Design of Ka-band Satellite Ground Station Antenna/RF System

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Abstract

This paper describes the design of the Ka-band Antenna/RF system, which was developed for the experiment of the high-speed satellite communications with geostationary satellite. The design issues described here are the ka-band characteristics for having an optimum performance, and the system characteristic for having a reliable and an extensional operation.

Key Word : Ka-band Ground Station, Satellite

Introduction

According to the increase of the demand for the high data rate satellite communications, ETRI had the plan of the high-speed satellite experiment. For this experiment, ETRI developed the ka-band antenna/RF system for the link experiment for the 155 Mbps QPSK and 8PSK modulation signal to/from the Koreasat-3 in geostationay orbit. The main key for the design of this ka-band ground system is to meet the link margin for the communications of the 155 Mbps QPSK and 8PSK modulation signal, which have the 160 MHz and 80 MHz bandwidth, respectively. Also, in addition, the considerations for the design is the extension of system operation range, which has the wide range of 275 ~31 GHz for uplink, 17.7-21.2 GHz for downlink, and two polarization of RHCP and LHCP. If all products by the ideal link budget are provided in specified period, the system design is very easy. But especially for ka-band frequency band, it is not actually true. Therefore, this system design should be performed with the products searches, which are the commercial product or the development period. The minimum cost and maintenance and operation with minimum intervention by a person are basic for the system engineering.

The system consists of 7m antenna which is accommodated with four ports diplexer, TWTA, LNA, Ka-band Up/down converter installed in antenna hub to reduce the losses, IF(140 MHz) converter, UPC and tracking unit as shown in Fig. 1. For the extension of system operation range, two polarizations of RHCP and LHCP are employed. The center frequency for L-band is 1.2 GHz for uplink and downlink, and its frequency range is 0.95 GHz to 1.45 GHz. All active RF equipment have 1:1 redundant configuration, which is automatically selected to the equipment in case that one equipment fail. To reduce the interference from the transmission signal of the TWTA, there is a transmission rejection filter (TRF) at LNA input stage, and its rejection band is 27.5 to 31.0 GHz. The tracking unit, which consists of L-band down-converter, tracking receiver, antenna control unit, and servomotor, has the functions of step autotracking,

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program tracking, and manual tracking. For the compensation of rain fade, there is uplink power control unit of L-band, which detect the signal level from the beacon signal and control the uplink power level by using a correction algorithm in UPC.

There are three power detection points of the L-band beacon, L-band receive, and L-band transmission point for monitoring the signal level variation during 24 hrs. The L-band line between converter and ka-band converter with Ka-band output in antenna hub is RG214 for the lengths of 30m to have wide traveling range for azimuth. There are two pair transmission lines for the lengths of 150m between the shelter room and the building room. The lines for 140 MHz and L-band are RG216, and Andrew LDF4-50A (1/2 ") cable, respectively. All kinds of RF equipment are controlled by remote M&C in room, but the antenna control unit is only monitored to protect the antenna damage due to an operator fault, because in general the commercial earth station is maintained and operated by an non-exporter unlike to be maintained and operated by an exporter such as TT&C system.

The final test of the system is performed with the koreasat-3 satellite ka-band transponder and 45Mbps and 155 Mbps MODEM. The tests related to the receiving path such as Rx antenna pattern and isolation, G/T tracking is performed with the satellite beacon, and the tests related to the transmission such as Tx antenna pattern, and EIRP is performed with the TT&C station of the Koreasat-3. The final link verification is performed by the loop-back test, which is transmitted by 45/155 Mbps QPSK MODEM of ETRI's earth station, and received 45/155 Mbps QPSK MODEM through the koresat-3 ka-band transponder. ETRI has the plan for the link experiment of 155 Mbps 8SPK with CRL's 5m Ka-band earth station in Japan.

SYSTEM DESIGN AND PERFORMANCE

The main functions of the Ka-band antenna/RF system as the configuration shown in Fig. 1 are to transmit and to receive the 155 Mbps QPSK and 8PSK modulation signal to/from the Koreasat 3 satellite and other Ka-band satellite on the geostationay orbit. To reduce the RF loss, all RF equipment of TWTA, LNA, and up/down block converter are installed in the antenna hub. For a loop back test, there is a manual step attenuator 70 dB range with 1dB step in L-band stage instead of RF loop back, to reduce the decrease of the performance of G/T due to Ka-band adapter.

