University Amateur Radio Success
PSAT Mission Review and Lessons from 18 mos in Space

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Licensing in a Nutshell

- **2013 FCC clarification of Experimental Licenses**
- **Naval Academy Student Amateur Satellite missions**
- **Experimental is not possible for Federal Academies or Labs**
- **NTIA has no comparable Experimental license class**

As long as they meet requirements, anyone can build AmateurSATs.

**23 Bands**

<table>
<thead>
<tr>
<th>Non Federal</th>
<th>Federal</th>
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<tbody>
<tr>
<td>University</td>
<td>DoD Lab</td>
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<td>schools</td>
<td>.edu</td>
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<table>
<thead>
<tr>
<th>Amateur</th>
<th>Experimental</th>
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<tbody>
<tr>
<td>HF: 7, 14, 18, 21, 24, 28 MHz</td>
<td>VHF: 145 MHz</td>
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<tr>
<td>UHF: 435 MHz</td>
<td>902 MHz</td>
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<td>1260 MHz</td>
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- Millimeter: 47, 76, 77, 134, 241, 248 GHz
- Satellite Bands: 2.39 GHz, 2.4 GHz, 3.4 GHz, 5.6 GHz, 5.8 GHz, 10.4 GHz, 24 GHz
What is an Amateur Satellite?

(>200+? in 55 years since 1961)

Any size...

built by anyone...

But Operated:  “amateur”
- with a (non pecuniary) interest in the Satellite Art
- And serving an Amateur Radio Mission (individual education) (& users)
What is an **Amateur** Radio Satellite?

(>200+? in 55 years since 1961)

The main thing “*amateur*” about the Amateur Satellite Service is the non-pecuniary interest requirement. *(kinda like the Olympics)*

Many hands-on communications professionals also have amateur licenses to allow them direct access to frequencies throughout the Electromagnetic Spectrum for personal experience in the radio art.

The **Amateur Frequencies** provide parts of the EM spectrum for the public, protected from commercial/government exploitation; **like** the **National Parks** protect the wilderness and the land for public use. Just get a license or permit and follow the rules.
50% of Astronauts on the ISS have Amateur Licenses

They are paid government employees

They use them to bring value to the radio art (and students)
Senior Engineering Student Capstone Projects

Accredited Engineering now requires hands-on Design-Build-Fly type projects – All majors

Project Based Learning
Ten Astro Student Amateur Satellites over 16 years


KEY: Still Alive, De-orbited, Manifest, Immediate

Bob Bruninga, PE, WB4APR – US Naval Academy, Student Satellite Lab  bruninga@usna.edu  410-293-6417
A Mission & Global Internet linked Data Network

APRS Global Packet Radio Network
Internet Linked for live Communications

Automatic Packet Reporting System
Includes channels on Three Geostationary Satellites

OUTERNET

Simple Ground Station:

& SDR USB dongle
USNA Satellites and Global Ground Station Network

Of 80,000 packets
22,000 User Packets
550 Users
44 Countries
330 Gnd Stations

These are daily amateur satellite ground stations, users, experimenters using USNA satellites

pcsat.findu.com
Amateur Packet Radio (APRS) is Everywhere*

- Supports over 40,000+ terrestrial users and experimenters.

* APRS Pioneered at USNA

* But stops at the shoreline and has huge holes in the wilderness
APRS is Amateur Radio’s GIS system

Find any station, Any map, Anywhere- http://aprs.fi

300 stations
In 35 miles

35 mi
APRS is Amateur Radio’s GIS system *


Call or Obj Name

Posit Data Time Stamp

47 character comment text

Find any station, Any map, Anywhere- http://aprs.fi
Amateur Satellite Ground User Applications Focus
Why do we need Amateur Data Relay Satellites?

Global Wilderness Areas (90% of Earth)

Live Global Amateur Balloon Tracking experiments need satellite relay
As well as boats, buoys, hikers, travelers gathering data and learning
Example Remote Sensor Experiments using APRS

But now ‘Round the world is common
Why We Need APRS Satellites

• Transatlantic APRS balloon launched and tracked through terrestrial network
• Lost comms over Atlantic Ocean
• It could have been picked up by our Psat/Pcsat transponder or the ISS
Ground Terminal Applications Focus (force tracking and text-messaging)

Supports Student Experiments
Worldwide Amateur Radio tests
and Emergency Response Comms

Education Force Multiplier!
Not just our students but other Hams are involved

"When you have no comms, 1200 baud text/data is great!"

CAPT Chas Richard
W4HFZ

PCsat Afloat Operations Test

CDR Chas Richards W4HFZ (CO)
LTjg Brian Young KC5KLE
ETCS Curtis Mathews N1FDW
ENS Brian Scribeks PCsat design team

USS Parche SSN-683
USNA Amateur Satellites
Psat Space Transponder flown on as many spacecraft as possible provides continuity to remote data sensing...

