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The Development of a Low-Cost Amateur Microsatellite Ground Station for Space Engineering Education

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This paper presents the establishment of a low-cost amateur microsatellite ground station, which was primarily developed for use in space engineering education and training in National Cheng Kung University. The ground station was designed to allow for the tracking, telemetry and control of amateur microsatellites in orbit. Through the usage of this facility, along with the coursework in orbital mechanics, the aerospace engineering students were effectively benefited with hands-on experience in learning satellite tracking, ground station operations and data analysis.

INTRODUCTION

Current trends in space research and development agencies and industries gradually place greater emphasis on reducing the costs for the development and operations of the satellites in orbit. According to a survey, 60% of spacecraft costs were primarily derived from the satellite operations [1]. In order to decrease mission costs, it has become necessary to reduce operational costs, especially starting with the education and training of aerospace-majored students in the universities and colleges.

The Institute of Aeronautics and Astronautics in National Cheng Kung University (NCKU) has many years of experience in the establishment of a low cost, microsatellite ground station using amateur radio communications [2]. Such a ground station has provided the students in the space system courses with hands-on experience and opportunities in microsatellite system design, hardware and software development, and satellite operation studies [3]. Most of the students have benefited and shown strong interest in taking the orbital mechanics as a required course in their aerospace engineering study. This is tied in with the operation in practice of the home-established, low-cost ground station, which is in communication with the existing amateur microsatellites.

Since the advent of satellite communications in the 1960s, space engineering education has paid very strong attention to establish such courses in the curriculum, in order to fulfil the needs of the communications industry regarding knowledge and skills. Satellite operation and orbital tracking are indeed among the relevant issues that most students rarely have the opportunities to gain practical experiences in, besides acquiring the technical knowledge from textbooks or technical articles.

As an educational institution in aerospace engineering, space engineering education is also one of the important subjects that NCKU has invested the most possible contributions to catch up with international trends and to also address the urgent need for Taiwan's national space activities. With assistance from the world amateur satellite community, such as AMSAT [4][5], and from such educational institutions as the University of Surrey [6] and Korea Advance Institute of Science and Technology (KAIST) [7], the first NCKU microsatellite ground station was successfully established and became operational in 1990.

With low budget constraints from the administration, the station was designed to meet the goal of a low-cost concept but still to carry out such functions as orbital tracking, data/image receiving and decoding, and packet transmission in various formats of modulation and protocol communications. Later on, the second NCKU microsatellite ground station was established again at the campus of Aerospace Science and Technology Research Center (ASTRC) in 1998, but this time with more powerful and fully-automatic functions in microsatellite operations and tracking capabilities.

Based on past experiences in developing the low-cost ground station for space engineering education, this paper intends to present such a concept of space engineering education and describe the ground station briefly. It is worthy to mention that most of the facilities and relevant software used in the NCKU microsatellite ground station are commercially available in the marketplace. This is the major reason why costs be reduced in establishing the amateur ground station, but still maintain the sufficient provision of technology for student education and training.

AMATEUR DIGITAL MICROSATELLITES

Nearly all of the operational satellites in orbit, either commercial or scientific, transmit digital data, voice or images down to the ground stations. Likewise, amateur microsatellites also transmit messages in digital format. This is simply because the satellite's digital signals allow for very efficient use in the amateur radio spectrum in VHF, UHF, L and other amateur bands. As a matter of fact, the digital modes in communication are especially pervasive in amateur microsatellites, as depicted in Table 1, with the relevant groups of communication schemes in association with the microsatellites used or planned.

The digital operations of the microsatellites encompass a very wide spectrum of applications. Apart from the common applications in electronic mailing (e-mail), the microsatellite digital operations include the reception of picture images of the home planet, interesting experimental data, housekeeping data, utility files and even voice mails. Therefore, the operations of digital satellites will provide an excellent easy-to-assess structure for the satellite system to explore many new applications. Also they provide the challenges for improving satellite skills in digital communications and provide quick access for space engineering education.

Table 1: General groups of the amateur digital microsatellites.