The tracking accuracy of the system is maintained within 0.03 degree in rms to maintain an optimum performance. The isolation between the transmission and the reception in the

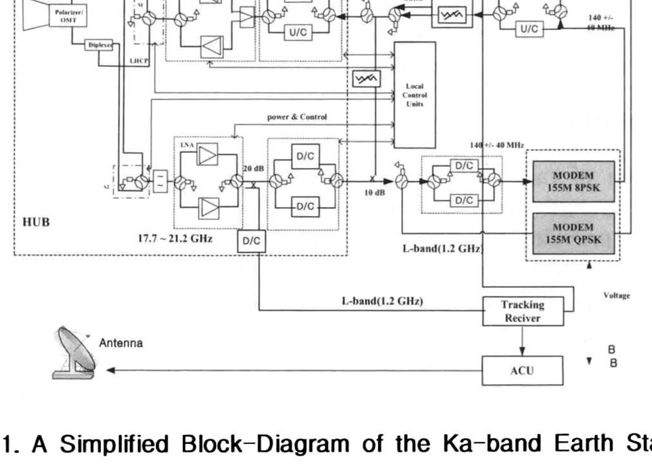

Fig. 1. A Simplified Block-Diagram of the Ka-band Earth Station

antenna diplexer is 80 dB, which is calculated for LNA intermodulation. The insertion losses in 27.5 to 31 GHz between the TWTA and antenna horn which includes polarization switch, diplexer, waveguide run loss and TWTA 1:1 redundant output loss switch is 2.4 dB. Also, the insertion losses between the LNA and antenna horn which includes polarization switch, diplexer, waveguide run, transmission rejection filter, and LNA 1:1 redundant input switch, is 2.6 dB, which to be obtained from design trade-off. The VSWR of the feed in antenna is 1.35:1. The polarization isolation between the RHCP and LHCP is 20 dB. To select the polarization of RHCP or LHCP, there is the local polarization selection unit in the rack of shelter room. The antenna EIRP at on-axis is normally about 71.0 dBW with the TWTA output back-off of above 3 dB. The G/T of the system at antenna on-axis at elevation of 45 degree is 32 dB/Ko. The traveling range is +/- 180 deg for azimuth axis, and +0 deg ~90 deg for elevation axis.

The antenna has the deicing unit on the reflector and blowing and heating and cooling unit in hub, which are to against for snow, and to maintain a constant temperature in hub. The IF frequency bandwidths of L-band and 140 MHz is 200 MHz and 80 MHz for QPSK and 8PSK, respectively. But at actual equipment, the bandwidth of L-band is 500 MHz for operational extension. Therefore, it is possible to operate the system until 500 MHz of transponder without an adjustment of RF frequency. The dehydrator provides the pressurization for the RF waveguide and feed assembly and to provide dry air for the RF waveguide and feed assembly.

Uplink/Downlink

The system provides the transmitting and receiving path for either a 155 Mbps QPSK signal or a 155 Mbps 8PSK signal. Thus the system provides the Ka-band up-conversion and amplification for either of these two carriers, enabling the selection of the transmission of either carrier, which controls the modem selection switch of the system. The output of the L-Band QPSK modem or IF to L-band up-converter is provided to the L-band uplink power control, which provides 20 dB attenuation to compensate for the current rain fade conditions of the satellite link based on the received beacon signal's strength. The output of the L-band UPC is provided to the switch, which decides whether to pass the QPSK or 8PSK carrier to the system's L-Band to Ka-Band up-converters. The L-Band to Ka-Band up-converters up-convert the selected uplink carrier (QPSK or 8PSK).

The LNA for traffic carrier signal, and the tracking signal provides it's output to the 1:1 redundant Ka-Band to L-Band down-converter and one Ka-Band to L-Band down-converter for the tracking error signal. A directional coupler is provided at the output of the LNA. This coupler is used to provide the main signal to the tracking unit. If the down-conversion to IF is selected (through the IF / L-band selection switch manually), the downlink signal is provided to the L-Band to IF down-converter, which further down-converts the downlink signal to 140 MHz and provides it to the 8PSK IF modem.

