The Future of CubeSat Communications: Transitioning Away from Amateur Radio Frequencies for High-speed Downlinks

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Abstract

This paper explores the evolution of CubeSat communications, starting with the first CubeSat launch in 2003 and ending with the latest ELaNa-6 launch from Vandenberg AFB on 13 September 2012. The communication systems for the first few CubeSats were based on COTS amateur radio gear, which worked extremely well but had very limited data rates. With the maturation of CubeSats from beep-sats to high-performance satellites with science or military missions, cheap, high-bandwidth communication systems are being developed. This paper aims to document these new high-bandwidth systems.

1 Introduction

The CubeSat program was started in 1999 by Dr. Jordi Puig-Suari at California Polytechnic State University and Robert Twiggs at Stanford University [1]. The 10 x 10 x 10 cm form factor was loosely based on solar cell sizes and airline carry-on luggage volume. From 2003 to September 2012, 72 CubeSats were delivered to orbit, 17 CubeSats decayed or deorbited, and 19 CubeSats launched but failed to make orbit [2].

2 CubeSat Classes

The CubeSat community is large and growing. Developers building CubeSats fall into two groups: teams that are new to the CubeSat concept and are learning how to start a program and build their first satellite, and established teams that already have one or more satellites in space.

2.1 Beginner CubeSats

New CubeSat teams start with designing a basic CubeSat. This is typically done by playing a systems integrator role by assembling off-the-shelf components and subsystems. These CubeSats typically carry a simple payload, such as a small camera. The main goal of these CubeSats is student education and development of processes and procedures for building satellites. Mission lifetimes are frequently less than one year.

These so-called "beep-sats" typically use VHF or UHF amateur radio frequencies, due to existing inexpensive terrestrial hardware that can be easily repurposed for satellite use. The amateur radio service is also allocated worldwide, so satellites can autonomously beacon down data and use amateur radio operators spread across the world for both telemetry reception and satellite commanding.

The exceptions to the beginner CubeSat rule are the universities that have existing small satellite programs, such as the University of California Berkeley and the University of Colorado Boulder, and some government labs. They leverage their current processes and procedures to build their first CubeSats, with mixed results.

CP4: This 1U CubeSat was the first Cal Poly satellite to achieve orbit, on 17 April 2007. Its main payload was an energy storage and dissipation device, but the payload was never exercised on orbit. The communication system was based on a single-chip CC1000 transceiver, which worked well for transmitting but had serious receive problems. The modulation scheme was 1200-baud FSK at 437.325 MHz, which required precise tuning of an SSB receiver for decoding [3].

Libertad-1: The first satellite built in Colombia by Universidad Sergio Arboleda, this 1U CubeSat contained a StenSat transceiver. Due to funding and time constraints, this spacecraft contained no payload and only primary batteries. It beaconed housekeeping data on 437.405 MHz every ten minutes in several AX.25 1200-baud frames [4].

HRBE: After several failed launch attempts, Montana State University finally launched their first 1U CubeSat on ELaNa-3 on 28 October 2011. This CubeSat also used a CC1000 transciever, which had the same receive problem as CP4. After launch, the team traveled to SRI International to use their 18-m dish. A link was successfully established and the link deficiency was discovered empirically. The team then purchased a 1.5 kW amplifier for their primary yagi ground station [5, 6].

