Call for Support

on

Tracking and Receiving RF Signal

for First Interplanetary University Satellite UNITEC-1

Ver.1

May 29, 2009

UNITEC-1 Development Team

University Space Engineering Consortium

Japan

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Abstract

University community in Japan for nano-satellite development named "UNISEC (UNIversity Space Engineering Consortium)" are jointly developing a interplanetary nano-satellite "UNITEC-1 (UNIsec Technological Experiment Carrier-1)" to be inserted into Venus encounter trajectory in May or June 2010, which will become the world first university satellite which goes beyond Lunar orbit. The main mission of UNITEC-1 is to perform technological experiments of onboard computer and long-range communication using amateur-band RF frequency.

Due to the limitation of development time and available funding, UNITEC-1 does not have any attitude control system, and will have a tumbling motion in the interplanetary trajectory. Therefore, it is impossible to point its antenna towards the Earth direction all the time to send strong RF signal to the Earth, and very weak RF reaches the Earth only when the antenna is directed towards the Earth during the tumbling motion. The RF is modulated in very simple 1 bps CW, i.e., ON or OFF of a carrier wave of 5.8 GHz, and using this signal, the house keeping and mission data should be downlinked. Tracking of the satellite should also be done using the same weak signal.

UNISEC would like to cordially ask world-wide AMSAT and other amateur RF engineers' community to support us in getting very weak RF signal from UNITEC-1, decoding it and enabling us to track the satellite over a long journey to Venus. In the current plan, the operation scenario is like this. UNITEC-1 transmits RF (CW) for 30 minutes in every two hours (TBD) triggered by onboard timer, and CW signal will occasionally reach the Earth when the satellite antenna direction is towards the Earth, and then such amateur ground stations that face towards UNITEC-1 direction will receive the signals. We hope to develop world wide ground station network using internet such that the received and decoded signals at those world-wide ground stations will be transferred directly to the UNITEC-1 Mission Operation Center in Japan so that the real-time signal analysis can be performed. Besides, the information from the receiving ground stations about the direction of incoming RF signal and the amount of Doppler Shift will also be sent to the Operation Center to continually estimate the satellite trajectory (position and velocity). This trajectory data will return back to all of the world amateur ground stations to tell them from which direction and with what Doppler Shift the RF signal will come in the next satellite operation timing (i.e., two hours later).

This paper describes the introduction to UNITEC-1, its communication system and current plan of ground station operation for UNITEC-1.

1. Brief Description of UNITEC-1

Twenty two universities and colleges of UNISEC (University Space Engineering Consortium)[1)] are now jointly developing a interplanetary satellite named "UNITEC-1 (UNIsec Technology Experiment Carrier-1)", which is roughly 15 kg , 35cm cubic nano-satellite (see Fig.1). This is planned to be the world-first interplanetary probe developed by university, on which we plan to have "Onboard Computer (OBC) Surviving Contest" in the interplanetary space environment which is expected to be harsher than LEO environment. This satellite project was proposed and accepted as a piggyback payload to be launched by H-IIA in May or June 2010, with the main payload of Planet-C, a Venus orbiter developed by JAXA/ISAS.

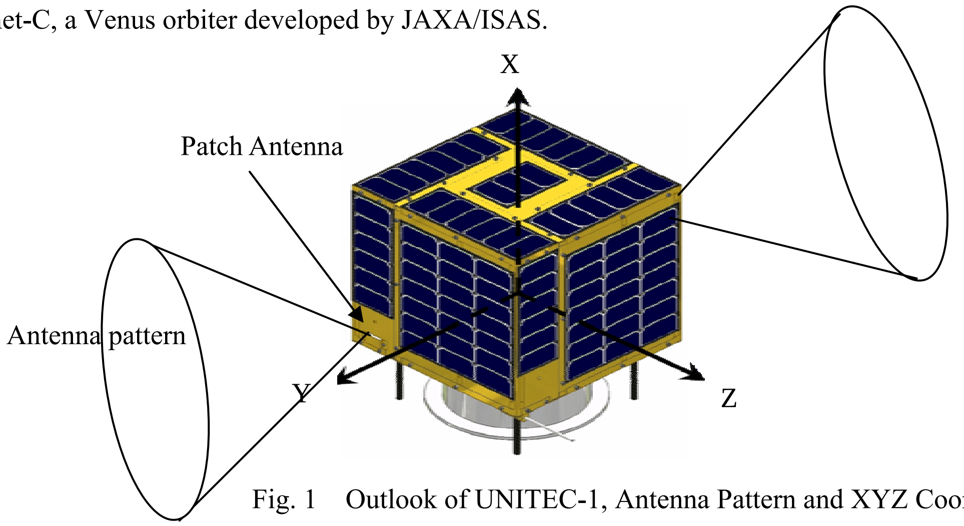

Fig. 1 Outlook of UNITEC-1, Antenna Pattern and XYZ Coordinate

The main mission of UNITEC-1 is to experiment various OBCs developed by universities in UNISEC on the trajectory towards Venus, which is expected to give more radiation and higher temperature to spacecraft than the usual LEO environment. The experiment is planned to be performed in a competition manner; OBCs developed by several universities will occasionally be assigned certain tasks by the main OBC and their response will be evaluated. The test results will be downlinked to the Earth via 1 bps low speed communication link, and the OBC which survives to the last will win the competition. We currently have 13 universities entries, from which 6 OBCs will be selected as "space qualified OBC," in the process of ground test using a vibration table, a thermal chamber, and a vacuum chamber.

