Development of CINEMA Mission Uplink Communication System

Nayoung Yoon¹, Seyoung Yoon¹, Yongho Kim², Jiwon Yoon¹, Ho Jin¹, Jongho Seon¹, Kyu-Sung Chae³, DongHun Lee¹, and Robert P. Lin¹,³

¹School of Space Research, Kyung Hee University, Yongin 446-701, Korea
²Department of Radio and Electronics, Kyung Hee University, Yongin 446-701, Korea
³Space Science Laboratory, University of California, Berkeley, CA 94705, USA

Triplet Ionospheric Observatory (TRIO) CubeSat for Ion, Neutral, Electron MAgneticfielDs (CINEMA) is a CubeSat with the weight 3 kg that will be operated in the orbit conditions of about 800 km altitude and 90° inclination angle, using the S-band and ultra-high frequency (UHF)-band communication frequencies. Regarding the communication antenna loaded on the satellite, the two patch antennas has the downlink function in the S-band, whereas the two whip antennas has the function to receive the command sent by the ground station to the satellite in the UHF-band. The uplink ground station that communicates through the UHF-band with the CINEMA satellite was established at Kyung Hee University. The system is mainly composed of a terminal node controller, a transceiver, and a helical antenna. The gain of the helical antenna established at the Kyung Hee University ground station was 9.8 dBi. The output of the transceiver was set to be 5 W (6.9 dB) for the communication test. Through the far-field test of the established system, it was verified that the Roman characters, figures and symbols were converted into packets and transmitted to the satellite receiver in the communication speed of 9,600 bps.

Keywords: CubeSat, ground station, satellite, satellite communication

1. INTRODUCTION

There are at present about 100 CubeSats that have been launched and used in various areas including earth observation, low earth orbit mobile communication and space science experiments (Bouwmeester & Guo 2010). CubeSats have the advantages that it takes a short period of time from the mission settings to the design and launch, and that the fabrication costs less. Taking such advantages of the Cubesats, universities in the U.S., Japan and Switzerland fabricate CubeSats for the purpose of education by establishing a platform for technological test and scientific mission.

A CubeSat is a small satellite with the accurate volume of 1 Land the weight of 1.33 kg (Hunyadi et al. 2002). The unit size of a standard CubeSat is 10 × 10 × 10 cm, and the CubeSat of the size is called 1 U CubeSat.
with the ground station through the beacon signals carrying the status information of themselves (Bryan et al. 2009). Packet data are transmitted when the command is transmitted from the ground station to the satellite, and the data follow the AX.25 Protocol.

On the other hand, CINEMA employs the UHF-band which is for the armature radio communication frequency for uplink, while it transmits the measurement data to the ground station through the S-band for downlink. It transmits a beacon signal to the ground station just after launching in order to inform the position of itself, and then the ground station transmits the command to turn off the beacon signal after verifying the position of the satellite. After that, the satellite is operated by means of packet communication.

This article describes the establishment of the communication system between the CubeSat CINEMA and the ground station for the uplink communication as well as the communication test of the system.

2. COMMUNICATION SYSTEM OF CINEMA

Fig. 1 is the diagram that represents the ground systems that are to communicate with the CINEMA satellite. Since the CINEMA ground systems are geographically separated, they need to be connected.

For the downlink, the satellite transmits data to the ground station in the 2,200 MHz band which is within the S-band. The status information of the satellite and the scientific data measured by the payloads are encoded into Reed Solomon codes and transmitted through the FM method at the speed of 1 Mbps. The S-band ground station stores the data received from the satellite in a hard disk and then transmits it to the ground station at Kyung Hee University. The two ground stations are connected through the conventional internet network, and all the data received from the satellite are processed in the ground station at Kyung Hee University. The transmitted satellite data are transferred to the Ground Support Equipment Operating System (GSEOS) as digital signals in the Consultative Committee for Space Data Systems (CCSDS) frame type, and then displayed on the computer in the form of CCSDS packet through the GSEOS. The ground station at Kyung Hee University directly controls the S-band destination station in order to make the ground operation smooth. Getting an idea from the example of University of Stellenbosch, South Africa, where the software was designed in order to integrate the ground stations through the internet network to enable multiple missions, the two ground stations of the CINEMA Mission were also connected through the internet (Barry & Nel 2002).

