Design and manufacture of a nanosatellite for space technology education and potential application

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Abstract

Space is the next frontier for mankind and utilization of space is human's ultimate quest. Although we have been in the Space Age for more than half a century, the cost associated with developing a space system is still very high. First proposed by California Polytechnic State University(1) almost 10 years ago, the idea of cubesat has caught the attention of many organizations around the world because of low development cost and short project schedule. Inspired by the idea, FSpace laboratory of FPT Software JSC and FPT University have joined force in a project to design and manufacture a nanosatellite measuring 10x10x22cm, weighing 2kg (2U cubesat) to give students and young engineers a chance to study about space technology and its application.

Since the beginning, our young team members also have been learning and self-training on various topics of aerospace engineering. Out of these we found that building simple antenna to receive signals from Low Earth Orbit (LEO) satellites, notably the APT signal from NOAA satellites, is not as hard as we previously thought. This activity also turned out to be of great educational value when it is introduced to young people as they can repeat the experiment themselves using inexpensive equipments and get useful data from space.

The nanosatellite (called F-1) itself is an Earth observation satellite and qualification platform as we hope to demonstrate the use of many Commercial Off The Shelf (COTS) components to reduce development schedule and cost. It carries 02 low-resolution cameras (0.3Mp), a high-resolution camera (1.0Mp) and various sensors including temperature, magnetic and current sensors to take photos of the Earth and study space environment. To ensure reliability, critical subsystems such as the power supply unit, onboard computer and communication are double or even triple-redundant.

With a schedule of only 18 months (from Jan 1, 2009 to June 31, 2010) and an estimated development cost of less than 100,000EUR (launching cost is not included since it depends on the launch provider), the project will help to foster the idea of cubesat and demonstrating the potential application using small satellites.

This paper will describe our experience in developing a simple ground receiving station and the basic design of F-1 nanosatellite.

I. Introduction

FSpace laboratory is founded by a group of young engineers from FPT Software JSC and students from FPT University. The team proposed the idea of designing and manufacturing a nanosatellite (2U cubesat) to the company late 2008 and after many meetings, the idea was finally approved and the project was kicked off on the first day of 2009.

II. Mission goals

- Training young engineers and students with practical experience in designing and manufacturing a space system
- The satellite must survive and study space environment for at least 1 year
- Demonstrate the application of COTS products in space

III. First step, building the ground receiving station

Before stepping into satellite design, we decided to start developing the capability to receive signal from other satellites orbiting on similar orbit with our intended one (Sun-synchronous, Low Earth Orbit, 600-800km altitude). We believe this first step is necessary because it's meaningless to have a fully functional satellite on orbit but one cannot receive its signal.

In a simplified view, a ground receiving station consists of an antenna, a receiver and the necessary software to record and decode the signal.

1. The antenna

There are two types of antenna typically used for receiving signal from LEO satellite: omni-directional antenna (lower gain and no pointing required) and directional antenna (higher gain but requires exact pointing and tracking). We decided to build both types of antenna ourselves and by studying the problem, we found that there are many amateur radio operators who have succeeded in building antenna to receive satellite signal. Among many designs available on the Internet we've found the following ones are easy to follow and they offers good antenna performance:

- Omni-directional antenna design: *"Double Cross — A NOAA Satellite Downlink Antenna" by Gerald Martes, KD6JDJ* (2)
- Directional antenna design: *VHF/UHF Yagi Antenna Design by Martin E. Meserve* (3)

Using readily available material such as coaxial cable, aluminum tube, PVC water tube and camera tripod, we have successfully constructed omni-directional (Double cross dipoles) and directional antennas (Yagis) for both VHF (2m) and UHF (70cm) bands.

Figure 1. Different types of antenna built by FSpace team

2. The receiver

The radio receiver is much more complex than the antenna so we decided to buy a commercial one for use in our project rather than building one ourselves. With a suggestion from a ham radio friend and our own study, we decided to buy newly developed USRP (Universial Software Radio Peripheral) together with the TVRX (50-470Mhz receiver) and DBRSX (800Mhz-2.4Ghz receiver) daughter boards from Ettus Research LLC[4]. Setting up the hardware is straight forward and we connected the antenna to the USRP via coaxial feeder line (a BNC-to-SMA adapter is required) and the USRP with a laptop via an USB cable.