Another important mission is communication experiment to be performed in collaboration with amateur RF engineers; to find and detect very weak and low bit rate signal coming from deep space. We expect many amateur radio engineers all over the world will receive and decode very weak signal, which will then be sent via internet to a certain UNITEC-1 Mission Operation Center in Japan. Tracking of the UNITEC-1 is also planned to be performed by this international collaboration, by measuring the direction of coming RF and its Doppler shift combined in Kalman filter.

One scientific instrument, a radiation counter, was selected to be onboard UNITEC-1, which will detect the incoming radiation with several energy levels.

The development of UNITEC-1 started in August 2008, and had PDR in January 2009. Now EM of various subsystems are under development. The qualifying tests of OBCs of 13 universities will be made in August 2009. The launch is currently planned in May or June 2010, with the target arrival date of Venus in December 2010. Fig. 2 shows the planned trajectory of UNITEC-1. The trajectories of Earth and Venus are also shown.

We sincerely hope that this project will contribute to the technology development and human resource training of participating universities and colleges especially for OBC design, fabrication and test and project management, as well as further facilitating the collaboration and friendship between the university and radio amateur communities. We also expect that the project will contribute to the outreach of space activities to the general public.

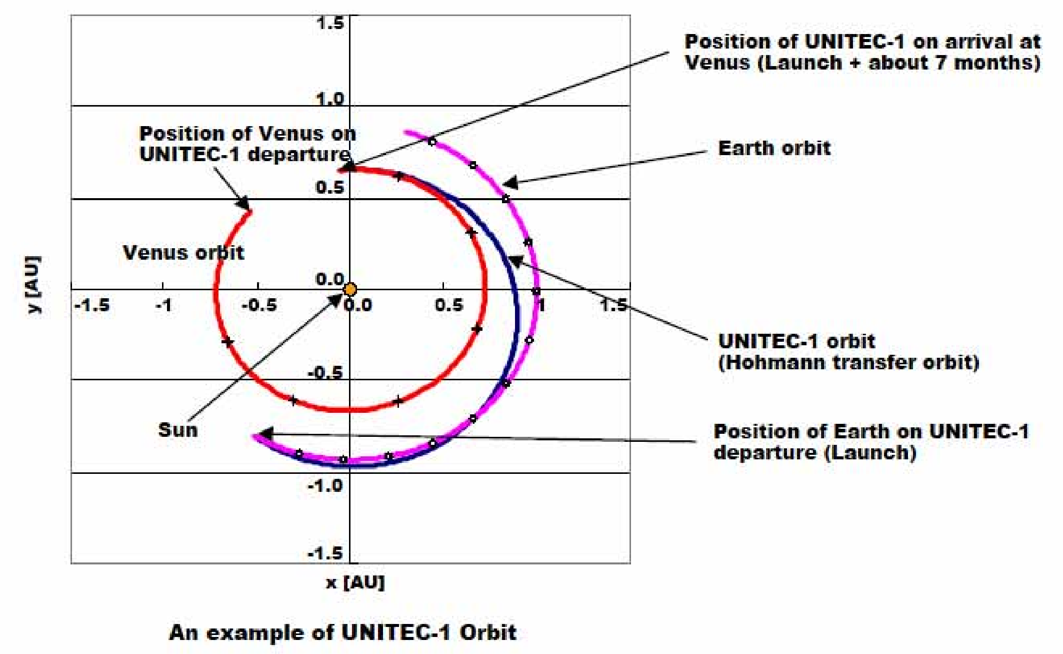

Fig. 2 Trajectory of UNITEC-1 towards Venus

2. Overview of Design of UNITEC-1

Throughout the conceptual design phase of UNITEC-1, the following requirements and restrictions are assumed which are reflected in the design:

(1) The development period is very short such as 1 year and a half (August 2008 – Jan 2010).
(2) We cannot expect the usage of large communication antennae of space organization on the ground.
(3) The budget is very stringent (such as less than $0.1M).
(4) The safety and simplicity of the satellite is considered as the top priority.
(5) Collaboration with amateur RF engineers can be anticipated