Group A	1200 bps, AFSK, AX.25 DO-17, AO-21, MIR, SAREX
Group B	1200 bps, PSK, AX.25 FO-20, AO-21
Group C	1200 bps, PSK, PASAT Protocol AO-16, WO-18, LO-19, IO-26
Group D	9600 bps, AFSK, PASAT Protocol UO-22, KO-23, KO-25, PO-28, FO-29, TO-31, UO-36, SO-33
Group E	1200 bps, AFSK, HEX / ASCII UO-11
Group F	400 bps, PSK, HEX / ASCII AO-13, AO-21

DESIGN AND DESCRIPTION OF THE NCKU MICROSATELLITE GROUND STATION

The Institute of Aeronautics and Astronautics in NCKU has already offered several in-class courses on space engineering in the senior and graduate levels for many years. In order to enhance the satellite technology development in Taiwan and promote the teaching and learning efficiency with emphasis on the hands-on experience as related to satellite tracking and operations, the Institute focuses its efforts in establishing the micosatellite ground station, with the financial support from the NCKU administration. In consideration of signal access opportunities, degree of technology difficulty, and budget constraints, the Institute made a smart decision to fully utilise the amateur microsatellite operation as the target education mission for orbit tracking and signal reception.

In designing the NCKU Microsatellite Ground Station, the educational and technical objectives are seriously considered and seek to serve the main goal of space technology education. These objectives include the following aspects:

- To provide a forum for communicating with orbiting satellites, as well as other terrestrial amateur radio stations.
- To provide testing and mission support for future projects.
- To serve as a test-bed for new operation concepts.
- To serve as a teaching tool for inexperienced or novice short-wave radio users.

In short, three major components of the NCKU Microsatellite Ground Station are integrated as follows:

- Antenna System
- Radio System
- Computer System

The functional layout of the ground station is shown in Figure 1. The electrical layout with the associated equipment is depicted in Figure 2. The exterior view of the antenna system located on the top of the building roof and the control room of the NCKU ground station located inside the building, but right beneath the antenna system, are respectively depicted in Figures 3 and 4.