Figure 2. TVRX daughter board (upper left) mounted on the USRP

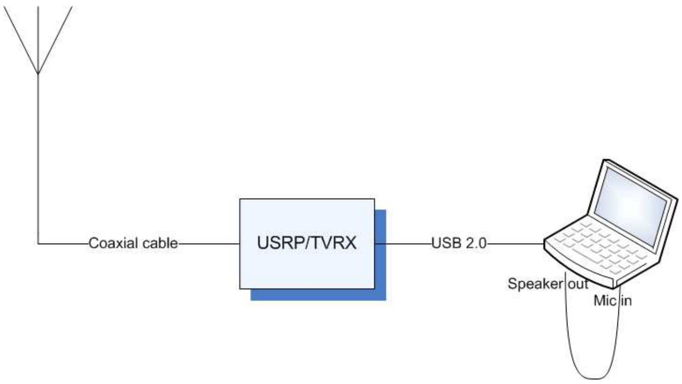

Figure 3. Simple ground receiving station setup

In fact, it's not necessarily to have the USRP to receive signal from LEO satellite but any suitable radio receiver will work as well. The receiver must cover the desired frequencies and have enough bandwidth for the incoming signal. The later requirement is important because if the receiver's bandwidth is too narrow, part of the signal may be loss and if the bandwidth is too wide, too much noise may enter the receiver. In our case we have an old Maruhama RT-723DX scanning receiver with FM-W (wide) and FM-N (narrow) modes but it is not suitable for receiving NOAA APT signal (40kHz) since it's too wide (200kHz) in FM-W mode and too narrow (15kHz) in FM-N mode.

The reason we used USRP is simply because we believed in its potential for future application. Unlike traditional radio hardware which is very difficult to upgrade, the USRP's functionalities can be upgraded by using new software.

3. Software

The software for the USRP hardware is GNU Radio, a free software toolkit for learning about, building, and deploying software-defined radio systems. Started in 2001, GNU Radio is now an official GNU project and its source code is available on the website[5]. We used the provided example Python scripts *usrp_wxapt_rcv.py* to receive NOAA APT signal and *hfx2.py* to receive CW beacon signal from the USRP and the received audio is outputted to the laptop's speakers. To record the audio, an audio cable with TRS connectors (3.5mm) at both ends was used to route audio from the headphone socket to the microphone socket.

A freeware, Free Sound Recorder[6] was used to record NOAA APT audio signal, it allows unlimited recording duration and on-the-fly adjustment of recording volume. We recorded the audio in a wave file (WAV format, 11kHz, mono, 16bit) which is later imported by APTDecoder – the free software used to decode the APT audio signal into images.

For satellite pass prediction we used Orbitron software[7] which is simple and easy to use. Moreover it can automatically get latest orbital information of any satellites in TLE format (Two-Line Element)[8] from CelesTrak site[9]. Since we haven't setup the computer-controlled antenna rotator mechanism yet so manual antenna tracking of the satellite is required. This turned out to be an fun and exciting teamwork activity where we usually have 4 people:

- The "captain": in charge of controlling all software and recording the signal
- The "speaker": in charge of saying out loud the coordinates (azimuth and elevation) of the satellite in real time as the it passes overhead
- The "gunner": in charge of preliminarily aiming the Yagi antenna at the provided coordinates
- The "navigator": in charge of fine-tuning the antenna pointing accuracy (Az & El) via a compass and an inclinometer

4. Result

Using self-made antennas, USRP&TVRX hardware plus the mentioned software, our team has successfully received and decoded NOAA APT pictures and CW beacon signal from other small satellites on Low Earth Orbit.