Communication is one of the most difficult issues and so considered as an important mission because of the above restriction (2) and the fact that the attitude of UNITEC-1 will not be controlled because of the requirement (1),(3),(4). So UNITEC-1 adopts very low speed CW beacon (such as 1bps) transmitter as the primary communication media, by which all of the H/K date of the satellite, the results of test of each OBC and the radiation counter measurement should be downlinked. In addition to that, we plan to implement high speed (1200-9600bps) FM downlink line so that more date can be downlinked when UNITEC-1 is near the Earth. As to the ground station, we would like to expect fundamental supports from amateur RF engineers' international community with their many and world-spread 3 m size dish antennae. We hope that amateur RF community in the world will enjoy experiments of receiving very low power RF signal from the deep space, and improve and test their technologies using this opportunity. In order to enable such collaborations, we will use amateur frequency in C-band (5.8GHz) for downlink. We are also searching for a large antenna (such as 34m dish) in Japan, with which we could expect to get beacon even over the distance of 63,000,000 km when the satellite is arriving Venus. We would also like to construct the international ground station network of amateur radio engineers such that the signal decoded at their ground stations can be automatically transmitted via internet to the UNITEC-1 Mission Operation Center which will be constructed in a certain university of Japan.

If Amateur radio community get interested, we encourage them to hold "a competition of getting very weak beacon and decoding it" among amateur community all over the world. The signal is coded in CW beacon with a speed of 1 bps, which could enable it to integrate many receiving signals by different ground stations after alignment of time line to improve the S/N ratio. The competition may be such that the individual or a group who can get and decode the signal of UNITEC-1 from the longest distance will win. We hope that this project will serve as a base for further collaboration and friendship between amateur radio community and university satellite developers.

The satellite design has been made as simple, safe and of low cost as possible. There are no attitude control system, no deployable parts, no nychrom heaters to cut something, and no redundant systems. As to the main OBC, a radiation tolerant MCM will be employed, and the intra-satellite communication between subsystems is made via RS-422.

3. Mission Operation Plan

Considering the needs to downlink various data with low bit rate communication line within the the available power, the following operation plan is currently adopted.

3.1 Operation Cycle

Major operation cycle is six hours, in which all the operations are performed, and this major cycle is iterated. Within this major cycle, we have three minor cycle each of which continues for two hours. In each minor cycle, UOBC experiment and RF downlink are performed. The three minor cycles are slightly different; in one of which (Minor 1) the camera operation to take a star image is made and the downlink signal include much of UOBC experimental data ("Downlink Format Type 1"), and in the other two minor cycle, camera operation is not performed and the downlink consists mainly of the radiation counter data ("Downlink Format Type 2"). The time line within the major cycle is summarized in the following table. Type 1 and type 2 will be explained in section 4.3.

Table 1 Operation Sequence in One Major Cycle

Time (s)	Frame	Operation	Duration (s)	Required Power (W)
0	Minor 1 (2 hours)	Waiting	3240	12.2
3240		Camera capturing star images	360	13.7
3600		UOBC experiment (6 UOBC tests, each taking 5 minutes)	1800	15.2
5400		RF Downlink Type 1	1800	48.8
7200	Minor 2 (2 hours)	Waiting	3600	12.2
10800		UOBC experiment (6 UOBC tests, each taking 5 minutes)	1800	15.2
12600		RF Downlink Type 2	1800	48.8
14400	Minor 3 (2 hours)	Waiting	3600	12.2
18000		UOBC experiment (6 UOBC tests, each taking 5 minutes)	1800	15.2
19800		RF Downlink Type 2	1800	48.8

In each of the above phase, the power consumption is also calculated as in Table 1. The average power consumption is 22.1 W from which 19.7 W will become heat generated inside of the satellite.

3.2 Test of UOBCs

University Onboard Computers (UOBCs) will be occasionally tested onboard by the Main OBC (MOBC) which plays as "a test supervisor." In the current plan, within each two hour minor cycle, five minutes' test will be given to each of six UOBCs sequentially, coordinated by MOBC. The test includes whether UOBCs can perform typical functions to be required for usual onboard computers, such as receiving information from outside sensor, checking error detecting code, analyzing the incoming data and outputting the calculation results.

Fig. 2 shows the subsystems related to this UOBC test. As in Table 1, once in the 6 hours major cycle, star images are taken by star camera. MOBC uses this camera data and make it transferred to UOBC during the test. The following tasks should be properly performed by UOBC.