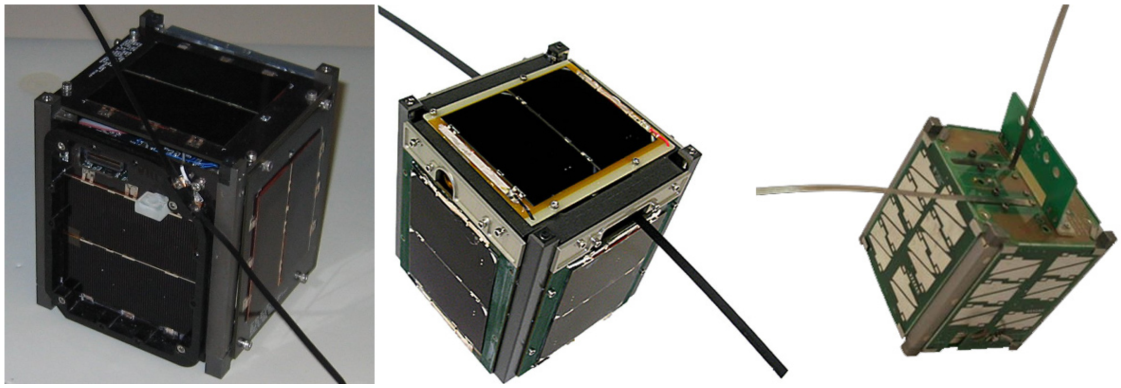

Figure 1: CP4, HRBE, and Libertad-1 CubeSats.

2.2 High-performance CubeSats

Once a CubeSat team builds a low-performance CubeSat, they gain the expertise and knowledge to build more complex spacecraft. CubeSats in this category are expensive to build, typically more than $1 million. In the United States, only the government, through the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), or the military, has funded these high-performance CubeSats to date.

As teams transition into the high-performance CubeSat realm, they quickly realize that the 1200- or 9600-baud communications that are prevalent in the beep-sats no longer meet their data requirements. While the amateur radio satellite service does have 3 MHz of spectrum, the International Amateur Radio Union has allocated CubeSats in the spectrum between 437.100 and 437.575 MHz, with a maximum single satellite allocation of 20 kHz. This was done to protect the existing and future amateur radio voice satellites [7].

Non-amateur radio licenses prohibit autonomous beaconing of satellite data. This is a big disadvantage because the CubeSat teams can no longer rely on the existing network of amateur radio operators to downlink beacon data and forward it to the team. Non-amateur satellite licenses are usually point-to-point, so all ground stations commanding and receiving satellite data must be on US territory and must be licensed, an expensive and time-consuming process.

2.2.1 NSF CubeSat Program

The NSF CubeSat Program was started by Therese Jorgensen in 2008. The primary mission is space weather, with higher education as a secondary objective. Teams submit a science proposal, are selected by an open review process, and are funded at around $1 million over two years to build the entire spacecraft and perform operations. NSF provides a launch for their projects [8].

To date, eight CubeSats have been selected for funding, and four have flown in space. Three of the NSF CubeSats that have flow in space are the following:

RAX: The RAX-1 spacecraft was the first NSF CubeSat launched from Kodiak, Alaska, on STP-S26 on 19 November 2010. It contained a radar receiver and looked for field-aligned irregularities induced in the aurora. Solar panel degradations caused RAX-1 to fail shortly after launch [9]. However, a backup flight spare was quickly upgraded and RAX-2 was launched on 28 October 2011 on a Delta II from Vandenberg. RAX-2 is doing well and still collecting science data 10 months after launch [10].

The RAX satellites use a AstroDev Lithium-1 radio at 9600-baud GMSK. The RAX satellites are using the amateur radio satellite service, and have pledged to perform RF spectrum noise analysis with the radar receiver when the primary mission is done.

Additionally, the RAX satellites also have a Microhard MHX-2400 S-band transceiver on board. Unfortunately, the effective data rate is not much faster than the 9600-baud downlink with a much larger DC power draw, so that radio was only exercised for initial checkout and for keeping the batteries heated.

DICE: The science payload for these two 1.5U CubeSats required a high-data-rate downlink, much faster than any existing CubeSat has used. After extensive reading of the NTIA Red Book, the DICE team selected the 460-470 MHz Meteorological-satellite (space-to-Earth) band. Red Book footnotes impose serious power flux density limitations in this band, so a large dish is required to close the link [11].

DICE was launched on the ELaNa-3/NPP mission from Vandenberg AFB on 28 October 2011. The 18-m dish at Wallops Flight Facility was used as the primary earth station. The 18-m dish at SRI International was used as a backup, but local terrestrial interference limited its usefulness [12].

The spacecrafts flew L3 Cadet radios, which use about 3 MHz of RF bandwidth for a 1.5 Mbit/sec data throughput with heavy forward error correction. DICE is the first CubeSat to get a license through the NTIA [13].