Figure 4. FSpace team receiving and decoding NOAA APT signal

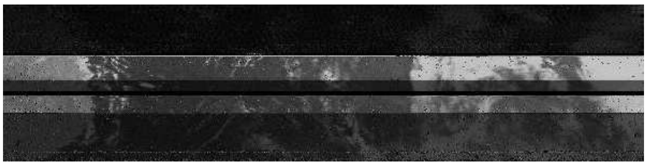

Figure 5. First signal from NOAA 17 satellite, Feb 04, 2009, different bands of shades are due to unequal volume adjustment during the recording

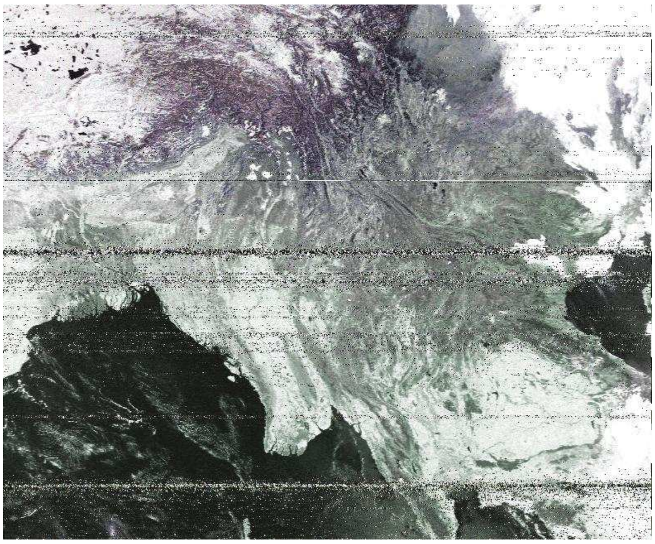

Figure 6. False color image from NOAA 17 received by FSpace and decoded using APTDecoder software[10]

Figure 7. FSpace team testing Yagi and helix antennas

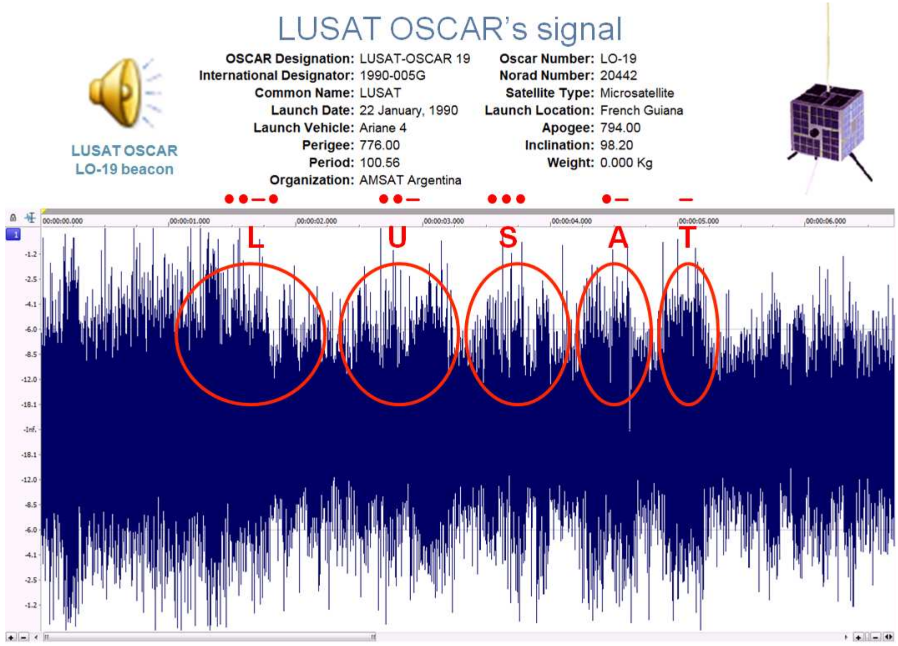

Figure 8. LUSAT OSCAR[11] LO-19's CW beacon signal recorded by FSpace team on Feb 07, 2009

Our satellite receiving sessions draw attention from many people, mostly youngsters. To many of them, the ability to predict the moment a satellite appears and track it moving overhead without actually seeing the satellite is incredible. Seeing the project team's achievement, some of them are excited and wanted to repeat the experiment which we offered help and advice.

IV. Basic design of the satellite

Aerospace engineering is difficult and it is very important for new satellite developers to learn from other missions, both success and failure ones. Keep this in mind we have studied lessons learned from other cubesat missions before designing our own. Many meeting and brainstorming sessions have been held to discuss the pros/cons of each idea and decision. We are also keen to look for experts from external organizations and listen to their comments and suggestions. Leveraging external experts' experience is a good way to compensate for the team's lack.