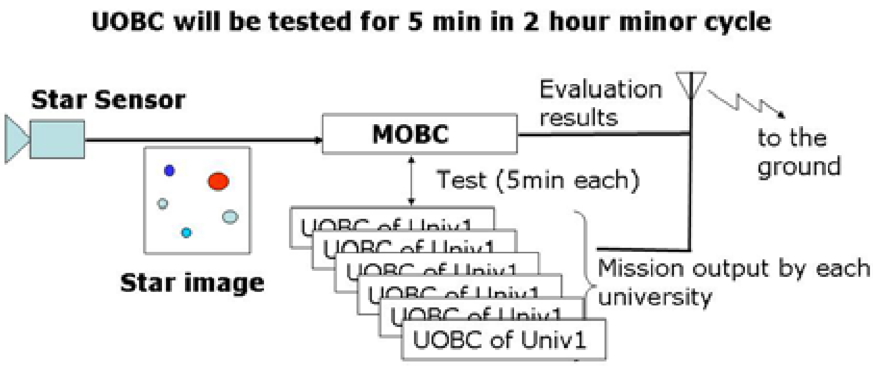

Fig.2 MOBC, UOBC and Camera System

1) UOBC should send one packet to MOBC after start-up, which means the readiness of UOBC to start the test.
2) MOBC sends star image data to UOBC with CRC. Sometimes CRC is intentionally made illegal, when UOBC should detect it and send back re-send request.
3) UOBC should properly send ACK message to MOBC for each receiving packet.
4) When a certain amount of data is sent to UOBC, UOBC should make a certain calculation using the received image data and send back the result to MOBC. This calculation is pre-defined by each university at its own intention.

MOBC will evaluate whether the above sequence is properly performed by UOBC, and give a certain mark to each task. The results of this evaluation and the output of each UOBC's calculation (which can be considered as "mission output data" of each university) will be downlinked to the ground.

4. Satellite Communication System and Downlink Signal

4.1 Overall Specifications

Table 2 shows the specifications of communication system. From the basic design philosophy depicted in chapter 1 and 2, 1 bps CW signal is the main downlink. Uplink is only needed when we need to stop the downlink signal. Fig.3 shows the design of CW transmitter. The transmit power will be split into two patch antennae which are placed opposite directions of the UNITEC-1 surfaces as in Fig.1 (only one of two antennae is shown) whose antenna pattern is shown in Fig.4. A very simple transmitter system is employed such that CW is coded in ON (carrier exist) or OFF (carrier not exist) switched at every 1 second. As explained in 3.1, CW continues for 30 minutes in every 2 hours, considering the overall power consumption plan.

Table 2 Specifications of UNITEC-1 Communication System

Transmitter	
RF Transmit Power	9.6 W
Frequency	5.84 GHz (band width 20MHz)
Type	10M0F2D
Modulation	1200bps FSK / 1bps CW
Input Voltage	+12V DC
Power Consumption	Max 61.1 W
Weight	700g
Size	230 mm × 136 mm × 30 mm
Receiver	
Frequency	145 MHz band (width 200kHz)
Type	30K0F2D
Input Voltage	5 V
Power Consumption	0.125 W
Weight	200g
Size	70 mm × 60 mm × 30 mm