And enhances student access to space education and applications
Number of Buoy Packets Received Per Day via PCSAT-1 and PCSAT2

March 2006

- Telemetry
- Position
- Beacon

- PCSAT-1 shut down due to negative power budget

- PC2 shut down 18 hrs for Soyuz docking
- PC2 jammed by school contact
- gnd was off
- PSK experiments on PC2 most passes
Accredited Engineering majors now require hands-on Design-Build-Fly type projects.
Huge reduction from transponders on PCSAT’s 1, 2, ANDE and RAFT missions

Now reduced 18:1 in volume/mass for 4” cubesat 2009

Earlier reductions to 5” cubesat on RAFT (2006)
VHF Comm Board has 5 channels Analog TLM

System Current Load Telemetry History

Battery Temperature Over 18 Month Period
Battery Temperature channel shared with User Mode Bit

Accredited Engineering majors now require hands-on Design-Build-Fly type projects
Battery Temperature channel shared with User Mode Bit

Overlaying, shows low-Voltage events triggered Safe Mode

It also shows that early on we were not diligent in restoring user mode until user demand pretty much requested it later on.

Figure 13: Bus Voltage Telemetry History
Unique PSAT EPS system and Radiative Spin

Terrestrial Si Cells. Total cost $4 per panel

In Series For 8v Bus

Good packing factor
Unique PSAT EPS system and Radiative Spin

Terrestrial Si Cells. Total cost $4 per panel

Requires Spin!
Unique PSAT EPS system and Radiative Spin

Terrestrial Si Cells. Total cost $4 per panel

Requires Spin!

Notice offset color scheme!

0.6 – 0.8 RPM on PCSAT since 2001
PSAT Radiative Spin Plots and Aliasing

Representative Plot Displaying Z Axis “Wobble”

Representative Plot of Z Axis Aligned with Sun Vector

Figure 20: Highest Observed Spin Rate

DK3WN Signal Strength Plot over 1 minute
PSAT Radiative Spin

Initial Spin plot (manual) decayed to near Zero
Then in full sun period spun up to over 10 RPM

Each +Z/-Z Temperature peak shows a period when they spin is END-ON to the Sun.
Wrapping 4 Antennas to one Burn Resistor

Two 6” UHF whips
Orthogonal

One 19” VHF whip
One 72” HF whip

3rd Enable Switch
PSAT-2 is full up Cubesat with $20,000 solar cells (double the power 3W)

SATT4 Comms Board VHF & UHF and watchdog system

9600 baud UHF downlink
QIKCOM-1 APRS DIGIPEATER

Unique Antenna Deployment System

On ISS Awaiting Deploy
QIKCOM-2
APRS and DTMF Digipeater
Converts DTMF to APRS and also Voice downlink

APRStt (touchtone)

NovaWurks DARPA eXCITE mission
Not one of these missions was funded by external research $$$

Funding is/was general support for undergraduate capstone student projects, some Gift funds and FREE RIDES
The Amateur Satellite Service provides students vital access to space at low cost

• As long as missions meet the rules:
  – a mission that serves the general Amateur Community and/or
  - provides self training and investigations relative to radio Technique
  - and the operations are without any pecuniary or conflicts interest

• For communications experiments it has several unique features:
  - Very large cadre of communications participants and volunteers
  - Worldwide users without specific a priori listing in the license
  - With these numbers, can fully load and test protocols
  - Greater frequency options – for exploring radio technique (23 bands)
  - Can use COTS hardware (which meets FCC amateur criteria)
USNA Amateur Satellite Command and control, telemetry, and 2-way User data relay
Licensing Distinctions:

Experimental and NTIA: [License the hardware and the institution]

An FCC Experimental or an NTIA license is for a specific satellite, a specific launch, a specific mission and is given to an institution for that purpose for that satellite.

Amateur Satellite License: [uses the existing license of the control operator]

Public Notice 2013: note[1]... rules do not... issue a specific amateur satellite license....

FCC Part 97: Any Amateur station can be a space station. Any License class operator can control the space station...
FCC Public Notice of 2013 clarified Amateur and Experimental Licenses:

