TT&C SYSTEM FOR NASDA NEW GROUND NETWORK

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ABSTRACT

In response to a NASDA decision to upgrade their satellite ground network (GN) to provide worldwide coverage as well as interoperability with other agencies, MELCO has assembled remote ground stations that include the L-3 Communications Telemetry & Instrumentation (L-3 T&I) NETstar 2000[1] TT&C system. Software developed by Mitsubishi Electric Corporation (MELCO) controls a variety of COTS products in the remote stations, including the L-3 T&I system. L-3 T&I's TT&C system provides modem services, high accuracy ranging, Doppler compensation, command verification, and CCSDS protocol processing for a wide range of LEO/MEO/GEO satellites.

KEY WORDS

TT&C, Ranging, CCSDS, Satellite, Modem

INTRODUCTION

NASDA (National Space Development Agency of Japan), Japan's Space Agency, launches satellites by their own rockets, operates Japanese satellites, and supports satellites of foreign agencies by request. NASDA also requests foreign agencies to support Japanese satellites with tracking coverage outside the existing Japanese Ground Network (GN), which has narrower coverage than the New GN. In order to have worldwide commonality for interoperability and flexibility to interface between satellites and the ground, NASDA is adopting a new data system recommended by CCSDS (Consultative Committee for Space Data Systems). NASDA plans to reduce costs by using commercial-off-the-shelf (COTS) equipment to support compatibility testing.

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[1] *NETstar 2000 has recently been renamed Astra™.*

Mitsubishi Electric Corporation (MELCO) selected the newest generation of TT&C products from L-3 T&I (NETstar 2000) as the equipment to meet their system requirements.

Part 1: NASDA NEW GROUND NETWORK (GN) SYSTEM CONCEPT

(Izumi, Fujiwara)

NASDA planned to develop a New GN to:

(1) Renew the existing GN and start to operate satellite launches in the summer of 2002
(2) Adapt the new data system recommended by CCSDS
(3) Reduce the operational cost (automatic unmanned station operation with PC control and WAN)
(4) Expand the tracking capability for worldwide coverage (increase foreign stations from 1 to 4)
(5) Install the Tsukuba Test Station with a cable interface point with the satellite in order to reduce the cost of the Satellite Simulator and the travel required to each station for compatibility testing
(6) Ensure all stations have the same design and manufacturing to have the capabilities described in above items (4) and (5).

The New GN configuration (Figure 1) consists of the two main location areas, Tsukuba Control Center and 7 remote stations (3 domestic plus 4 overseas). The Tsukuba Control Center includes the Satellite Test Building, Space Management Control System, and other systems outside of the New GN system. Tsukuba is the only interface point not only to Japanese users, but also to foreign agencies. Therefore, the New GN requires the Tsukuba Control Station to interface with outside operators. The Tsukuba Test Station is installed in the Satellite Test Building. Each remote station is run without an operator other than maintenance staff, using automatic and remote control capabilities from the Tsukuba Control Station to reduce operational cost.

(1) 3 domestic stations and 4 overseas stations (Figures 2 and 3)
(2) Earth station and Tsukuba Control Center is connected via WAN (TCP/IP)
(3) All earth stations and test stations are controlled at Tsukuba Space Center
(4) Each station tracks satellites independently and automatically
(5) New GN has interface from/to other systems such as FDS (Flight Dynamics System), SMACS (Spacecraft Management Control System), RTEP (Real-Time Trajectory Estimation Program), and GEANS (TLM/CMD Protocol Converter for NASA/ESA)

The Tsukuba Test Station Concept is designed:

(1) To use the same equipment as the earth station
(2) To conduct compatibility testing between the earth station and satellite prior to launch

The Tsukuba Control Station Concept includes:

(1) Operation Planning
   a. To supervise the operation plan for all stations
   b. To supervise the database for all stations

(2) Terminal — To monitor and control all stations by connecting to Ground Controller via WAN

(3) Network Controller – To monitor status of router and traffic with SNMP (Simple Network Management Protocol)

4) Tsukuba Controller
   a. To supervise Tsukuba NETstar 2000
   b. To convert protocol between Tsukuba NETstar 2000 and SMACS

The Tsukuba NETstar 2000 Concept is designed:

(1) To provide interoperability with other organizations' stations

(2) To process CCSDS telemetry, which is received from foreign agency (NASA/ESA) stations via GEANS, and to transmit Packet Telemetry to SMACS

(3) To process CCSDS commands received from SMACS and to transmit CLTUs to foreign agency stations via GEANS

The trackable satellite is:

(1) Satellite on lower than geostationary orbit

(2) From the launch period to orbit

(3) New GN interface to the satellite through USB RF frequency with 1 Mbps maximum transmission rate of telemetry (in order to support real-time transmission of more than a few 10's of kbps between station and Tsukuba Control Station, the WAN has to be upgraded to a higher bandwidth line)

(4) To track the satellite for zenith position and on lower circular orbit more than 500 km high

The station has two major mechanical assemblies (Figure 3), a 10m-diameter structure and a shelter. The antenna has the functions of transmit/receive in USB frequency, with 3-axis movement for zenith tracking and 4 channels LNA, as well as a downconverter. The shelter includes RF, the NETstar 2000, a PC, and network equipment (leased line and backup ISDN line). This simple mechanical configuration is very useful for transportation and has a simple civil/power/communications interface. The shelter has a 1 kW solid state power amplifier, an upconverter, a telecommand echo downconverter, a 4-channel diversity tracking receiver with pre-combiner, a NETstar 2000 with modem/decom/ranging and Doppler measurement/CCSDS, a time standard and 10 MHz frequency reference, a PC for unmanned and automatic operation, and network equipment (Figure 2). NASDA awarded New GN system integration to MELCO, and MELCO awarded Modem/Decom/Ranging and Doppler measurement/CCSDS to L3 T&I. MELCO and L3 T&I are in the factory integration phase.