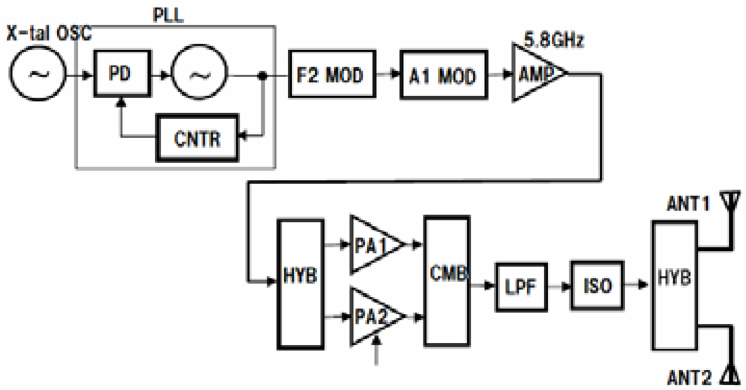

Fig. 3 RF Transmitter System Block Diagram

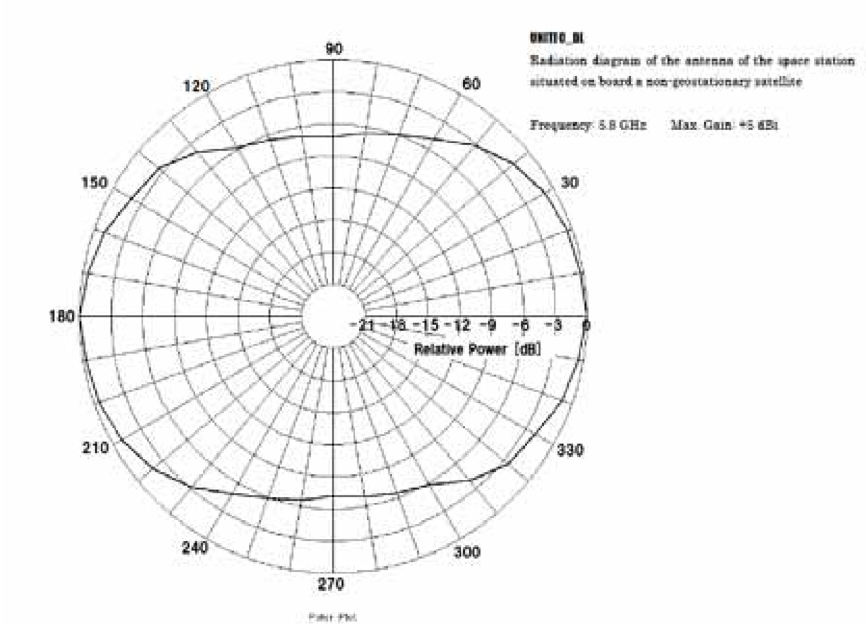

Fig. 4　Downlink Antenna Pattern

4.2　Link Equation

Table 3 shows the downlink link equation when UNITEC-1 is about 3,600,000 km away from the Earth. It is observed that with 3 m dish antenna and usual receiving equipment, 1bps transmission is possible. If larger antenna is used or more than one antenna receiving signals are integrated, decoding of the downlink signal would be possible at larger distance.

Table 3　Link Equation at the Distance of 3,600,000 km

Frequency	GHz	5.80		
Transmission EIRP	dBW	6.82		
Transmitter Power	dBW	9.82	9.6	W
Transmitter Line Loss	dB	3.00	split into 2	
Transimit Antenna Gain	dB	0.00		
Pointing Loss	dB	0.00		
Power Distribution Loss	dB	0.00		
Space Loss	dB	238.84	3,600,000	km
Polarization Loss	dB	0.20		
Atmospheric Loss	dB	0.60		
Rain Loss	dB	0.00		
Other Losses	dB	0.00		
Receiving G/T	dB/K	10.50		
Antenna pointing Loss	dB	0.10		
Receiving Antenna Gain	dBi	41.00		
Distribution Loss	dB	3.00		
System Noize Temprature	dBK	27.40		
Receiving C/N0	dBHz	6.28		
Bit rate	bps	1.00		
Eb/No	dB	6.28		
Bit Error rate		0.0010		
Required Eb/No		4.00		
Implementation Loss		2.00		
Margin		0.28		
Time to reach this distance	s	1458600.00		
	day	16.90		

4.3 Format of the Downlink Signal

Fig. 5 shows the relationships between satellite attitude and downlink possiblity. By carefully designing the satellite separation system from the rocket, it is anticipated that UNITEC-1 will rotate with a rotational speed of 2.6 – 5.0 degree/s.

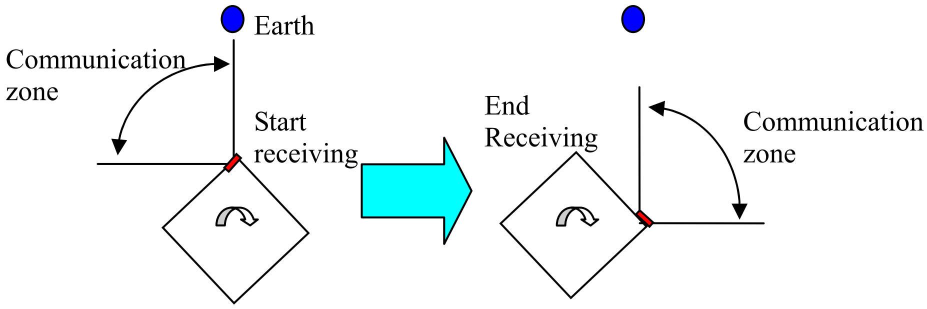

Fig. 5 Relationships between UNITEC-1 Attitude and Downlink Possibility

Therefore, the signal coming from UNITEC-1 is “piece-wise.” In the downlink operation, we would like to establish the linkage between a certain time-point of the downlink signal format and a certain time-point of the actually received signal with better accuracy than 1 second. If we establish such linkage, then we can predict what kind of information will be downlinked at what timing, which makes the decoding much easier. The difficult issue is that “0” and “no signal (because antennae is towards wrong direction)” cannot be discriminated, and so a special coding method is required.

In order to realize it, the Header part of the downlink signal continuing for 30 minutes consists of the following sequence.

1) Preamble part (60 bits for 60 seconds)

1010101010101010101010101010101010101010 ---------- 10101010101011111111

2) Locking part (69 bits for 69 seconds)

111111111

0011111111

00011111111 <1>

000011111111

0000011111111 <2>

00000011111111

First the ground station receives preamble signal at the predicted downlink timing. The downlink is triggered by the clock of the Main Onboard Computer (MOBC), its prediction accuracy should depend on the accuracy of the MOBC clock. Currently we anticipate that this downlink start timing can be predicted with better than 1-2 minute accuracy. Then after preamble part, the ground station will receive a certain number of “0” between a series of “1”. If this number of “0” is three, then we can estimate that this is <1> part of the above sequence. If the number of “0” is five, then it should be <2>. In this estimation, we assume that it will not happen that the breakage of signal reception due to wrong antenna direction will not be so short as 2 to 6 seconds. In other words, if we receive after series of “1”, short period (less than 6 seconds) of “no signal,” and then series of “1” again, then we can say that this short period of “no signal” can be considered as the intentional “0” in this “locking part.” If we receive such specific length of “0” sequence, then we can lock the received signal with the predicted downlink format.