Rain Fade Compensation

For compensation of rain fade, the system has the function of the uplink power control based on the signal strength from beacon signal, which is received by the tracking receiver. The tracking receiver provides the UPC unit and ACU with the dc signal proportional to the beacon signal strength, which decreases as the rain increase. Under clear sky condition, the uplink power control unit has the maximum attenuation of about 20 dB. The ratio of the downlink signal attenuation to the dc signal decrease for the rain fade is calibrated in UPC unit. Also, the ratio of the uplink signal attenuation to the downlink signal attenuation can be applied by the 1.84, or other correction algorithm in UPC unit. Therefore, the TWTA output back off (BOo, dB) under clear sky condition is determined by the required EIRP of the system for the normal operation of the satellite.

The input back-off setting for TWTA output back-off is determined by the TWTA transfer curve given by a vender. The level from the Modem of 8PQPSK and QPSK to TWTA input is linear characteristic, because the TWTA input back-off setting is adjusted by the attenuator of the UPC unit. Therefore, the ka-band up-converter is operated in linear region. The UPC has the fixed attenuator, which is used in case that in the event of an attenuator fault or power loss to an attenuator. In that case, uplink signal is switched to a fail-safe path with the fixed attenuator, which is setting to clear sky condition for QPSK or 8PSK Modem path.

Antenna Design

The antenna consists of antenna mount, reflector, feed and feed horn, diplexer, antenna control unit, tracking down-converter, and other auxiliary units. The reflector geometry of antenna is the cassgrain yoke type to have minimum loss at feed. The antenna hub is equipped with enough space to install the TWTA, LNA, and ka-band up/down converter for transmission and reception of traffic data, and one ka-band down-converter for auto-tracking.

The antenna structure has yoke-tower mount type to have the wide traveling range of 180 for azimuth axis. The access into the antenna hub is easy for the maintenance. The system has two operating modes, single-update and time update mode. In single-update mode, the system maximizes the signal and switches off the drive until the operator decides to begin the tracking. In time-update mode, the system updates the antenna automatically at regular intervals thereby maintaining an operational antenna gain throughout. This interval is set from a few seconds to several hours. The system track the satellite to maintain the operational gain of the antenna receive beam within 0.6 dB of the peak gain at all times. The antenna has "Stow" functions for elevation axis to protect the antenna against strong wind velocity.

Antenna Feed and Horn

The insertion losses between the TWTA and antenna horn, which includes polarization, switch, diplexer, waveguide run and TWTA output switch is 2.4 dB. The insertion losses between the LNA and antenna horn, which includes polarization switch, diplexer, waveguide run, transmission rejection filter, and LNA input switch is 2.6 dB. These design data are the maximum loss obtained from the trade-off between the antenna size, TWTA output size, and required G/T.

Diplexer

For selectable RHCP or LHCP of uplink, and RHCP or LHCP of downlink, the diplexer is circularly polarized four port device, which consist of one waveguide common port, one rectangular to circular transition, rectangular transformer for impedance matching, corrugated waveguide polarizer for Tx, OMT to combine E-plan and H-plan of Tx, WR28 to window branch for H-plan and E-plan, Rx branch for LHCP and RHCP, two TRF, Hybrid to extract E-plan and H-plan, and transformer Hybrid to WR42 port for two Rx. The diplexer covers the performances that has the band of 27.5 ~ 31.0 GHz for Tx, of 17.7 ~ 21.2 GHz for Rx, Tx/Rx Isolation: 80 dB, VSWR: 1.35:1, polarization Isolation of 20 dB, insertion loss of less than 0.6 dB.

Transmission Rejection Filter and Feed Horn

The transmission rejection filter (TRF) is installed at the input stage of the LNA to reduce the interference of receive stage due to the TWTA's high power output. The antenna horn has a conical corrugated horn type, which has the efficient illumination for the sub-reflector and the main reflector with minimum cross-polarized energy, and has the characteristics of wide range at all transmit and receive frequencies in the required Ka-band range. The horn is designed to prevent the formation due to snow

Tracking Assembly

The tracking assembly consists of 20 dB directional coupler, the dedicated L-band down-converter, tracking receiver, antenna control unit, and motor etc as shown in Fig. 2. The tracking receiver can accommodate simultaneously two outputs, each with different time constants. One of them is used for tracking and has a fast time constant. The other is used for uplink power control with a long time constant. These time constants are easily adjusted.