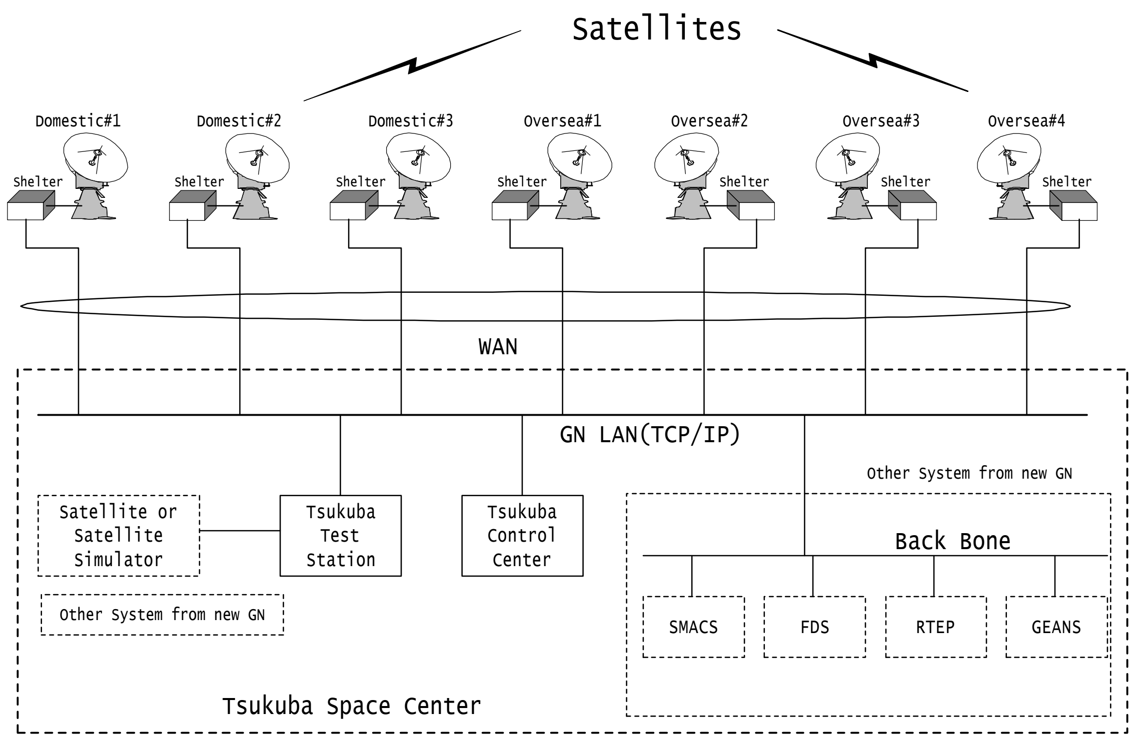

Figure 1. Tsukuba New GN System and Global Network

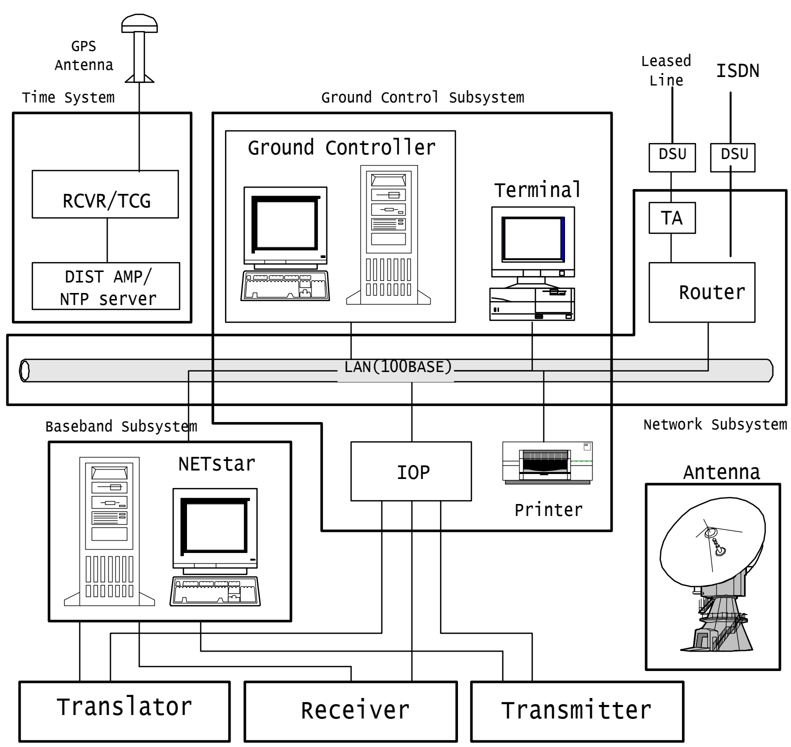

Figure 2. New GN Station

Figure 3. Ground Station (New GN): 10m Tracking Antenna with Electronics Shelter at Left

Part 2: MEETING NEW GN NEEDS WITH L-3 T&I'S NETSTAR 2000

(Sutton, Meyers, Willis)

Key challenges from the MELCO and NASDA requirements that have been met include:

(1) Providing TT&C support for a wide variety of satellite missions, including LEO, MEO, GEO, and elliptical orbits
(2) Overcoming range measurement bias and random errors in the presence of high Doppler dynamics
(3) Maintaining high-performance, multi-mode signal acquisition and demodulation in the presence of high Doppler dynamics
(4) Combining SATCOM MODEM signal processing and digital CCSDS and TDM processing in the same box
(5) Maintaining reliable and repeatable performance

L-3 T&I started a project to develop the ultimate, multi-mission telemetry, tracking, and commanding (TT&C) MODEM before MELCO selected NETstar 2000 for the NASDA New GN program. We not only wanted to provide superior parametric performance in key areas like range and range rate accuracy, lock-on performance, spectral purity, and bit error rate (BER), we wanted to achieve these parameters under a wide variety of challenging input signal conditions, including high Doppler (LEO and elliptical orbits) and low signal-to-noise ratios (S/N_o). Additionally, the system had to adapt to a wide range of different data structures, modulation formats, and ranging techniques. The result was a good fit for MELCO's needs.

To achieve both the flexibility and performance required, we needed to apply the latest advancements in digital signal processing and build a *software-driven* TT&C MODEM. In reality, it needed to be not just *software-driven*, but *software/firmware-driven*. Field programmable gate arrays (FPGAs) were selected to handle high-speed DSP for data rates above a few hundred ksps. We did consider application specific integrated circuits (ASICs), which are very powerful and cost-effective. However, their operation cannot be changed, and NASDA's application environment requires the highest flexibility available. DSP microprocessors were selected for low rate operations, including automatic gain control (AGC) and automatic frequency control (AFC) loops.