Then in the latter part, the downlink signal will code the following information, which is a little different from Type 1 to Type 2 (see section 3.1)

Type 1:

1) H/K telemetry
2) Science Data
3) UOBC test result
4) FM packet (FSK coded)
5) Others

Type 2:

1) H/K telemetry
2) Science Data
3) Others

Each data will be downlinked for four times consecutively in order to compensate for the breakage of the signal reception caused by satellite rotation.

In Type 1, FSK coded data will also be downlinked which can only be decoded when UNITEC-1 is near the Earth (such as less than 50,000km). This data will include camera data and more detailed experimental results from each university.

5. Satellite Tracking

5.1 Deep Space Tracking Strategy

Satellite tracking is very important to keep the contact with UNITEC-1 while it goes away into deep space from the Earth on a trajectory as in Fig.2. As the signal from UNITEC-1 to be detected on the Earth is one bps beacon signal and there is no uplink, the information to be used for tracking UNITEC-1 is the direction of the incoming RF signal which corresponds to the relative direction of UNITEC-1 in respect to the Earth position, and the Doppler shift of the received RF wave which corresponds to the relative velocity (more precisely, the speed of the distance change) of UNITE-1 in respect to the Earth (Fig. 6). In this section, the feasibility of tracking UNITEC-1 with only this information is analyzed using simulations.

Kalman Filter has been formulated to solve this problem. The measurements consist of the above two information, i.e., incoming RF signal directions (two degrees of freedom) and Doppler shift of the incoming CW wave. The system equation is made assuming a ballistic movement of UNITEC-1 in Solar gravitational field. The disturbances include gravity from the third bodies and the solar wind pressure. These disturbances can be modeled to some extent, and therefore it is assumed that only the fluctuation of solar wind pressure is source of system noise, which is modeled as white noise with the magnitude of 100 % of the predicted solar wind pressure. Extended Kalman Filter (EKF) is performed with UNITEC-1 position (3 DOF) and velocity (3 DOF) as state variables to be estimated, and we should find out whether the incoming direction of RF signal and its Doppler shift can be estimated with enough accuracy so that the signal can be tracked by the ground station.

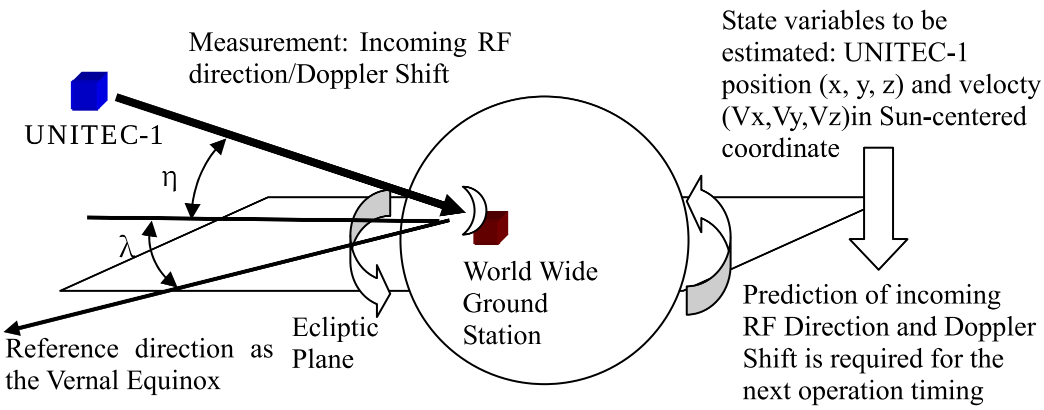

Fig.6 Concept of Tracking of UNITEC-1

The design parameters include the interval of the measurement (i.e., interval of the satellite operation), the accuracy of the measurement of incoming RF signal direction, and the accuracy of the Doppler shift measurement. Therefore, in the simulation study, we change these parameters and evaluate the output of prediction accuracy of the incoming RF signal direction and its Doppler shift.

Fig. 7 shows one result of the case when the operation interval is 6 hours, Doppler shift measurement accuracy is 1KHz and RF direction measurement accuracy is 10 degree. It is observed that Kalman Filter works effectively and that the Doppler Shift prediction accuracy becomes better than 100 Hz after 100 days and the RF direction accuracy better than 1 degree very soon (after 50 days). It is obvious that the convergence to the final accuracy takes about 100 days, and therefore the initial estimation of the accuracy is very important. In Fig. 7, the initial error in the knowledge of the UNITEC-1 position is set at 100km and error in velocity is 100m/s in all the three axes. If the initial knowledge on the velocity becomes ten times more accurate, then we can observe that the Doppler and RF direction accuracy is much improves in the initial phase as in Fig. 8. This shows the importance of the initial knowledge of the UNITEC-1 trajectory, which indicates that the information coming from the co-passenger (such Planet-C) would be very helpful for tracking UNITEC-1.

