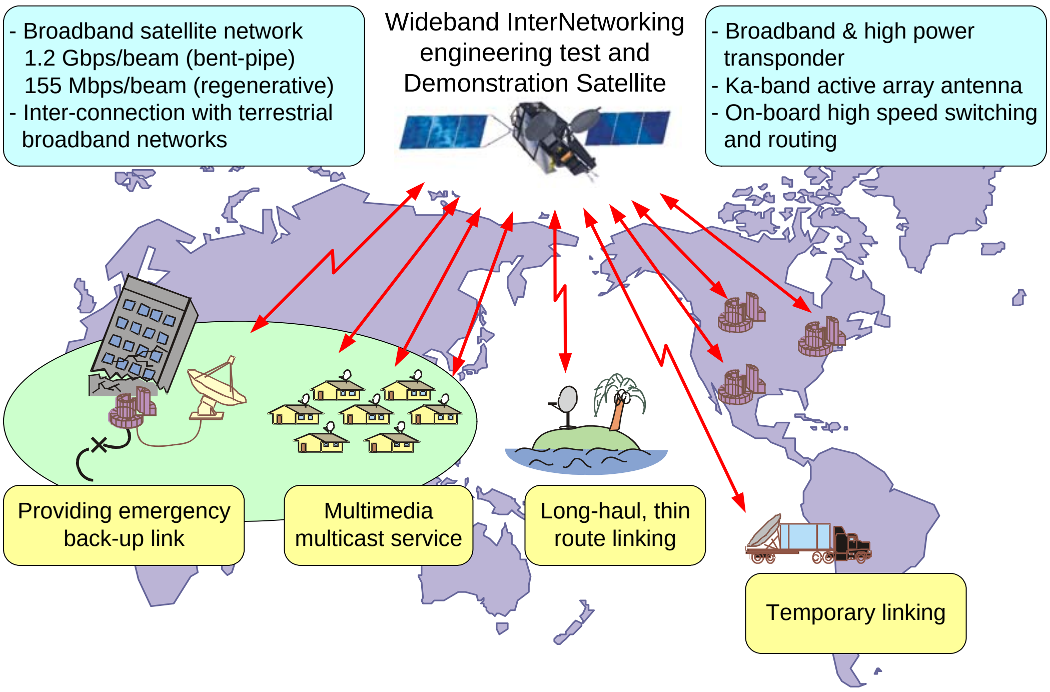

Figure 1. Concept behind the WINDS project

The satellite bus was designed based on the COMETS satellite bus [3] and has 2.4 ton of dry mass. Fig. 2 shows an external view of WINDS. It has two types of antenna systems. The first is a fixed multi-beam antenna system (MBA), and the second is an active phased array antenna system (APAA). Two MBAs dishes both with a diameter of 2.4 m cover Japan and other Southeast Asian countries with 19 fixed spot beams. The APAA covers almost all the entire area visible from the satellite with scanning spot-beam control technology.

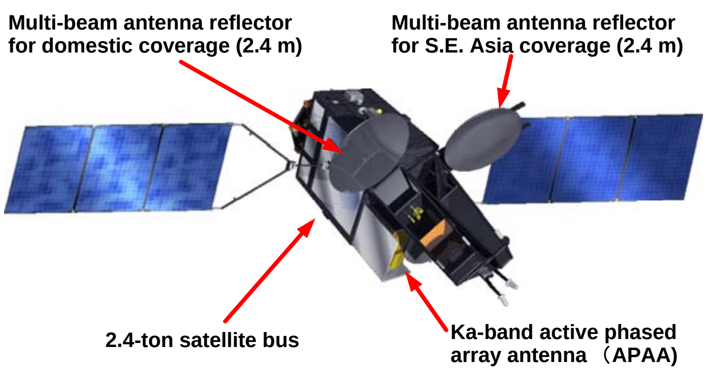

Figure 2. External view of the WINDS

Fig. 3 outlines the coverage of the satellite. Twelve domestic beams cover the main islands and Okinawa Japan, Seoul Korea, Beijing and Shanghai, China. Seven beams for Southeast Asian countries were prepared by using another MBA. The APAA can transmit two beams and receive two beams. These beams are scanned in intervals of 2 ms synchronized with SW controller. The beam scanning area of the APAA is outlined in Fig. 3.

Table 1 lists the major specifications for the WINDS satellite. The flight models for the mission equipment are being constructed. The APAA generates wider beams than the MBA as can be seen from Fig. 3; the EIRP and the G/T of the APAA are lower around 10 dB than those for the MBA.