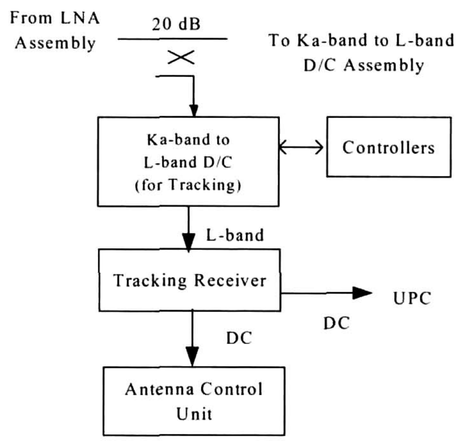

Fig. 2. Tracking Assembly

RF Equipment In Antenna Hub

The RF Equipment such as 1:1 redundant TWTA, LNA, 1:1 redundant and alone ka-band up/down converter for traffic and easy operational controlled and monitored by the remote controller in shelter room. Also, these equipment are selected to be normal operation for high humidity and temperature from several vender. But the hub is designed to maintain a constant humidity and temperature, and easily to access the equipment for maintenance.

The power supply unit for TWTA is included in one TWTA equipment in hub. The output power of TWTA is 115 dBW at TWTA flange for 27.5 to 31 GHz. Its Gain is 60 dB and 65dB for large signal, and small signal, respectively. The DC power for LNA is supplied by remote controller in room. The operating frequency range of LNA is 17.7 to 21.2 GHz, and its gain is 50 dB. The L-band to ka-band upconverter converter either the QPSK L-Band output carrier of the system's modem via UPC or the 8 PSK output carrier via UPC and IF to L-Band Upconverters to Ka-Band output, and provide it to the TWTA.

Uplink Power Control Equipment

The L-band uplink power control equipment provides attenuation to the QPSK L-band modulator output and IF to L-band up-converter in order to compensate for rain fade attenuation. This unit calculates the appropriate attenuation (up to 20 dB in 0.2 dB steps) factor to apply to the modulator's output based on the currently received beacon signal level. The beacon signal level is provided to the UPC equipment by the tracking receiver as an AGC voltage. The UPC then provides the attenuated output of the modulator and IF to L-band up-converter to the MODEM selection switch. The UPC is configured with three attenuator channels. Each attenuator is capable of providing upto 20 dB of power correction. In the event of an attenuator fault or power loss to an attenuator, the signal is automatically switched to a failsafe path as shown in Fig. 3 and 4. The UPC equipment includes fail-safe attenuator, which is 30 dB step attenuator with 1 dB step.

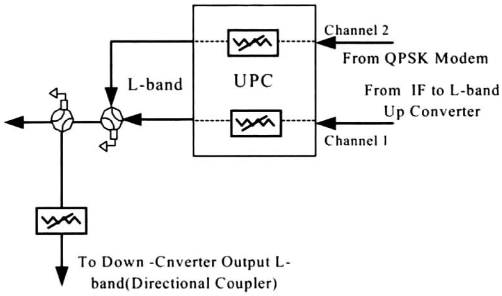

Fig. 3. Uplink Power Control Equipment

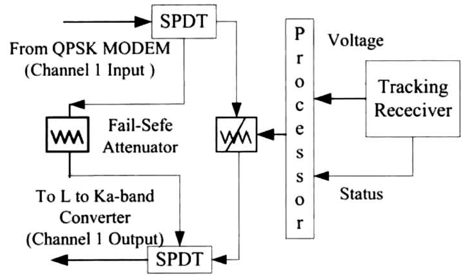

Fig. 4. Internal Functional Diagram of UPC

MEDEM Selection and Loop-Back Test Unit

For a loop back test of traffic data of 155 Mbps QPSK and 8PSK, the system has the loop-back test unit. The output signal from 155 Mbps QPSK or 8PSK MODEM is connected to the loop-back test unit by the coaxial switch and is coupled to the downlink chain of L-band by the coupler of 10 dB via the manual 1 dB step attenuator with range of 70 dB as the Fig. 5. The loop-back test unit consists of the coaxial switch, manual step attenuator, and coupler. This unit is installed in 19-inch standard rack, and the path switching and adjustment of the attenuator is easily handled at the front panel of the rack. The front panel of the rack indicates the communication path and the loop-back path by LED or others for actual path of the signal.