After four months of study, discussion, prototyping and reviewing, we've completed our components selection and basic design of the nanosatellite.

Table 1. Summary of F-1 nanosatellite's components

Subsystem	Component	Specification/Notes
Power Supply Unit (PSU)	Solar cells	Azurspace's 3G28 cells with 28% efficiency, built-in diode protection
	Main power supply	Tri-M's HESC-104 high efficiency switching DC-DC converter with smart battery charging and UPS function
	Rechargeable battery	Tri-M's BAT104-NiMh battery pack (22Wh)
	Backup power supply	Self-made with power supply auto-switching capability and circuit over-current protection
OnBoard Computer (OBC)	Main computer	EmbeddedARM's TS-7260 single board computer featuring ARM9 processor, 128M NAND Flash, 64M RAM and consumes less than 1W
	Backup computer	02 Microchip's PIC18F6722 microprocessors
Communication (COM)	Default transceiver	02 Yeasu VX-3R handheld transceivers
	Modem TNC	Paccom's PicoPacket with AX.25 protocol loaded
	Emergency command decoder	CM8870 DTMF chip
	High-speed transceiver (for downlink only)	Microhard L-400 OEM radio using UHF band, GMSK modulation, FEC, 1.2~19.2kbps transmission speed
Payload	Low resolution camera	C328-7640 JPEG camera module (640x480 resolution)
	High resolution camera	C6820 enhanced JPEG module (1.0Mp resolution and video capability)
	Sensors	Current, temperature and HMC2003 magnetic sensors

In brief, we are confident with the reliability of our design due to good redundancy and usage of flight-proven components such as the Azurspace solar cells, PIC microcontroller, VX-3R HT and PicoPacket modem TNC… The design also features components that never been used in a cubesat mission before such as the HESC-104 power supply, TS-7260 single board computer and L-400 OEM radio as we hope to test-flight them for potential application in future missions.