In the regenerative mode of the WINDS communication subsystem, The QPSK receivers in the ABS demodulate up to 51 Mbps in the uplink signals. Nine channels for the receivers have been installed. Each receiver works as 14 channels of a 1.5-Mbps demodulator through the use of trans-multiplexing technology. Therefore, 126 channels for 1.5 Mbps users can be accommodated simultaneously. Three channels of QPSK modulators, which work at 155 Mbps of the time division multiplex mode, have been installed for downlink transmission.

In the bent-pipe mode, 1.1 GHz of the transponder with IF switch matrix capability can be applied to satellite switched TDMA operation.

Fig. 4 shows the mission configuration for WINDS. Eight ports of the Ka-band multi-port TWT amplifier, which has 280 W of total transmission power, are connected to the MBAs. The RX and TX IF switch matrices work at switching intervals of 2 ms according to the switch controller. The connection tables and ABS control data can be downloaded from the Network Management Center (NMC) that works as a reference earth station in Tsukuba space center (JAXA).

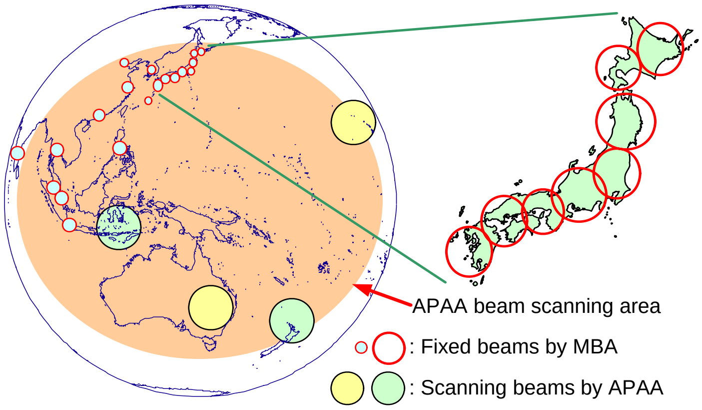

Figure 3. Coverage of WINDS

Table 1. Outline of WINDS satellite

Launch schedule	End of FY2007 by using H-IIA2024
Orbital location	GEO 143 degrees East (or 144.5 deg. E)
Satellite bus	2.4 tons, Zero-momentum 3-axis stabilized
Generated power	5,200 W
Satellite mass	4,850 kg (launch), 2,400 kg (dry)
Frequency band (Comm. Channel)	Uplink: 27.5– 28.6 GHz Downlink: 17.7– 18.8 GHz
EIRP	> 67.3 dBW (MBA), > 54.6 dBW (APAA)
G/T	> 16.3 dB/K (MBA), > 7.1 dB/K (APAA)
Regenerative mode	Uplink: 1.5 Mbps; 126 channels, or 1.5, 6, 24, 51 Mbps; 9 channels, or 155 Mbps (triplex of 51Mbps); 3 channels Downlink: 155 Mbps; 3 channels
Bent-pipe mode	Bandwidth: 1.1 GHz, up to 1.244 Gbps of transmission capability

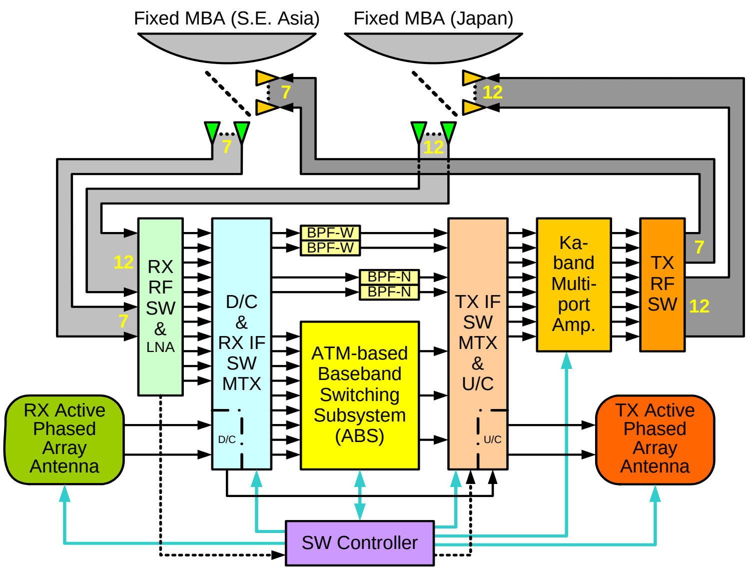

Figure 4. Mission configuration for WINDS

Fig. 5 shows the operation mode for the WINDS transponder. In the regenerative mode, 280 W of transmitting power is shared at the lower half of the bandwidth. All the receiving and transmitting signals are connected to ABS. Two channels for 622-Mbps TDMA signals can be transmitted through the 1.1 GHz bandwidth transponder in bent-pipe operation. Optional 1.244-Gbps TDMA transmission is also being studied.