CINEMA: This 3U CubeSat used a 1 Mbps Emheiser transmitter in the 2.2 GHz Space Research Band. UC Berkeley has extensive experience with this radio system, and already had a complete ground system for communicating with their larger small satellites. This CubeSat launched on ELaNa-6/NROL-36 from Vandenberg, California, on 13 September 2012. Its mission is to study ions, neutrals, and electrons at high ecliptic latitude [14].

Both DICE and CINEMA got their spectrum certification and frequency authorization through the NTIA, because they considered themselves a federal satellite. However, during the process, the NTIA became concerned that federal/non-federal joint projects were being submitted to the NTIA instead of the FCC [15]. While they did authorize DICE and CINEMA, they recommended that future CubeSats obtain an experimental license through the FCC [16].

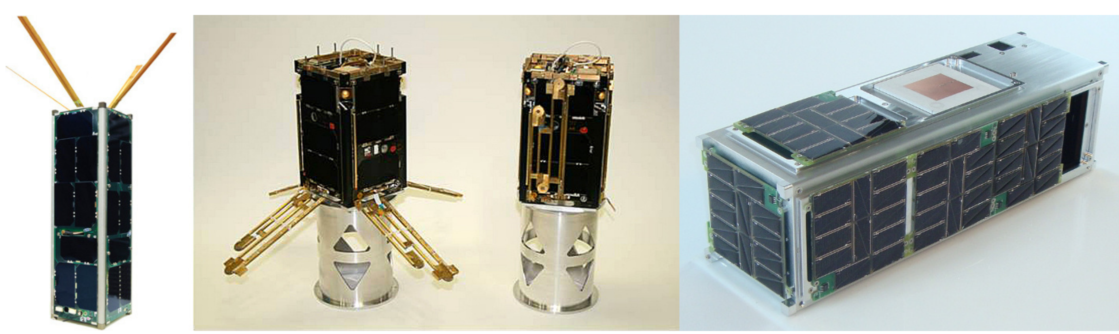

Figure 2: RAX, DICE, and CINEMA CubeSats.

2.2.2 Federal CubeSats

Recently the US federal government has started to see the utility of CubeSats. In particular, the National Reconnaissance Office (NRO) has been actively buying CubeSat busses and providing them to various educational institutions, national labs, and FFRDCs. Teams then build a payload, and the NRO provides a launch [17].

Government-funded CubeSats cannot use amateur radio frequencies for many reasons, including the fact that teams are paid to build and operate the spacecraft, and encrypted links are typically used. Due to these requirements, the federal government has been very active in funding radio manufacturers to design and build CubeSat radios. Over time, these designs will become available to the general community, although prices may be too high for all but the well-funded satellites.

QbX: Two of these 3U spacecraft flew on the second flight of the SpaceX Falcon 9 on 8 December 2010. The primary mission was a communications experiment using an experimental spacecraft radio. The spacecrafts communicated with the existing Mobile CubeSat Command & Control (MC3) System, built by the NRL [18]. Various experiments were conducted with the UHF telemetry radios, including passing data from one spacecraft to the other via an MC3 station. Crosslinks between spacecraft were not attempted [19].

AeroCube: The Aerospace Corporation has a long history of flying small satellites. Most of their CubeSats have used a 915 MHz spread-spectrum radio locked on a single frequency. They are using an experimental license with a data rate of 38.4 kbaud. Three similar 1U Aerocube-4 satellites flew on the latest NROL-36 launch on 13 September 2012 with the CINEMA spacecraft mentioned above [20].

3 Higher Frequency Communications

While beginner CubeSats will probably always use UHF amateur radio frequencies due to equipment and license availability, high-performance and military CubeSats are beginning to use higher frequencies for communications. DICE is barely above the UHF amateur radio band, and CINEMA is using 2.2 GHz.

As CubeSats' communications transition to these higher frequencies, the radios and ground stations get difficult and expensive to build. However, much more bandwidth is available in all the satellite services, including the amateur radio service, should teams decide they fit there. Japanese CubeSats scheduled for launch from the International Space Station in October 2012 are using 5.83 GHz and Ku-band transmitters.