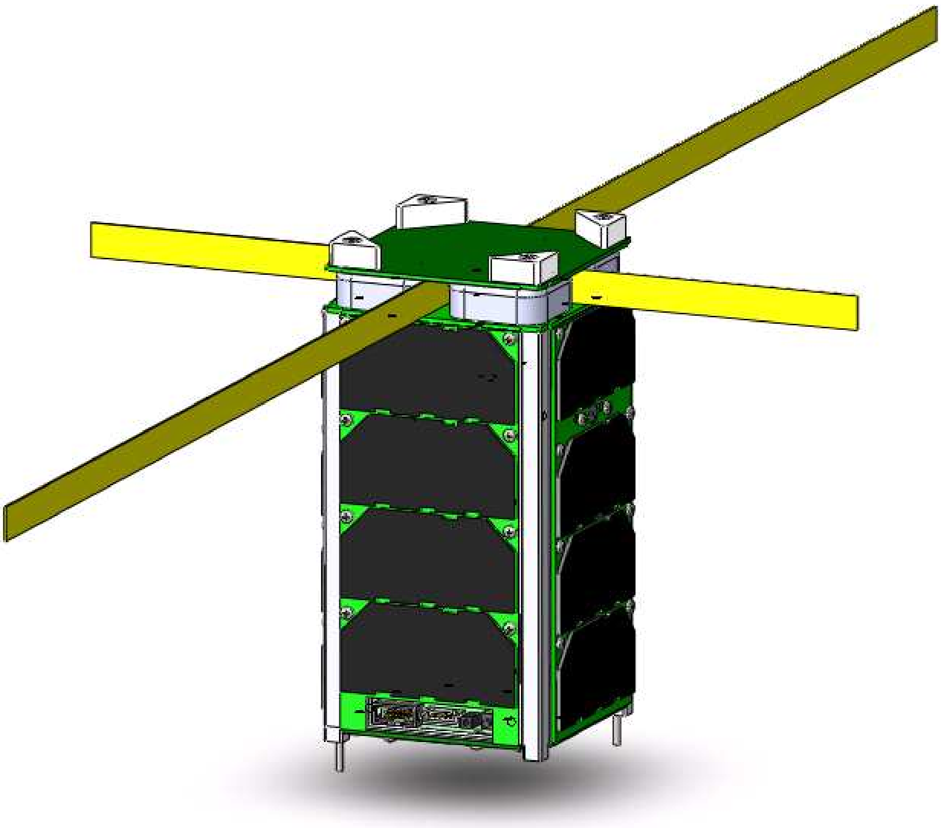

Figure 9. External view of F-1's structure model

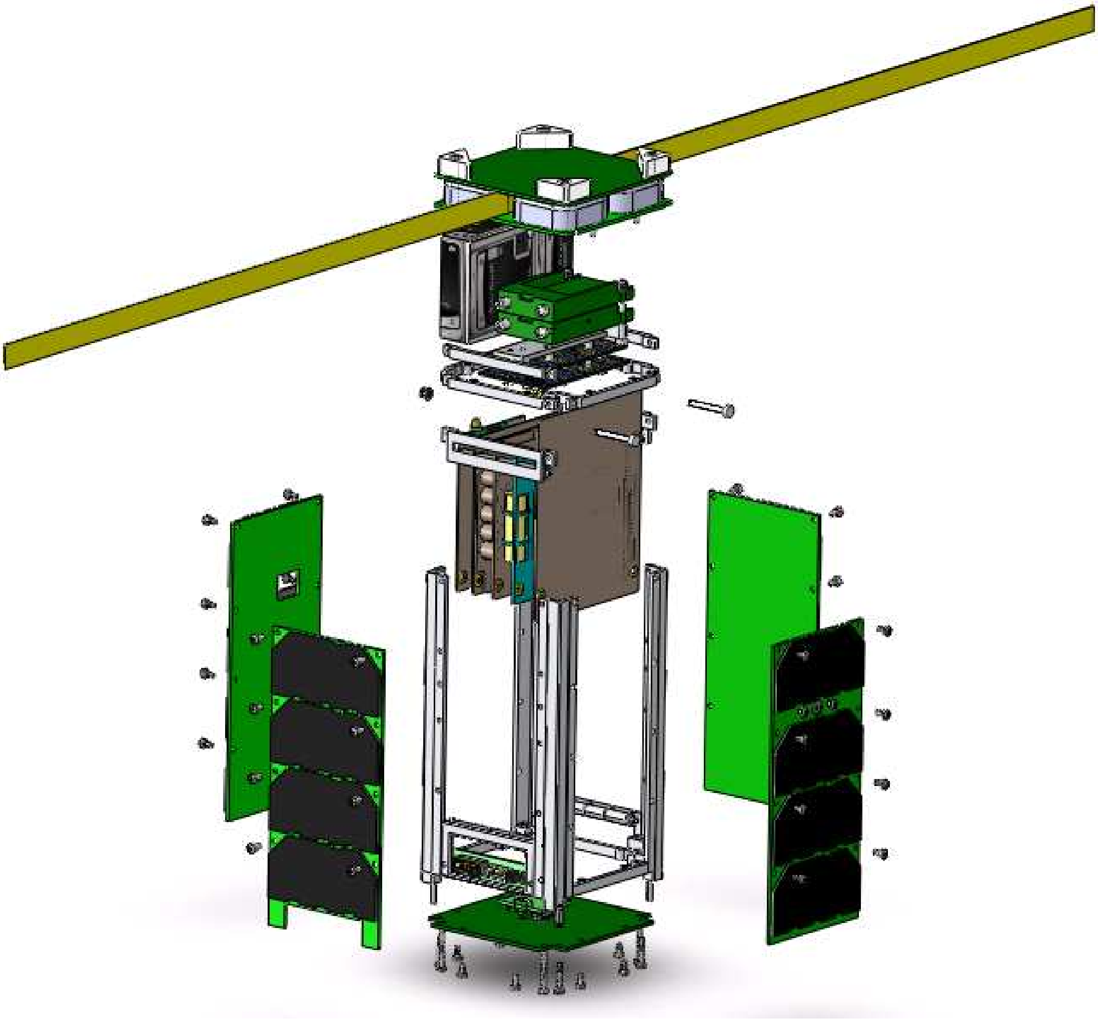

Figure 10. Exploded view of F-1 nanosatellite