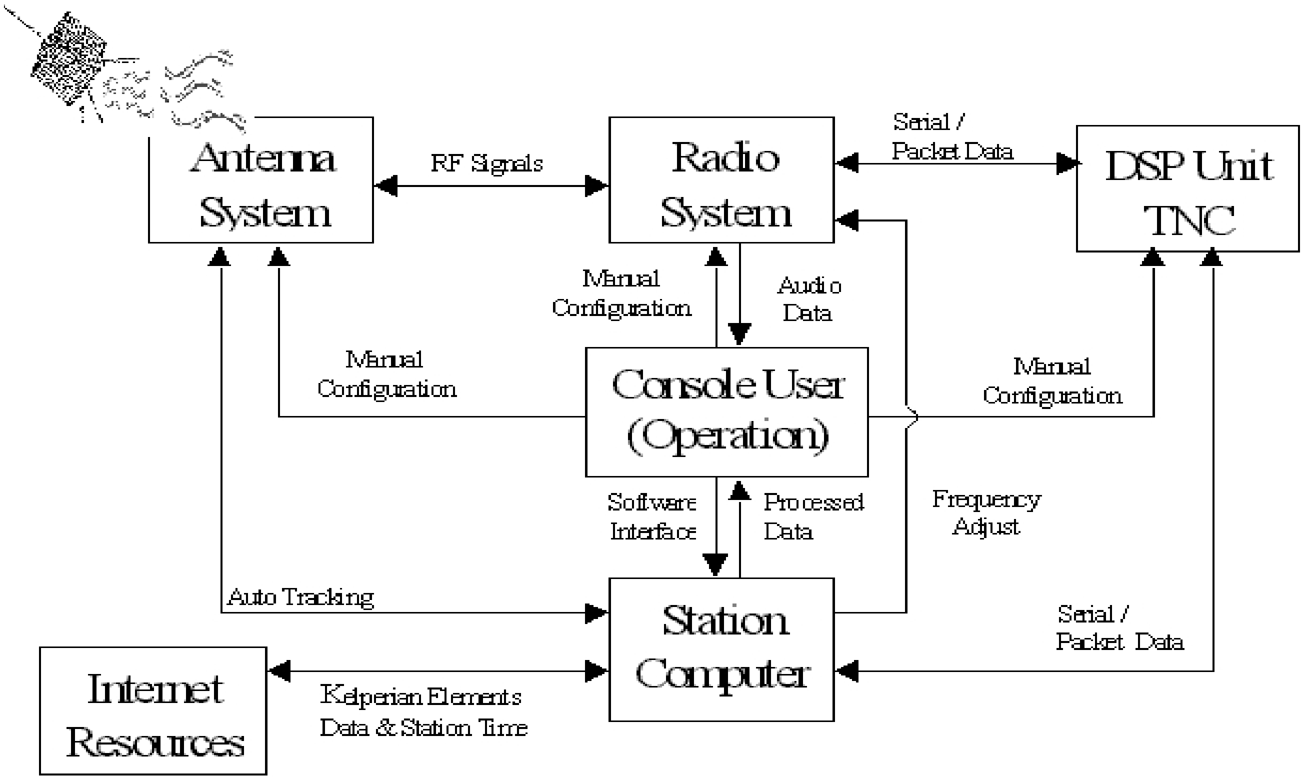

Figure 1: Functional layout of the NCKU Microsatellite Ground Station.

The working performance of the ground station is significantly affected by many factors, while the antenna system usually stands out as being the most important one. In the present ground station, the antenna system consists of three Yagi antennae, respectively for VHF, UHF and L band receptions, and two rotors to control the antenna's azimuth and elevation angles through the Computer System.

The radio system consists of a transceiver, a preamplifier, feed-lines and a digital signal processor (DSP) unit. The computer system consists of a personal computer (PC) and an interface card called the Kansas City tracker/tuner (KCT/T). This card interfaces the computer with the antenna rotor controller and the transceiver. Through the satellite

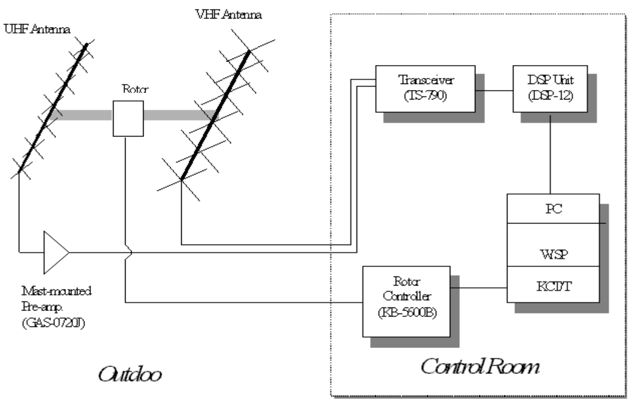

Figure 2: Electrical layout of the NCKU Microsatellite Ground Station.

Figure 3: Exterior view of the NCKU Microsatellite Ground Station.

Figure 4: Control room of the NCKU Microsatellite Ground Station.

tracking software WiSP, a product of the Radio Amateur Satellite Corporation, it works together with the KCT/T and antenna rotors to perform a complete ground station operation.

PERFORMANCE AND COST BREAKDOWN

Indeed, there are many compatible products commercially available and many different ways to construct a similar amateur microsatellite ground station like this one at NCKU. The students in senior and graduate levels are truly benefited and highly satisfied with their use of the ground station, while taking the space-related courses at NCKU. Hence, this paper intends to recommend the method already successfully demonstrated and would offer assistance to those in colleges and universities who would like to develop their own ground station for the space engineering education.

In terms of the expenditures of the NCKU Microsatellite Ground Station established here, Table 2 clearly lists the cost breakdown of each item used in the station. As for the typical functional tests, the ground station has successfully communicated and obtained some e-mail messages and satellite housekeeping data with several existing amateur microsatellites, such as UO-22, KO-25 and TO-31.

Table 2: Equipment cost breakdown.

Item	Cost (US$)
VHF, UHF Band Antenna	575
L Band Antenna	81
Rotors	1,060
Transceiver	3,030
Preamplifier	263
DSP Unit	921
KCT/T Card	319
WiSP Software	50
PC (P II 233 MHz)	1,315
Feedlines, connectors and expendables	700
Total	8,314

BENEFITS OF GROUND STATION OPERATION IN SPACE ENGINEERING EDUCATION

After the completion of the current microsatellite ground station, most of the curricular subjects offered in the space system program were immediately streamlined and adapted with the operation and hands-on training. The relationship between the course subjects and the ground station development stages is illustrated in Table 3.