- It clarified the rules for experimental and amateur licensed spacecraft
- It did NOT require all research or university satellites to be experimental
- It did NOT change any specifics with the Amateur Satellite Service that has worked well for the last 57 years and over 300 satellites
- It did NOT say that individuals at government or Federal institutions cannot build/operate Amateur Satellites
FCC RULES, PART § 97.207 Space station.
(a) Any amateur station may be a space station... Any class operator...
may be the controller operator of a space station ...
(b) A space station must be capable of effecting a cessation of
transmissions by telecommand whenever... ordered by the FCC.
(c) The following frequency bands and segments are authorized to space stations:
   (1) The 17, 15, 12, and 10 m bands, 6, 4, 2 and 1 mm bands; and
   (2) [segments in the] 7, 14, 145, 435, 2400 MHz and 3, 5, 10, and 24 GHz bands
(d) A space station may... retransmit... signals of Earth stations and other space stations.
(e) A space station may transmit one-way communications.
(f) Space telemetry transmissions may consist of specially coded messages...
   to facilitate communications or related to the function of the spacecraft.
(g) The license grantee of each space station must make ... notifications...
   (1) Pre-space notification... Appendix 4 ... including [orbital debris mitigation]:
       (i) Statement ... [on] limiting the amount of debris...
       (ii) Statement [assessing]... probability of accidental explosions...
       (iii) Statement ... limiting... the probability of ... collisions...
       (iv) Statement detailing the post-mission disposal plans...
       (v) If any ... item ... changes..., a replacement ... notification shall be filed...
(2) An in-space station notification...no later than 7 days following [activation]...
(3) A post-space station notification... no later than 3 months after termination...
"Amateur Satellite Service: A radio communication service [using space stations on Earth satellites] for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest." [RR 1.56] [RR 1.57]

Commission rules and policy explicitly permit instructional personnel to operate while being compensated in the course of classroom instruction, [and] not confined to the physical confines of a normal classroom”

The purposes of an amateur satellite should be to:

1. Provide communication resources for the general amateur radio community and/or
2. Self training and technical investigations relating to radio technique. [See RR 1.56, 1.57, and 25.2]
"Radio technique" means having a reasonable possibility of application to radio communication systems. Examples relating to radio technique include, but are not limited to:

- communication protocols
- attitude determination methods
- command and control procedures
- receivers, transmitters, and transponders
- antennas
- sensors to study spacecraft performance
- telemetry protocols
- power controls and supplies for use in space
- spacecraft computers, memory, operating systems, programs, and related items
- radiation effects on electronic components
- radio wave propagation
- meteor trail reflection
- measurements of the orbital environment

55 years of Amateur Satellites in space by the hundreds
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License Class Is not determined by any of these Technical Explorations And Experiments

Nor by ownership

License Class Is determined by Comms Mission

55 years of Amateur Satellites in space by the hundreds
Three Spacecraft Licensing Procedures:

Part 25: commercial and remote sensing
Part 5: experimental operations
Part 97: Amateur Radio Satellites

Amateur radio transmissions are primarily for the purpose of exchanging messages with other amateur stations, and our rules prohibit “communications in which the station licensee or control operator has a pecuniary interest, including communications on behalf of an employer....”

Commission rules and policy explicitly permit instructional personnel to operate while being compensated in the course of classroom instruction, [and] not confined to the physical confines of a normal classroom.

For experimental licenses,
The scope of permitted services includes experimentation under contractual agreement with the United States Government, and communications essential to a research project.
Three Spacecraft Licensing Procedures:

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Unintended consequence:
Most universities, etc (without an amateur radio mission) filed for experimental licenses and the rare amateur satellites were lost in the noise.
“Everyone” in the launch business expected to see a spacecraft LICENSE before manifesting a payload.

Catch 22: But the FCC does not issue any license or documentation for Amateur Satellites

Commission rules and policy explicitly permit instructional personnel to operate while being compensated in the course of classroom instruction, [and] not confined to the physical confines of a normal classroom.”
For **amateur radio service satellite** operations, available frequencies are identified in Section 97.207(c) of the rules. [IE, 7, 14, 18, 21, 24, 28, 145, 435, 902, 1296, 2400, 5600, 10,000 MHz, etc]

For **experimental operations**, there are no specific bands identified in the rules, and operations are on a temporary, non-interference basis, ... Common frequencies authorized for small satellite operations to date have been for the 145-148 MHz, 420-450 MHz, 902-928 MHz (ISM), and 2.390-2.450 GHz bands.

**Federal** frequency bands commonly used for small satellite operations ... include 420-450 MHz, 902-928 MHz, 2.390-2.395 GHz, and 2417-2450 GHz.
To: Karl Kensinger, FCC International Bureau
From: David Sumner, ARRL (and AMSAT)
Date: January 14, 2014
RE: Small satellites

We appreciate the Commission’s ongoing efforts to prevent commercial and governmental exploitation of the frequency allocations to the amateur and amateur-satellite services. [in the] Public Notice of March 15, 2013

However, we are finding that there is continuing confusion among the builders of small satellites such as CubeSats, particularly among those whose projects are conducted under the auspices of universities and other educational institutions.
ARRL, AMSAT and NSF endorse the use of the amateur-satellite service by non-commercial, university CubeSats. Use of the amateur-satellite service is mutually beneficial to the radio amateur and university communities since:

1. It helps provide more satellites that amateur radio operators can use.
2. It enables universities to engage the world-wide amateur radio community in gathering telemetry information from their satellites.
3. It promotes awareness of amateur radio to university students and licensing of new operators as well as helping to develop the next generation of amateur satellite builders.