There are many advantages to DSP implementations. First, there is no component aging like one sees in an analog modem. After ten years, the DSP algorithms will perform in the same manner as they did on the first day. L-3 T&I's next-generation TT&C system uses FPGA and DSP microprocessor-based designs, which can easily adapt to new and different modulation or demodulation schemes just by loading new firmware. An additional benefit to using DSP processing is that it is very easy to implement filters with perfectly flat differential group delay characteristics, which is critical in a high-performance ranging system.

In all coherent turnaround ranging systems, the time delay of a ranging signal from the ground station's signal generator to the spacecraft transponder and back again to the ground station's range processor is measured. This time delay is then converted to range using the property that the electromagnetic waves travel at the speed of light. Notice that this is a closed loop system. Everything in the loop affects the range delay measurement to some extent. Since most TT&C systems use linear Phase Modulation (PM) as the final modulation stage, the phase characteristics of each element in the loop are important. Circuit propagation delays, non-linear phase characteristics in filters, AGC phase variations, local oscillator phase noise, A/D and D/A aperture uncertainty, as well as atmospheric distortions of the electromagnetic wave are only some of the range error contributors. Most ranging systems account for static propagation delays or phase shifts through both the satellite transponder and the ground station. However, it is the dynamic phase shift elements that are most troublesome. These are the errors caused by signals moving in frequency through filters and phase shifts that are common in most AGC designs.

Obviously, anyone attempting to design a high-performance ranging measurement system must incorporate the design of the complete TT&C system, including modulators, demodulators, up/downconverters, power amplifiers, and, of course, the satellite transponder. L-3 T&I has optimized the most critical areas of the ground station, including the IF processing, modulation/demodulation, and range processing. We have also incorporated a special DSP processing algorithm, which overcomes a critical limitation of classic tone range processing systems.

Most tone range processors to date have used phase-locked loops (PLLs) to lock onto the frequency and phase of the noise and Doppler-corrupted receiving tone. To achieve high accuracy, classic system designs typically used very small loop bandwidths to reduce random errors on the PLL. However, if the signal happened to move because of residual Doppler (LEO and MEO orbits), bias errors would develop in the PLL. So there has always been a trade-off between loop bandwidth (random errors) and bias errors, which limit tone range system accuracy.

L-3 T&I has found a way to get both low random errors and low bias errors at the same time. Our system uses a digital PLL (DPLL) and follows it with a series of DSP processing algorithms that unwrap the phase difference between the transmit tone and receive tone and apply unique algorithms to phase-difference data. The DPLL can be operated at relatively high loop bandwidths because the unique processing algorithm acts like a tracking filter. The algorithm reduces the random errors, while following the difference signal dynamics. Since, the DPLL can be operated at a higher loop bandwidth, bias errors are greatly reduced. Actual systems testing has shown that the combination of this superior DSP-based tone range processor and a system design that is optimized for ranging accuracy has produced a TT&C system with nearly theoretical performance.

The NETstar 2000 design is now complete and the result is a highly versatile, modular, high-performance system for satellite TT&C in a PC chassis. The system runs under the NT operating system with highly portable Java control software.

Physically, the systems provided to MELCO for use in the New GN program for NASDA consist of a large, industrial grade PC that holds the 14 modules required to meet NASDA's demanding needs (see Figure 4).

Figure 4. Rack-Mount TT&C System Chassis with Flip-Up Display

The modules shown in the block diagram (Figure 5) constitute five major subsystems:

(1) Uplink
(2) Downlink
(3) Command Echo Verify
(4) Ranging
(5) Data Processing

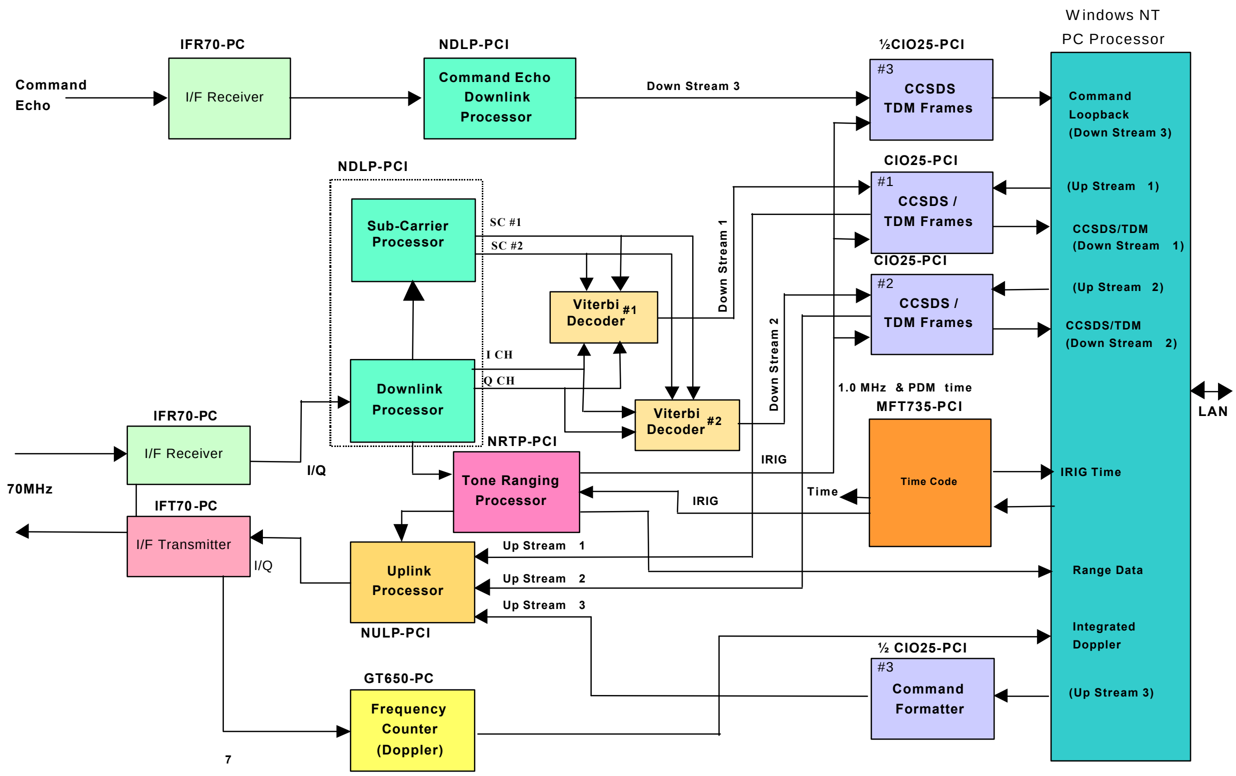

Figure 5. NASDA New GN NETstar 2000

System Components

The Uplink subsystem consists of the IF Transmitter module and a DSP-based Uplink Processor. The Uplink processor creates a baseband signal with main modulation of either direct BPSK/QPSK or linear PM with secondary modulating signals, including direct PCM, up to two tunable BPSK/QPSK subcarriers, and ranging signals. L-3 T&I's next-generation TT&C system currently supports multitone ranging. However, development plans include PRN ranging for SGLS , GSTDN, and MPTS ranging. The IF Transmitter takes the baseband I/Q digital data from the Uplink processor and performs digital-to analog (D/A) conversion, filtering, quadrature upconversion to 68-72 MHz (70 MHz, nominal). Besides being able to set the output frequency, the system can scan the output frequency to aid the satellite in locking on. The IF Transmitter provides good spurious suppression of <–60 dB.

The Downlink subsystem consists of IF Receiver, Downlink Processor, and Subcarrier Processor modules. It is able to receive and demodulate any of the signals produced by the uplink in order to support loopback testing. It can perform main carrier linear PM or BPSK/QPSK demodulation and can also, in composite linear PM demodulation mode, receive and demodulate PCM and/or up to two BPSK/QPSK subcarriers and ranging signals. The IF Receiver is optimized for low group delay and low noise for the support of highly accurate ranging in LEO spacecraft. The system performs Fast Fourier Transform (FFT) processing on the incoming signal to aid in rapidly acquiring the signal, even when Doppler shifts the signal by up to 160 kHz at rates up to 3 kHz/second.