In the hybrid mode, 280 W of total power should be shared for 622-Mbps TDMA signals and two channels for 155 Mbps (or 6 channels for 51 Mbps) regenerative mode signals.

III. Regenerative mode operation

Fig. 6 shows the on-board switching architecture. Eight beams selected from 19 of the MBA beams by RF switch units, are connected to IF switch matrices. Two beams from RX and TX APAA units are connected to the RX and TX IF switch matrices respectively. The ATM baseband switch (ABS) unit receives 9 channels for IF signals, which is 51 Mbps maximum. Three channels for 155 Mbps TX IF signals are output from the ATM switch.

Fig. 7 shows the configuration for an ATM based baseband switch (ABS). The ABS consists of digital demodulators (DDEM-1, 2 and 3), ATM switches (ATMS-A and B), and modulators (MOD-1, 2 and 3). Table 2 lists the major specifications for the ABS.

The engineering model (EM) for the ABS was developed in 2004 and evaluated in system interface tests with IF and RF equipment developed by JAXA. A proto-flight model of the ABS is being developed and will be completed in 2005.

A. DDEM-1, 2 and 3

The DDEM unit consists of frequency demultiplexers, QPSK demodulators and Reed-Solomon decoders. FPGA devices were used to make development and modification easier.

The demodulator can operate at multiple data rates of 6.1, 24.0, and

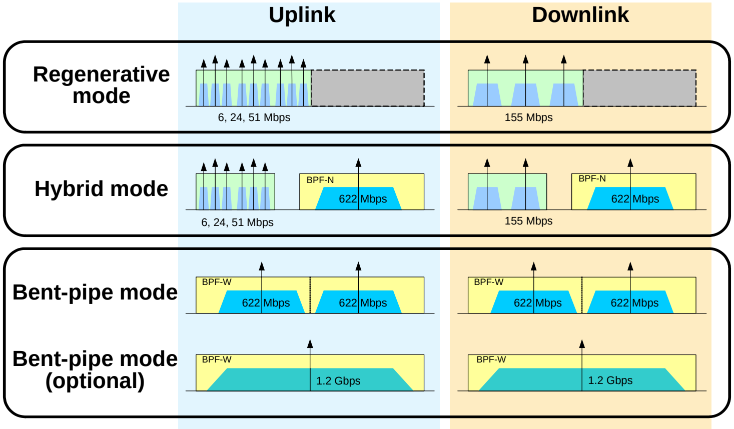

Figure 5. Operation mode for WINDS transponder

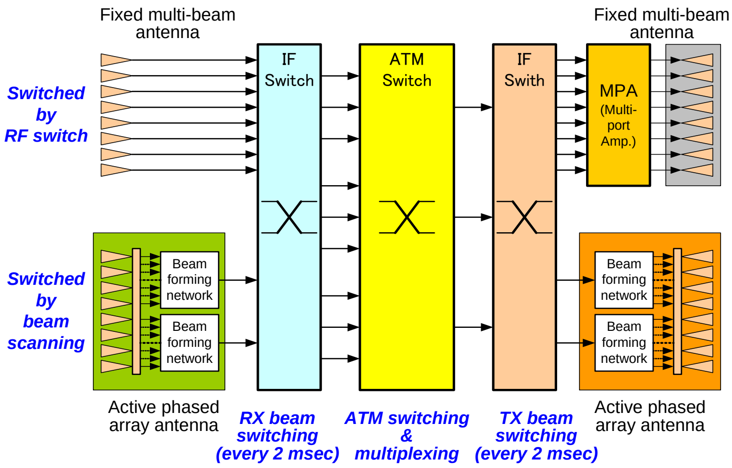

Figure 6. On-board switching architecture

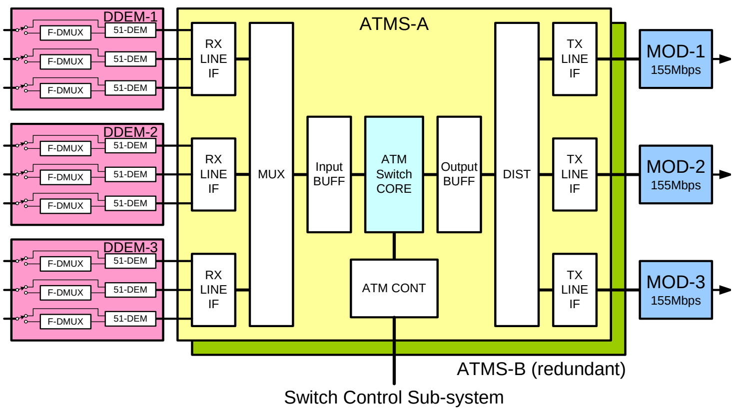

Figure 7. Configuration of ATM based baseband switch

51.84 Mbps by employing digital signal processing technology. The frequency demultiplexer unit in front of the demodulator works to receive 14 channels for 1.5 Mbps signals. There is a photograph of the EM in Fig. 8. The bit error performance of the EM is plotted in Fig. 9.