For the uplink, the Kyung Hee University ground station analyzes the data received from the satellite, generates the commands required for the satellite operation, and transmits them to the TNC as the CCSDS packets through GSEOS. The data type follows the AX.25 Protocol (William et al. 1997). The data are modulated by the 9,600 bps Gaussian low-pass-filtered minimum shift key-
Computer 2 analyzes the data received from the satellite through the mission planning system (MPS). On the basis of the analytical results, the MPS generates commands that are transmitted to the satellite through the GSEOS. The TNC and transceiver are respectively connected with Computer 2 through RS232 cables. The TNC converts the digital signals to analog signals and then transmits them to the transceiver through the prepared cable. Finally, the commands of the ground station are transmitted through the helical antennas (Kim 2003).

3.1 Terminal Node Controller

The TNC is the instruments that converts digital signals to analog signals or inversely. The function is similar to that of a wire modem, serving as a sort of interface that connects a transceiver and a computer. The KAM-XL model (Kantronics) is used as the TNC for the CINEMA operation which allows data modulation into the GMSK type and communication at the speed of 9,600 bps.

3.2 Transceiver

A transceiver is an instrument that is used in amateur radio communication to transmit and receive voice signals with a far counterpart, being connection with an antenna. Using such a function, the signals converted by the TNC from digital type to analog type are transmitted to the transceiver and then the commands are consequently transmitted to the satellite through the antenna. The output of the transceiver on the ground is 20 W according to the requirement of the CINEMA. The TS-2000 model of Kenwood (Shibuya, Tokyo, Japan), which enables communication in the 430 MHz band, is used for this study.
3.3 UHF-Band Helical Antenna

The Uplink antenna required for the CINEMA Mission needs to enable communication in the range of 400 MHz~500 MHz and the antenna gain needs to be higher than 9 dBi. To meet the requirements, the H-065 model (TACO, Harrisburg, PA, USA) was established at the Kyung Hee University. Fig. 3 shows the antenna installed at the Kyung Hee University ground station.

To verify the characteristics of the antenna, the antenna pattern and gain were measured by the Radio Research Laboratory. Fig. 4 shows the measured antenna pattern, indicating that the antenna gain is 9.8 dBi if it is used in the left hand circular polarization directivity and 435 MHz band (blue line).

4. GROUND STATION SYSTEM TEST

4.1 TNC Transmission Test

The TNC is the instrument that is firstly passed through by the commands transmitted from the ground to the satellite. For this reason, a test was performed to verify whether the TNC transmits the data from the computer to the transceiver. For the test, two TNCs were individually connected with the computers through the RS232 cable so that the data transmitted and received by the terminal software could be checked out. The two TNCs were connected through the nine-pin cable with the No. 2 Ports for the UHF-band at the rear side of the TNC instrument, as shown in Fig. 5. The result showed that the Roman characters, symbols and figures transmitted by the terminal software were received without an error by the TNC of the receiving part.

4.2 Transceiver Voice Transmission Test

To test the voice transmission through the transceiver, the two transceivers were connected through the nine-pin cable with the UHF-band connectors in a similar way used for the TNC test. The transceivers were set to the FM mode, and the frequency of both transceivers was set to be 435 MHz for the transmission and reception of voice signals. The result showed that there was no occasion where the voice was discontinued or not heard because of noise, although the voice signals were mixed with noise. The counterpart in the communication accurately received all the transmitted voice signal information.

4.3 Test of the Connection between the TNC and the Transceiver

The port through which the TNC signals are put out is a nine-pin port, while the port through which signals from the TNC are put into the transceiver is a 13 Din pin. Since the type and pin number of the input and output port of the TNC and the transceiver are different, a cable was pre-
pared according to the pins through which signals of each port are input and output. Table 2 shows the number of pins of the ports to connect the TNC and the transceiver.