Key to performing both high-performance IF processing and digital processing in the same chassis is a set of proprietary techniques for shielding the IF components from the noisy digital environment. These techniques have proven highly effective in producing noise floors in the IF receiver of -100 dB.

A second set of IF Receiver and Downlink Processor modules perform command echo verification to detect whether the command that went out the antenna matches the command that was to be sent.

The Ranging subsystem consists of the NRTP-PCI DSP Range Processor working through the Uplink and Downlink Processor modules. This combination of modules generates, modulates, receives, demodulates and compares a series of tones to determine satellite range accuracy to better than 1 meter rms, even in high Doppler (500 Hz/sec) conditions. The IF architecture provides a mechanism for continuous downlink Doppler detection, called the Doppler Error Metric circuit. This circuit enables the TT&C system to perform continuous integrated Doppler measurements. Then, the integrated Doppler information is used to calculate multiple differential ranging solutions, and when combined with the range measurement, forms a high accuracy range and range rate (RARR) measurement.

For cost-effectiveness and versatility, the Ranging, Uplink and Downlink modules of the NETstar 2000 are all based on the general-purpose Advanced Processing Module (APM). This module consists of a set of FPGA and DSP chips that enable the system to be set up to perform a wide variety of processing functions just by loading different images into the APMs. In this way, within minutes, the system can be set up and checked out to service a different satellite type requiring different demodulation methods. This same capability enables the upgrade of system performance in the field with just a new software load.

The remainder of the modules in the system were provided to support digital signal processing. The Viterbi decoder module performs soft-bit decoding of convolutionally encoded signals. The CIO frame syncs (with sync logic), derandomizes, and performs Reed-Solomon and CRC processing in support of the CCSDS recommendation for downlink signals. It also supports CRC and randomization functions for the uplink commands. The IRIG board decodes IRIG-B and provides 1-2 microsecond accuracy timing to the other modules.

The Time Interval Analyzer card supports integrated range rate (Doppler) processing.

The PC/NT processor supports the balance of the CCSDS and telemetry frame/subframe/measurand processing.

System Software

The NETstar 2000 is designed to work with two relatively new software packages from L-3 T&I: Impact and Vista. Impact provides full CCSDS processing compliant with both conventional (Telecommand) and AOS recommendations for both the uplink and downlink. Vista provides system setup and control completely via a powerful application programming interface (API). Both Impact and Vista are implemented in Java for complete portability between workstations and for remote use over Ethernet networks. A GUI used on a flip-up flat panel display also uses the API. In the New GN application, part of the Vista is located on a server workstation and communicates via RMI (Remote Method Invocation) over an Ethernet LAN to the PC. Static information is held in a database in the system grouped by "project." Each satellite is a different "project," so all of a satellite's standard characteristics can be stored and later recalled and/or modified for use in supporting a pass.

A variety of test capabilities are provided with the NETstar 2000 to aid in initial system integration, routine system checkout just prior to a satellite pass, and/or system fault isolation. These include:

(1) Loopback test capability of each modulation/demodulation mode
(2) BER testing
(3) Telecommand decoding to complement the telecommand encoding capability
(4) Ranging calibration procedure to zero out ground delays
(5) Command monitor display to show the commands that reach the system
(6) PC Anywhere to allow remote manual operation of the system

CONCLUSION

L-3 T&I and MELCO have cooperated to provide the NASDA New GN program a high-performance commercial baseband system to support LEO/MEO/GEO satellites. This system, called NETstar 2000, is available as a COTS product for utilization by the space industry. The salient features of high accuracy ranging and multimission capability offer users of the product a solution that can support legacy, current, and future scenarios. Because this product is based on Windows NT with a Java application programming interface, product obsolescence is not a factor. The major feature of the system is that it can be used for all types of ground station scenarios, including launch and early orbit, and station keeping. Since the hardware is configurable via firmware downloads, the system is an ideal solution for users flying satellite products from multiple manufacturers. Commercial ground stations of the future can be designed to use one hardware solution to "fly" any type of satellite that the customer desires to purchase. Operator training and hardware and software maintenance will be reduced, ensuring low life cycle costs over the life of the ground station.