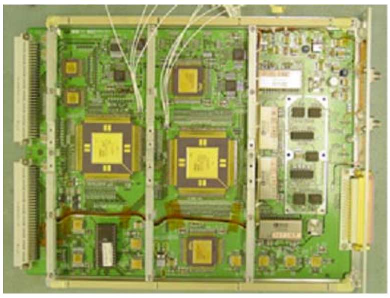

Figure 8. D-DEM sub-band filtering (F-DMUX) and demodulation board

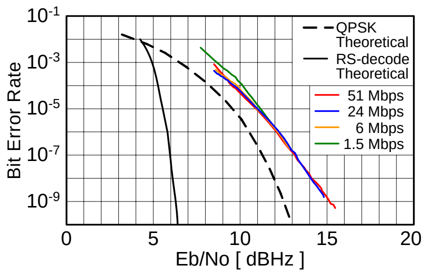

Figure 9. Bit error performance of D-DEM

The WINDS regenerative mode employs a TDMA-based access scheme as shown in Fig. 10. The figure shows the uplink frame format. Sixteen frames (Frames 0 to 15) makes up a super frame that has 640-ms intervals, and 20 slots (signaling and Traffic slots 1 to 19) make up a frame that has 40-ms intervals. The data rate for the signaling slot is fixed to 1.5 Mbps and has a 2-ms duration. The data rate of the traffic slot changes to 1.5, 6.1, 24.0, and 51.84 Mbps and has a 2-ms duration. The number of data blocks changes in accordance with the data rate.

Table 2. Major specifications of ABS

DDEM-1, 2 and 3	
Modulation scheme	Multi-Frequency TDMA-QPSK
Error correction code	Reed-Solomon (255, 223)
Multi-carrier	3 channels for each DDEM unit
Transmission rate	1.5 Mbps: 14 channels, or 6.1, 24.0, and 51.84 Mbps: single channel
Signal processing	Digital signal processing with FPGAs
ATMS-A and B	
Throughput of switch core	2.5 Gbps
Service class	Constant Bit Rate, Usable Bit Rate
Buffer size	32 k cells/line
DDEM interface	3 lines (UTOPIA-1)
Mod interface	3 lines (UTOPIA-1)
ATM switch core interface	UTOPIA-2
MOD	
Modulation scheme	TDM-QPSK
Error correction code	Reed-Solomon (255, 223)
Transmission rate	155.52 Mbps
Signal processing	Digital processing with analog filtering

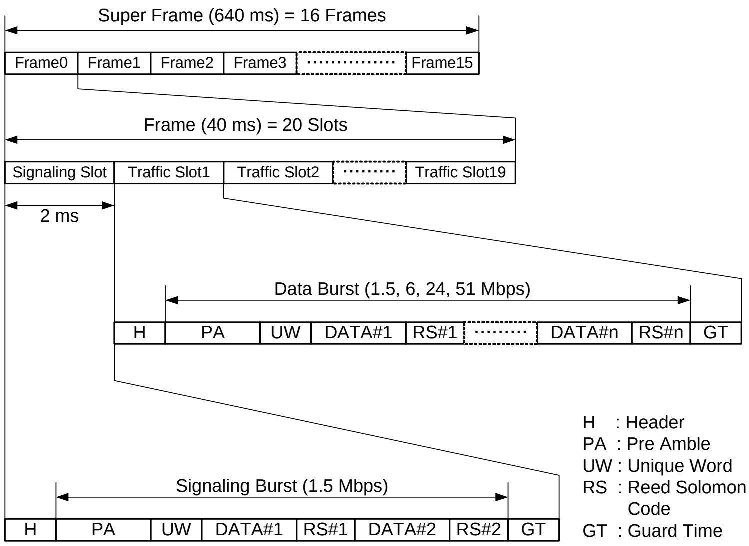

Figure 10. Uplink frame format

B. ATMS-A and B

As we can see from Table 2, the ATM switch core can manage 2.5 Gbps data throughput. However, the actual throughput for the regenerative mode is limited to three times 155 Mbps because of less frequency bandwidth, and equipment power consumption. There is a photograph of the EM in Fig. 11.