As in the case of the test with two TNCs, two transceiver-TNC connection sets were used for the test. Each TNC was connected with the computer. The result showed that the data were transmitted and received through the terminal software without an error.

### 4.4 Test of the Satellite Orbit Tracking and Controlling of the Frequency Deviation Change Caused by Doppler’s Effect

CINEMA is to be operated at the altitude of 800 km. When a satellite is operated on a low earth orbit, Doppler's effect is caused depending on the velocity of the satellite (Du 2005). To solve the problem, the ham radio deluxe (HRD) software, which is often used for amateur radio communication, is employed. HRD enables to control the calculated position of the satellite through an antenna and track the satellite position automatically, and monitors the frequency deviation by Doppler’s effect. Additionally, it controls the functions of transceivers by means of a computer, performs tracking of the satellite orbit by calculating the two line elements (TLE) values called from the North American Aerospace Defense Command (NORAD) and the display the real-time position of the satellite on the software monitor over the world map.

The test was performed to verify if the HRD functions could be applied to the instruments of the Kyung Hee University ground station.

Two tests were performed simultaneously: 1) The HRD software was executed by Computer 2 of the ground station, an arbitrary satellite was selected, and the orbit of the satellite was tracked. 2) The frequency deviation change by Doppler's effect was applied to the connected transceiver. In Fig. 6, the top monitor shows the current position of the satellite on the map based on the TLE values calculated by the HRD. The monitor on the left shows the current status of the transceiver as the transceiver is connected with the computer. When the software performs tracking of the satellite position, the frequency deviation by Doppler’s effect is calculated simultaneously. The result showed that the HRD displayed the continuously changing frequency value on the monitor and converted the frequency of the transceiver simultaneously.

#### 4.5 Antenna

### 4.5.1 The performance test of the ground station UHF-band helical antenna

To test the performance of the helical antenna, communication was attempted from the position about 1 km away from the ground station laboratory where the...
transceiver used for the CINEMA satellite operation was installed. The result showed both sides transmitted and received accurate voice signals, indicating that there was not a problem in the performance of the antenna.

4.5.2 Measurement of the performance of the UHF-band whip antenna for the satellite

The UHF-band antennas used by CINEMA are made of beryllium copper. According to the design, the diameter of the beryllium copper antenna is 1 mm, the length is 173 mm, and it is fabricated by connecting it with a sub-miniature type A (SMA) male type connector. Two UHF-band whip antennas are installed at both sides of the CINEMA satellite main body. Fig. 7 shows the fabricated whip antennas.

The performance of the fabricated antennas was measured with a network analyzer (model: Anritsu 37269C). As shown in Fig. 8, the measured center frequency of both antennas was 428.12 MHz. The beam width of the 173.17 mm antenna was about 40 MHz between 410.625 MHz and 450.000 MHz, and that of the 172.93 mm antenna was about 53 MHz between 403.75 MHz and 456.25 MHz. Since the center frequency that is to be used by the CINEMA satellite is 435.789 MHz and 436.211 MHz, and the beam width required for the CINEMA satellite is 30 kHz, the fabricated antennas of which length followed the design satisfied the functional requirements.

4.6 Test of the Wire Communication System

To test if the uplink RF chain system, excluding the helical antennas, has any problem in data transmission, a wire communication test was performed by connecting the transmitter of the ground station and the receiver of the satellite through the RF cable (Fig. 9). The system for the test consisted of computer (terminal)–UHF receiver of the satellite–transmitter–TNC–computer (terminal). The transmitter of the ground station and the receiver of the satellite were connected with 1 m RF cable. The data in which Roman characters, symbols and figures were mixed together was transmitted through the terminal software through the TNC and the transceiver. It was verified that the transmitted data were received in packet type by the configuration software provided by the producer of the satellite receiver. Fig. 10 is the screen shot of the terminal software connected with the ground station transmitter and the data received by the configuration software of the receiver for the satellite. The left of Fig. 10 is the terminal software with the A part showing the transmitted data and the B part showing the data received by the receiver. The B part shows Chinese character types before and after the data, which are the packets produced by the TNC following the AX.25 Protocol.
4.7 Wireless Communication Test (Long-Distance Ground Test)