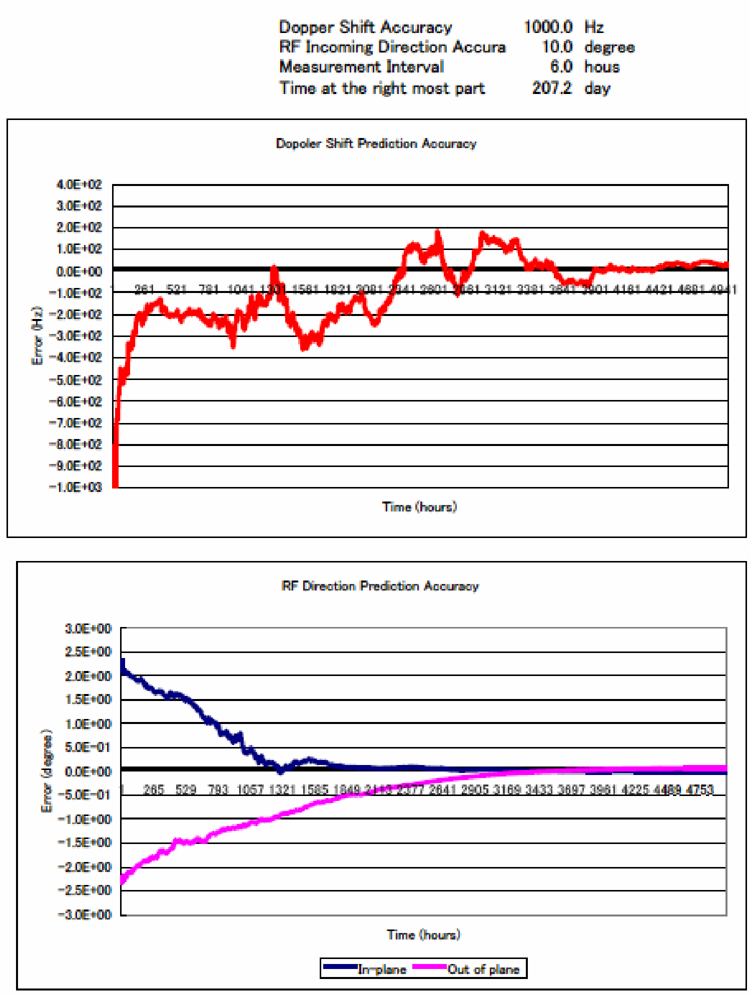

Fig.7 Kalman Filter Estimation Result (bad initial knowledge)

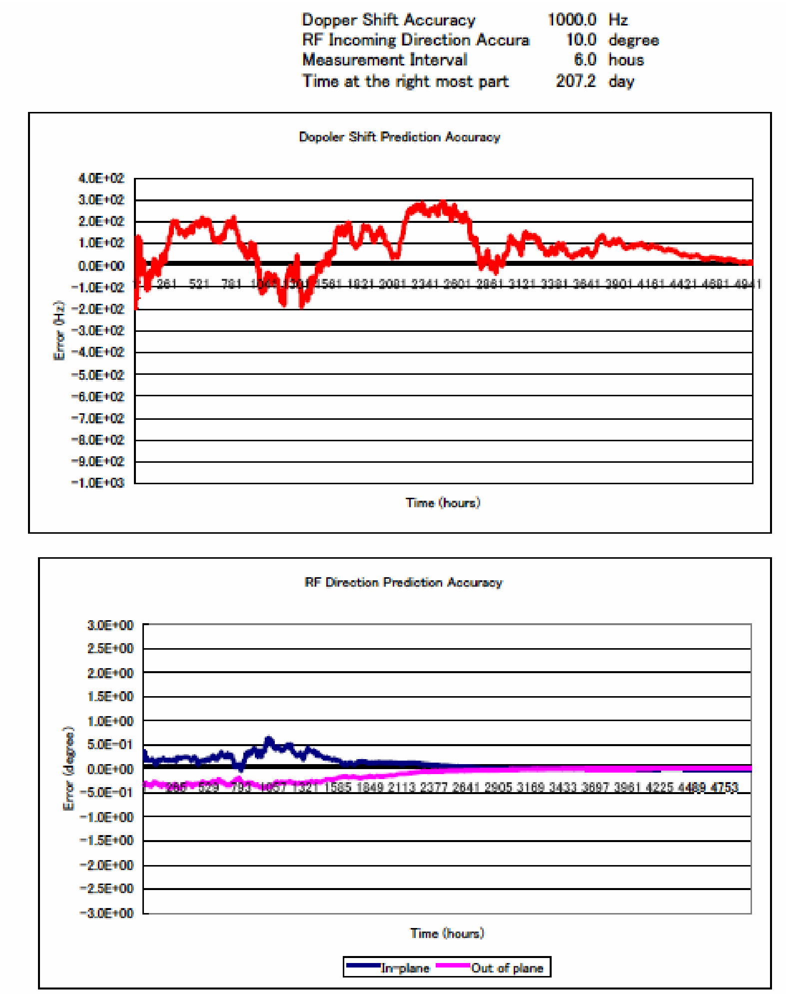

Fig.8 Kalman Filter Estimation Result (better initial knowledge in velocity)

The following observations are also made through this study.