Table 3: The curricular subjects of the space system program.

Ground Station Design and Development
• Space System Engineering • Aerospace Hands-on Experience • Satellite Communication Systems
Ground Station Operation
• Satellite Technology and Application • Satellite Communication Systems • Orbital Mechanics
Data Analysis
• Orbit Mechanics • Spacecraft Attitude Dynamics • Remote Sensing

Students can easily test and verify their knowledge learned in the classroom through the operations of the current ground station. Each student is required to operate the communication instruments by following the process sequence shown in Figure 5. Through the operation of this process, it is anticipated that students will practice and develop their space technical knowledge and obtain the key skills of the ground station operations and satellite communications.

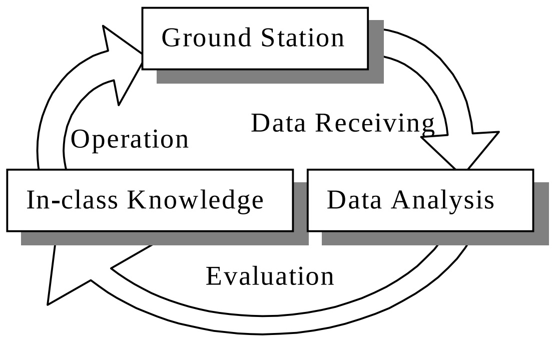

Figure 5: The three-stage learning process.

In using the orbiting microsatellites UO-22 and KO-25 as the students' learning examples, students can successfully receive the communication messages from UO-22 through the WiSP tracking software, as shown in Figure 6. After decoding the raw data, an interesting broadcasting directory was received by the

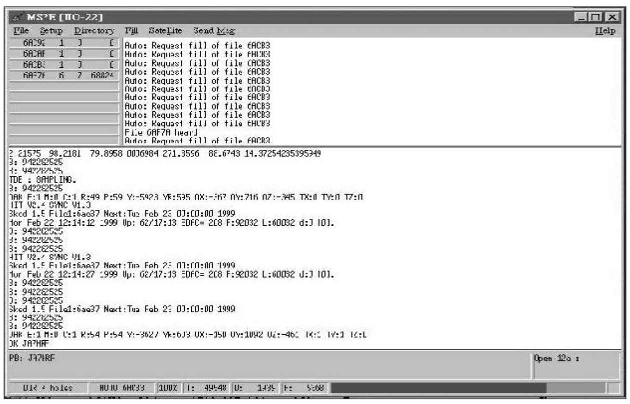

Figure 6: Communication message from UO-22.

students, shown in Figure 7, during the operations. This indicated that an efficient close communication link was successfully made. In addition, the on-board telemetry data from KO-25 was also easily decoded to be used for monitoring the microsatellite's health status, as shown in Figure 8. As a result, the current ground station developed can be beneficial and quite satisfactory to new students in learning the space system program as their major study.

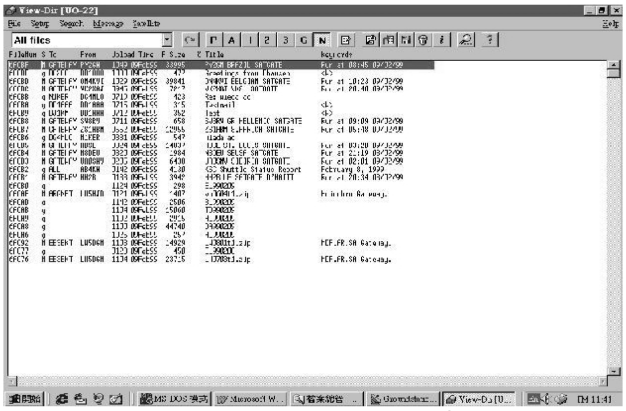

Figure 7: A broadcasting directory from UO-22.