4 Conclusion

CubeSat communications systems are maturing at a rapid pace. Five years ago, the only alternative to modified COTS amateur radio equipment was low-performance ISM radios. The fastest communications system had an effective throughput in the tens of kilobytes per second. Today, we see several radio manufacturers providing Megabit-class transmitters compatible with the CubeSat size and power restrictions. As CubeSat transmitters become higher in frequency, more bandwidth is available for high-speed communications.

References

[1] Jordi Puig-Suari, et al. “CubeSat Developments at Cal Poly: The Standard Deployer and PolySat.” In Proceedings of the 45th Annual Meeting of International Society for Optical Engineering (SPIE). Paper 4136-13. July-August 2000.

[2] Daniel Oltrogge and Kyle Leveque. “An Evaluation of CubeSat Orbital Decay.” In Proceedings of the 25th Annual AIAA/USU Conference on Small Satellites. SSC11-VII-2. Logan, Utah. August 2011.

[3] Derek Huerta. “Development of a Highly Integrated Communication System for use in Low Power Space Applications.” Masters Thesis. California Polytechnic State University, San Luis Obispo. May 2006.

[4] Bryan Klofas, Jason Anderson, and Kyle Leveque. “A Survey of CubeSat Communication Systems.” Presented at the 5th Annual CubeSat Developers Workshop. San Luis Obispo, California. April 2008.

[5] David Klumpar. “CubeSat Lessons Learned: Two Launch Failures Followed by One Mission Success.” In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-II-4. Logan, Utah. August 2012.

[6] Matthew Handley. “The On-Orbit Performance of the HRBE (E1-P) CubeSat Nearing Nine Months in LEO.” Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.

[7] Hans van de Groenendaal. Personal Communication. 22 September 2012.

[8] Therese Jorgensen. “CubeSat-based Science Missions for Space Weather and Atmospheric Research: A new NSF Program.” Presented at the 5th Annual CubeSat Developers’ Workshop. San Luis Obispo, California. April 2008.

[9] James Cutler, John Springmann, Sara Spangelo, and Hasan Bahcivan. “Initial Flight Assessment of the Radio Aurora Explorer.” In Proceedings of the 25th Annual AIAA/USU Conference on Small Satellites. SSC11-VI-6. Logan, Utah. August 2011.

[10] John Springmann, Benjamin Kempke, James Cutler, and Hasan Bahcivan. “Initial Flight Results of the RAX-2 Satellite.” In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-5. Logan, Utah. August 2012.

[11] Chad Fish, et al. “DICE Mission Design, Development, and Implementation: Success and Challenges.” In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-1. Logan, Utah. August 2012.

[12] Jacob Gunther. “DICE Telemetry Overview and Current Status.” Presented at the CHDC Meeting after the 9th Annual CubeSat Developers’ Workshop. San Luis Obispo, California. April 2012.

[13] Bryan Klofas. “Frequency Allocation for Government-funded CubeSats: NSF Paves the Way.” In Proceedings of the AMSAT-NA Symposium. San Jose, California. November 2011.

[14] David Glaser and Karla Vega. “CINEMA: CubeSat for Ions, Neutrals, Electrons, MAgnetic fields.” Presented at the 6th Annual CubeSat Developers’ Workshop. San Luis Obispo, California. April 2009.

[15] CINEMA Stage 4 Certification of Spectrum Support. Control Number SPS-18192/1. 6 September 2011.

[16] Bryan Klofas. “CubeSat Frequency Allocation.” Presented at the 9th Annual CubeSat Developers’ Conference. San Luis Obispo, California. April 2012.

[17] Maj David Shultz, et al. “Colony: A New Business Model for Research and Development.” In Proceedings of the 24th Annual AIAA/USU Conference on Small Satellites. SSC10-IV-2. Logan, Utah. August 2010.

[18] Giovanni Minelli. “Mobile CubeSat Command & Control (MC3) Ground Stations.” Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.

[19] Stephen Arnold, et al. “QbX - The CubeSat Experiment.” In Proceedings of the 26th Annual AIAA/USU Conference on Small Satellites. SSC12-XI-4. Logan, Utah. August 2012.

[20] David Hinkley. “AeroCube 3 and AeroCube 4.” Presented at the 9th Annual CubeSat Summer Workshop. Logan, Utah. August 2012.