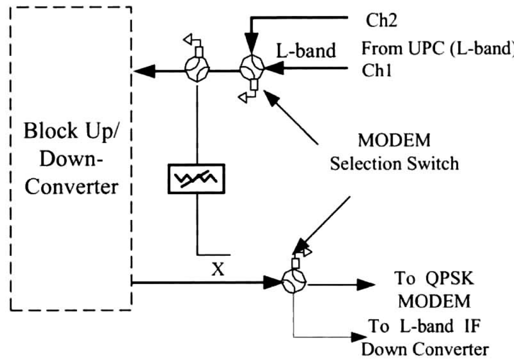

Fig. 5. Block Diagram Loop-Back test Unit

The system has the MODEM selection unit of 155 Mbps QPSK and 8PSK at L-band stage, which consists of the uplink and downlink coaxial switches. For QPSK communication path, the uplink path is connected to the channel 2 of the L-band UPC, and the downlink path is connected to the QPSK MODEM. Also for 8PSK communication path, the uplink path is connected to the channel 1 of the UPC, and the downlink path is connected to the 8PSK MODEM as showed in Fig. 5.

Installation and Test

The system installation includes the foundation of antenna, the brake panel for power supply, the antenna/RF installation, the grounding facility, all cables and cable trays installation between antenna site and shelter, the shelter and the Lab's room, and the on-site test and acceptance test after the system integration complete as shown in Fig. 6.

This system was installed in ETRI. The distance between the antenna and the shelter, and the shelter and the Lab are about 30 meter and 150 meter, respectively. The equipment to be installed in the antenna are the TWTA assembly, LNA assembly, Ka-band up/down-converter assembly etc. Also, the equipment to be located in the shelter are installed in two racks which include the RF equipment, the local controller to control and monitor the equipment in antenna hub, and the tracking equipment, and one rack which include the dehydrator. The rack is equipped with the grounding bar or the cable to ground the equipment to be installed in rack. Before installation, all equipment are tested in the factory and ETRI. The final verification test is performed by the loop-back of the koresat-3 satellite with 155M 8PSK signal.

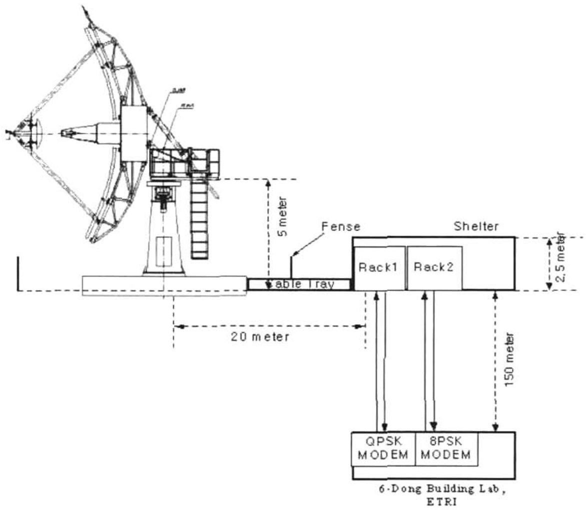

Fig. 6. Site Layout of System

Conclusions

The large Ground Station design and installation for Ka-band satellite communication might be first tried in Korea. The systematic purposes were to increase the G/T and EIRP within limited materials and period. For the purpose, the lengths of the antenna feed focal point to LNA and HPA were minimized. Therefor, all RF equipment were installed in Hub. Another purpose is the multipurpose for use other Ka-band frequency band and polarization of RHCP or LHCP. One of the difficult things for the design of the ka-band antenna/RF system was to obtain the equipment or device for the design trade-off within specified period and cost. Specially, To find out the equipment and device to be met the non-standard frequency band of 30 ~ 31 GHz for uplink and 20 ~ 21 GHz for downlink were not easy through the worldwide search. Also, initially for the system design, the equipment such as TWTA, LNA, ka-band up/down, and device like diplexer to meet frequency band of 27.5 ~ 31 GHz for uplink and 17.7 ~ 21 GHz for downlink were not available worldwide. The experiment results by this system such as 155 Mbps QPSK and 8PSK will be reported after long-term experiment after installation.

Acknowledgement

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