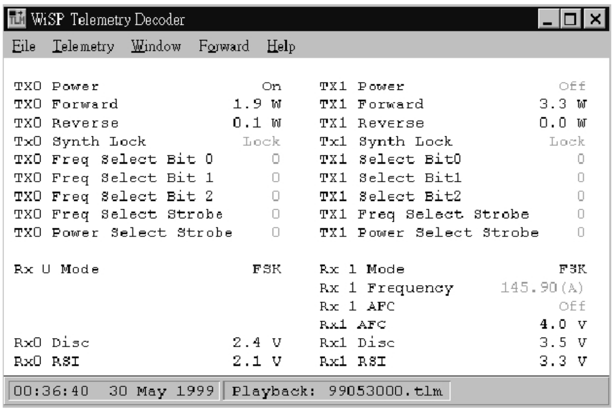

Figure 8: Onboard telemetry data from KO-25.

CONCLUSIONS

This paper describes a comprehensive way for the students to study and specialise in space technology using the ground station. This had been built at an affordable price for the university. Through this facility and by the evaluation process, students can not only be well trained for hands-on system design, but also be capable to verify what they have learned in the class and review the procedures of operation and data analysis.

The results of this space engineering education at NCKU are that students can more easily understand what the spacecraft is and how it works, having a real facility operated by students. Senior and graduate students really benefit and appreciate it for using the ground station with very high satisfaction while taking in-class courses in space system engineering. Hence, it is highly recommended to institutions where space engineering programs are offered for educating and training their students. It may be of importance that subsequent steps be taken to upgrade the existing facility, with the purpose that academic institutions can spend a smaller budget, but maximise the usage in teaching and research.

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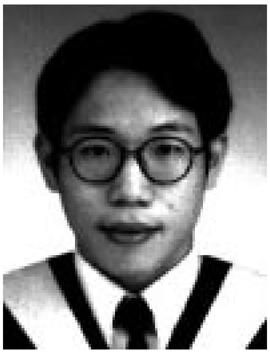
BIOGRAPHIES

Professor Fei-Bin Hsiao received both BS and MS degrees in power mechanical engineering from National Tsing Hua University, Taiwan, in 1976 and 1979 respectively, and a PhD degree in aerospace engineering from the University of Southern California, USA, in 1985. He joined the Institute of Aeronautics and Astronautics in National Cheng Kung University (NCKU) in 1985, and was promoted to full Professor in 1990. He was Visiting Professor in Kasetsart University in Bangkok and Universiti Sains Malaysia in Penang. Besides his teaching and research works at NCKU, he has actively participated in various duties in all levels of planning and development as well as international collaborations. He has been Associate Dean of Engineering since October 1999.

Prof. Hsiao's research areas of interest include applied aerodynamics, aircraft design and performance analysis, space engineering systems, and microsatellite technology development. He has published more than 120 technical papers in archival journals, national and international technical conferences. He is the Editor of the book *COSPAR Colloquium on Microsatellite as Research Tools*, published by Elsevier Science in 1999. Prof. Hsiao has received numerous awards, including: the IEEE M. Barry Carlton best paper award (1990), NCKU Best Adviser Award (1993), NSC Distinguished Research Award (1996), Distinguished Engineering Professor Award (1997) from Chinese Society of Engineers, the NCKU Engineering College Teaching Award (1998), and Service Award (1999) from the Society of Theoretical and Applied Mechanics. Currently, he is Associate Fellow of AIAA, Executive Secretary of Committee on Space Research in Taiwan, and a member of various national and international academic societies.

Mr Hui-Ping Liu is presently working as a Network Engineer at Taiwan Cellular Corp. He graduated from Tamkang University with a BS degree in 1997, and from National Cheng Kung University with an MS degree in 1999, both in Aerospace Engineering. His main research interests include low-cost microsatellite ground station development and data broadcasting transmission experiment.



Mr Chung-Cheng Chen graduated from the Feng Chia University in 1997 as an Aeronautical Engineer. He is presently a Masters student at the Institute of Aeronautics and Astronautics, National Cheng Kung University. His main areas of interest are microsatellite communication systems and ground station operation. Current research interests include applied forward error correcting code in amateur digital microsatellite communication.