As verified in Section 4.6, after checking out that communication was performed using the RF cable, the satellite receiver was connected with the UHF-band antenna fabricated in Subsection 4.5.2 to test the uplink wireless communication. Since the communication was performed not a cable but an antenna, a Far-Field test was performed from a position that was far from the antenna. The range of Far-Field according to the antennas was calculated by the following equation (Radio Communications Unit-ICTP, 2004):

\[
\text{Range} \geq 2 \times \left(\frac{\text{overall dimension of antenna}}{\text{wavelength}}\right)^2
\]

In Eq. (1), the overall dimension of antenna was substituted by the length of the ground station helical antenna, 1.72 m, and the wavelength by the wavelength corresponding to the frequency of 435.789 MHz, which is 0.687 m. The calculation showed that the range of the far-field in the UHF-band from the helical antenna installed at the Kyung Hee University was more than 8 m.

Thus, the satellite receiver was installed on a building rooftop about 1 km away from the helical antenna. An attenuator was connected at the outlet of the transceiver to give loss of 100 dB, and the output of the transceiver was set to be 5 W. The data received by the satellite receiver and the whip antenna constituted in the structure model shown in Fig. 11 were verified by the satellite receiver configuration software in the laptop computer connected with the satellite receiver.

5. CONCLUSIONS

The two CINEMA satellite produced by Kyung Hee University are planned to be launched in late 2012 by the Dnepr, the Russian projectile. Since the uplink and downlink ground stations for the communication with
result, a new system may be rapidly constituted by minimizing the time required for equipment development. Tests will be continuously performed in the future in order to establish a stable and highly reliable communication system.

ACKNOWLEDGEMENTS

This research was (partially) supported by World Class University (WCU) program through the National Research Foundation of Korea funded by the Ministry of Education, Science and Technology (R31-10016).

REFERENCES

Barry RM, Nel F, University of Stellenbosch satellite ground station operation and future plans, in Proceedings of the 6th Africon Conference in Africa, George, South Africa, 2-4 Oct 2002, 25-28. http://dx.doi.org/10.1109/AFRCON.2002.1146800

Bouwmeester J, Guo J, Survey of worldwide pico- and nanosatellite missions, distributions and subsystem technology, AcAau, 67, 854-862 (2010). http://dx.doi.org/10.1016/j.actaastro.2010.06.004

Bryan K, Jason A, Kyle L, A survey of CubeSat Communication Systems, The AMSAT Journal, Nov/Dec, 23-30 (2009).

Du Y, A satellite ground station control system, MS Thesis, Technical University of Denmark (2005).

Hunyadi G, Klumpar DM, Jepsen S, Larsen B, Obland M, A commercial off the shelf (COTS) packet communications subsystem for the Montana EaRth-Orbiting Pico-Explorer (MEROPE) CubeSat, in Aerospace Conference Proceedings, Big Sky, MT, 9-16 Mar 2002, 473-478. http://dx.doi.org/10.1109/AERO.2002.1036867

Kim YB, The implementation and test operation of HAUSAT ground station, in KSAS Fall Meeting, Kyungju, 14-15 Nov 2003.

Radio Communications Unit-ICTP, Antenna basics, in Radio Laboratory Handbook 2004, 63-77 [Internet], cited 2011 Oct 12, available from: http://wireless.ictp.it/handbook/ C4.pdf

Tarun ST, Nathan GO, Robert EZ, Low cost ground station design for nanosatellite missions, in AMSAT North American Space Symposium, San Francisco, CA, 5-10 Oct 2006. William AB, Douglas EN, Jack T, AX.25 link access protocol for amateur packet radio, version 2.2, revised July 1998 (Tucson Amateur Packet Radio Corporation, Richardson, 1997).