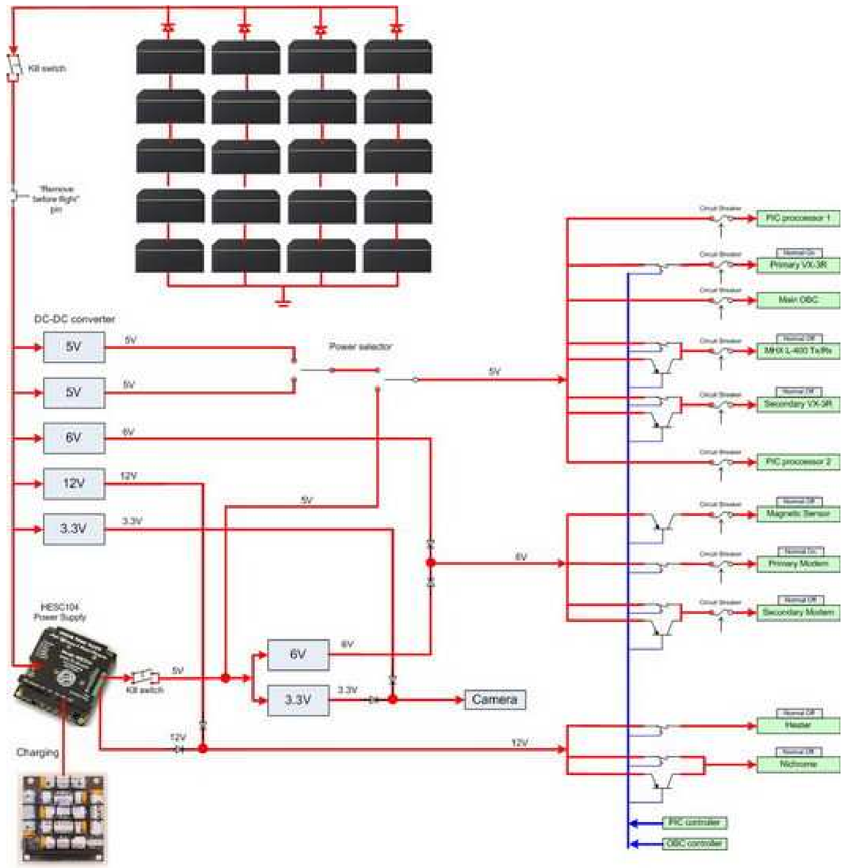

Figure 11. Power Supply Unit design with redundant power sources and circuit-breakers to protect major components from latch-up