Figure 11. ATM switch core board

The ATMS operates according to control signals from the NMC developed by JAXA by using the permanent virtual channel (PVC) mode for ATM control. The SVC control scheme is currently being studied, and will be developed in the future by NICT.

C. MOD-1, 2 and 3

The MOD unit generates 155 Mbps of a time domain multiplexed (TDM) down link signal. QPSK modulation with Reed-Solomon error correction coding is carried out with the FPGA devices and analog filtering circuits. The MOD unit generates a reference burst for uplink TDMA synchronization for the satellite and all earth terminals. The downlink frame format is similar to the uplink one. However, the signaling slot contains burst synchronization and signaling information, instead of the association-data information in the uplink frame format.

IV. Bent-pipe mode operation

In the bent-pipe mode, the WINDS operates according to the satellite-switched TDMA scheme by using the IF switch matrices with MBAs and APAA. For the bent-pipe mode with APAA, WINDS is a scanning spot beam multi carrier SS-TDMA satellite system.

The frequency allocation for the bent-pipe mode is shown in Fig. 12. 1.1 GHz of total bandwidth is divided into the upper and lower band, and two channels for 622 Mbps QPSK signals are transmitted through these bands. To achieve giga-bit communications through WINDS, NICT is developing a dual 622-Mbps QPSK modem by using state-of-the-art FPGA digital signal processing architecture.

The frequency allocation for the full-band mode is shown in Fig. 13. This mode was prepared as an option for future experiments with the 1.2 GHz-single carrier modem. NICT has plans to upgrade the 622 Mbps-QPSK modems to a multi-clock rate system up to 1.2 Gbps.

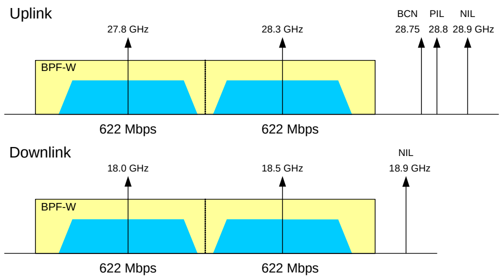

Figure 12. Frequency allocation for bent-pipe mode (half-band)

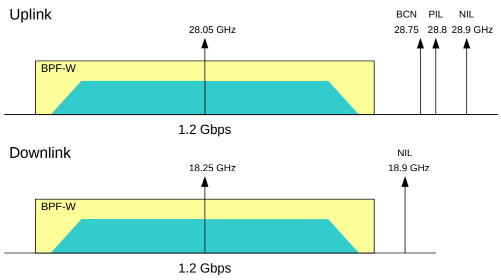

Figure 13. Frequency allocation for bent-pipe mode (full-band)

V. Development of earth stations for communication subsystem

A. NMC (reference earth station)

In the regenerative mode, the ABS of WINDS operates according to control signals from the NMC developed by JAXA. A 9.2-m dish for the NMC is shown in Fig. 14. The ABS is controlled with the permanent virtual channel (PVC) mode of ATM control. The connection tables are generated according to a pre-assigned schedule for communication experiments by using the operation scheduler at the NMC. The generated connection data and control information are transmitted to the ATM controller of WINDS through the traffic slots and a network information link (NIL). The regenerative link controller at the NMC works as connection control for the user terminals according to pre-assigned connection data.

Figure 14. NMC (JAXA)

Figure 15. USAT (45 cm antenna)

Figure 16. VSAT (1.2 m antenna)

B. USAT and VSAT

The USAT and VSAT terminals designed to operate with

WINDS ABS connections are being developed by JAXA. The 45-cm diameter USAT can transmit a 1.5-Mbps uplink data rate and receives 155 Mbps of the TDM downlink signal. A high data rate VSAT terminal, which can transmit up to 155 Mbps of uplink, is also being developed by JAXA. Figs. 15 and 16 show an ultra-small aperture terminal (USAT) and VSAT.