(1) The RF direction prediction accuracy is soon converged to less than 1 degree and so the pointing of antenna towards the satellite direction is rather easy.

(2) The final accuracy does not depend much on the RF direction measurement accuracy. 10 degree (1□) accuracy is enough.

(3) Doppler shift measurement accuracy has large effect on the Doppler shift prediction accuracy. Final prediction accuracy is about 10-20% of the measurement accuracy. If we need to tune the waiting frequency within 100 Hz, then we need to measure the Doppler Shift with accuracy better than 500Hz.

(4) The measurement interval has little effect on the convergence speed and on the final accuracy. Not the number of measurements but the measurement period matters.

Based on these results, we will discuss with amateur RF engineers how accurately we should ask them to measure the incoming RF direction and Doppler shift.

5.2 Proposal of World Wide Ground Operation Network

As the Earth rotates at the speed of around 360 degree per day, only such ground stations whose antenna can point towards UNITEC-1 direction can be used for signal reception and tracking. On the other hand, in the current plan, downlink is performed once (for 30 minutes) in every 2 hours. Therefore, it would be required to construct the world wide ground station network of C-band (5.8GHz) so that at least one ground station can receive signal from UNITEC-1 for every downlink occasion.

In the world wide university satellite community, an educational ground station network project using amateur frequency is being performed with the name of "GENSO (Ground-station Educational Network for Satellite Operation)." This would be a good starting point to construct such world wide network. The required functions will include:

1) Connecting ground stations via internet, so that the donwlinked data can be transferred to the UNITEC-1 Mission Operation Center in Japan, hopefully in real time.
2) The measurement data such as incoming RF direction and Doppler Shift is transferred to the Mission Operation Center to be used for tracking
3) The prediction of next downlink timing, incoming RF direction and Doppler Shift is transferred from the Mission Operation Center to each ground station
4) Management of data of each ground station including the Longitude, Latitude, Height and Orientation will be done at the Mission Operation Center, in order to transform the incoming RF direction in respect to each ground station to the direction in the inertial coordinate. Doppler Shift information should also be modified taking the Earth rotational motion into account.
5) Other information exchange between the Operation Center and the amateur RF engineers community.

We would cordially like to ask AMSAT and amateur RF community to help jointly develop the above world wide ground station network.

5.3 Challenge towards Very Weak Signal Reception from Deep Space

UNITEC-1 will provide an unique opportunity to receive very weak artificial RF signal from deep space. Making the most of this opportunity, we would be happy if AMSAT and amateur RF community might coordinate joint experiments on how to receive and detect such weak signal using multiple antennae or special equipment. It would also be interesting to hold a competition between several teams to find out who can receive the signal over the longest distance. We would be happy if AMSAT and amateur RF community will enjoy such competition or improve RF technologies through UNITEC-1 operation.

6. UNITEC-1 Development Team Structure

Total 22 universities and colleges participate in the development of UNITEC-1, together with many small industries and amateur RF engineers' community. Table 4 shows the bus development team structure. As to UOBC competition, currently 13 universities have made entry.

Table 4 UNITEC-1 Development Team Structure

Role	University & Colleges
Management	Univ. Tokyo, Hokkaido Inst. Tech., Metropolitan College
C&DH System	Tokyo Science Univ
Structure and Thermal Design	Hokkaido Univ., Kyushu Univ., Tsuyama College, Aichi Inst. Tech., Tohoku Univ.
Communication System	Kagoshima Univ. Soka Univ., Akita Univ.
Power System	Osaka Pref. Univ., Kagawa Univ., Keio Univ., Tokyo Metropolitan College, Osaka Pref. College
Radiation Counter	Kouchi Inst. Tech.
Ground Test	Kyushu Inst. Tech.
Ground Station	Akita Univ., Tohoku Univ.
Website Management	Tokai Univ.
UOBC Development Only	Univ. for Electro.Comm.Tokyo Inst.Tech.

7. Conclusions

UNITEC-1 project is providing an excellent opportunity for universities and colleges to brush-up technologies and know-how in the fields of their own specific strengths, which will be the basis for the future's collaborative development of more sophisticated and practical satellites by Japanese universities and colleges. It will make a milestone in the Japanese satellite development community. We sincerely hope that UNITEC-1 will also contribute to the friendship and encourage collaboration between university satellite developers and AMSAT and amateur RF community.

References

1) Nakasuka, S.,: Students' Challenges towards New Frontier -Enlarging Activities of UNISEC and Japanese Universities, Keynote Speech, 26th ISTS, ISTS-2008-Key-01v, Hamamatsu, 2008