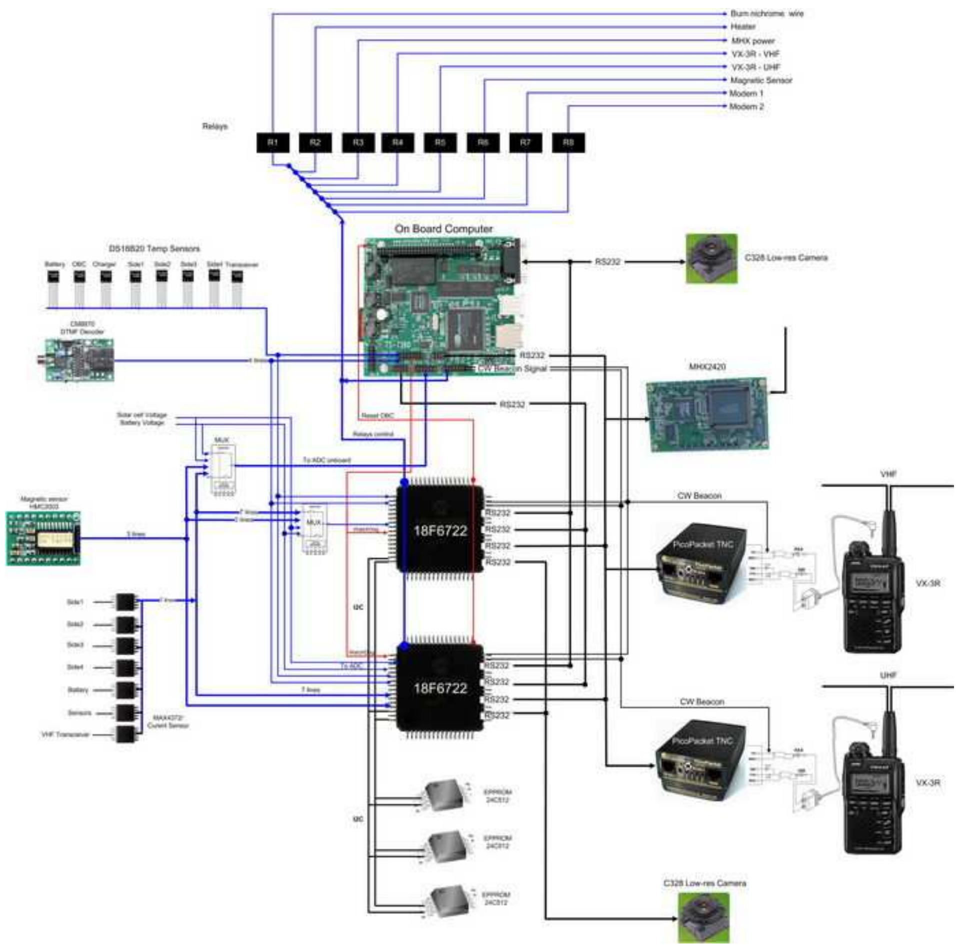

Figure 12. F-1 nanosatellite's components diagram with redundant parts to ensure high reliability

V. Conclusions

Starting the project with almost no experience on a real space mission before but with passion and dedication, we've learned a lot as the project progress. Inspired by our work, some members from Hochiminh Amateur Astronomy Club (HAAC) as well as some individual radio amateurs asked to join the project. We shared our experience and helped them to build their own antenna to receive NOAA APT pictures from orbit successfully(12). They are eager to learn more and willing to setup a second ground station in Hochiminh city to help us receive telemetry and mission data from F-1 nanosatellite once launched. This proves the great potential of a small satellite mission in encouraging youngsters to study and experiment with engineering.

As we finalized the design of our nanosatellite, preliminary experiment with the proposed hardware design has yielded good result: programming with the TS-7260 board is not as difficult as we thought and the young students can get familiar with C and Python languages quite well; the mechatronic engineers has completed the structure design of the satellite and performed vibration analysis and thermal analysis; all the transceivers and modems are working as expected and we have been testing communication between the prototype satellite and the ground station at increasing distance, the latest test went successfully at 7.18km range.

The project is moving on track to manufacture the breadboard model (BBM) as well as preparation for the next phases: manufacture of the Engineering Model (EM) and Flight Model (FM). Finally we hope to launch the satellite into Sun-synchronous, Low Earth Orbit, 800km altitude by the end of 2010 (negotiation with launch service providers is still underway). Over the project's 18-month course, the total development cost of the nanosatellite is estimated to be less than 100,000EUR. If succeed, we believe that it will help to foster the idea of cubesat and encourage universities/institutions and start-up companies to join the new trend of small satellites development. We are also looking for possible collaboration with other universities/organizations in the field of small satellite research and development.

VI. Acknowledgements

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VII. References

(1) Cubesat website http://cubesat.calpoly.edu/
(2) Double Cross — A NOAA Satellite Downlink Antenna http://www.poes-weather.com/~aptdecoder/jerry/CrossConcept/Documents/MARTES-QST-Feb-2008.pdf
(3) VHF/UHF Yagi Antenna Design http://www.dxzone.com/cgi-bin/dir/jump2.cgi?ID=11183
(4) Ettus Research LLC http://www.ettus.com/
(5) GNU Radio http://gnuradio.org/trac/wiki/Download
(6) Free Sound Recorder http://www.sound-recorder.biz/freesoundrecorder.html
(7) Orbitron 3.71 http://www.brothersoft.com/orbitron-132565.html
(8) Two-line element set http://en.wikipedia.org/wiki/Two-line_elements
(9) CelesTrak website http://celestrak.com/
(10) APTDecoder http://www.poes-weather.com/
(11) LUSAT OSCAR LO-19 http://www.amsat.org/amsat-new/satellites/satInfo.php?satID=12
(12) Satellite signal receiving project by HAAC members http://www.vietastro.org/forum/showthread.php?t=2416