C. 622 Mbps earth station for bent-pipe mode

In the bent-pipe mode, WINDS works as a transponder with a 1.1-GHz bandwidth. The user can transmit parallel 622-Mbps QPSK signals or a single 1.2-Gbps QPSK signal by using the 1.1-GHz transponder.

High-data-rate earth stations equipped with 5-m-diameter dishes with 622-Mbps and 1.2-Gbps QPSK modems are being developed by NICT.

Fig. 17 shows the configuration for a “Gigabit” earth station. Two channels for 622-Mbps burst modems are combined by the digital terminal. Users connected to a WAN/LAN can transmit up to 1.2 Gbps of data through WINDS.

The 622-Mbps QPSK modem has been designed to operate with a turbo product code FEC system as can be seen from Fig. 18, and has been predicted to operate with a BER of less than 1 x 10^{-10} at 4 dB of Eb/No. The baseband signal processing in the modem is achieved by using the digital signal-processing scheme with the FPGAs. Therefore, nonlinearity or degradation of frequency flatness occurring in the wide band transponder can be compensated for by using the equalizer function in digital processing.

Fig. 19 shows the receiving section of the high-speed burst modem. The signal processing can be carried out in two FPGA chips by using a parallel processing scheme. The demodulator board for the burst modem is shown in Fig. 20. This can be apply to 1.2-Gbps demodulation by merely changing the configuration data for FPGA operations.

A 1.2-Gbps QPSK modem is also being developed by NICT.

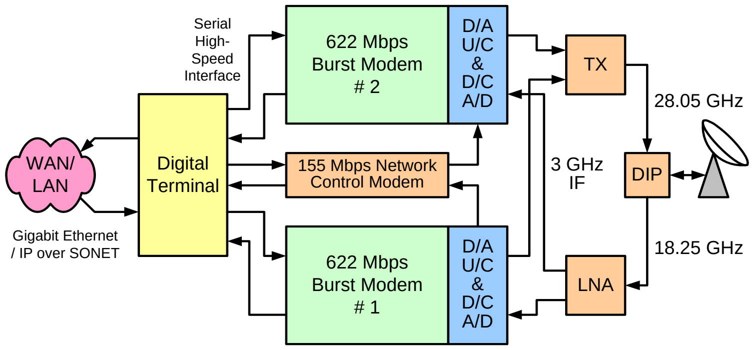

Figure 17. WINDS ground terminal for bent-pipe mode

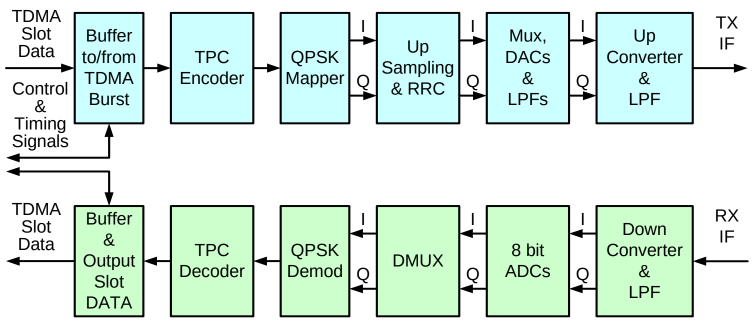

Figure 18. High-speed burst modem for bent-pipe mode

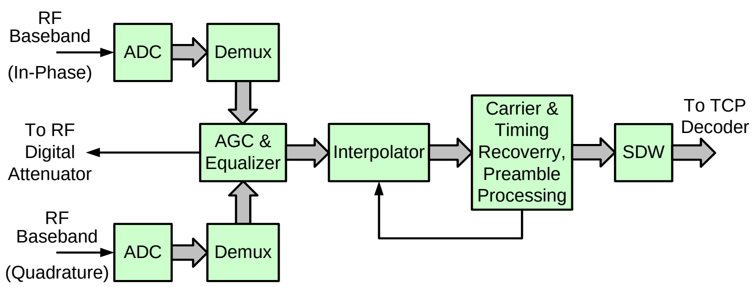

Figure 19. Receiving section of high-speed burst modem

Figure 20. Demodulator board for WINDS Burst Modem

VI. Conclusion

The development of the EM for mission equipment was completed, and it is at the flight model manufacturing stage. The development of the earth stations is at its busiest stage. We should prepare a certain number of earth stations for communication experiments before WINDS is launched. As much of the mission equipment employs digital signal processing technology, the developments can be sped up dramatically.

Acknowledgments

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