AMERICAN RADIO RELAY LEAGUE

Official Journal

International Secretariat of The International Amateur Radio Union
Why do we use 3rd party Volunteer Amateur Control Operators?

Station Control — who may operate a transmitter

All stations operating in the amateur service and the amateur-satellite service, including space stations and Earth stations, must be controlled by "duly authorised persons," that is, individual licensed amateur radio operators who must be acting "solely with a personal aim and without pecuniary interest." [See RR 1.56 and 1.57]

Even with these limitations, organisations and amateurs have common interests and work together for their mutual benefit.

AMSAT-NA, for example, is an organisation that owns and builds space stations to operate in the amateur-satellite service. However, because it is an organisation and not an individually licensed radio amateur, it may not control an amateur station.

Licenses under which AMSAT-NA owned [satellites] are operated may be ... an individually licensed amateur radio operator.[or] an amateur radio club ... where a licensed...trustee (the person responsible) for the club station.

http://www.iaru.org/amateur-radio-satellite-frequency-coordination.html
Why do we license our Amateur Missions via a 3\textsuperscript{rd} party Volunteer?

In every case, one individual, a licensed amateur radio operator who is neither employed nor paid by [the organisation] is legally responsible for the operation of each amateur station or amateur-satellite station.

Commonly, the licensee is an unpaid member of the organisation owning the amateur station equipment or is a volunteer acting in close association with it. In these cases, the owner's interest and the licensee's "personal interest" are usually the same.

Of course, it is...possible...that the licensee or trustee of an amateur satellite station may determine that something he or she is requested to do is not in accordance with the rules and regulations of the licensing administration. If this happens, the licensee will inform the organisation and, if possible, they will work out a solution together that satisfies and protects both.

Thus, the individual responsibility of each licensed amateur radio operator, imposed by the Radio Regulations, works as a legal safety check for the organisation and the amateur to protect both of their interests and those of the amateur-satellite service as well.

This arrangement has worked successfully and effectively for AMSAT-NA and its predecessor organization since the first amateur satellite (OSCAR I) in 1961.

http://www.iaru.org/amateur-radio-satellite-frequency-coordination.html
NTIA Freqs 449 MHz up & 900 MHz down are not workable

449 MHz band is full of megawatt Doppler Wind Profilers blocking uplinks around the world

There is no NTIA stage 4 certified cubesat scale radio in production for under $70,000

The NTIA now says that 900 MHz is no longer available (its full of unlicensed gadgets anyway)

Ergo - The only viable NTIA Cubesat command and control is now Sband (half-duplex)

Most smallsat/cubesat Experimental and NTIA assignments had come from within the Amateur Satellite Bands

Similarly the Amateur Satellite Service builders will not use 2.4 GHz for WIFI interference reasons
Arctic Buoy Student Experiment

- USNA Arctic Buoy deployed March 2012

The APRS piece
The USNA developed Cubesat comms card

Mission: Common low cost Cubesat Amateur Radio Transponder

Hardware: VHF simplex data radio on 145.825 MHz

Size/Mass/Power: 3.4” square, 1W orbit average

Antenna: 20” thin wire whip antenna

Benefit: Space Education AND ground experiments with student access

High visibility to worldwide educational institutions, fosters collaboration, orders of magnitude greater student experimental access to space systems (ground segment).

- Amateur Radio User Relay mission
- Independent telemetry command/ control channel,
- RS232 serial data, 16 on/off discretes, backdoor reset capability.
- Worldwide Telemetry Beacon access via global station network.
Who Should Apply? For amateur radio service satellite operations, the amateur satellite control Operator… [who] should have the ability to remove the satellite from a launch… and [cease] operations.

The Commission’s Part 97 [Amateur Rules] rules do not provide for the issuance of a specific amateur satellite license document, but instead require a licensed amateur operator to provide information to the Commission prior to launch of the satellite.

For experimental operations, the applicant should be the party that … controls decisions about the satellite’s mission..., design, construction, tendering... to a launch... provider or … launch integrator, and operations of the satellite once on orbit. This is in most cases a university or research institution, but may also be a commercial venture seeking to test equipment for developmental purposes.
What Information is Required to Apply?

For Amateur pre-launch notifications:

- A draft “Appendix 4” notification for submission to the International Telecommunications Union (ITU) Radio Regulations. The draft notification should be prepared using the ITU software “SpaceCap,” which can be downloaded from the following link: http://www.itu.int/en/ITUR/software/Pages/spacecap.aspx.

- A letter from the International Amateur Radio Union (IARU) indicating [frequency] coordination.
What Information is Required to Apply?

For experimental licenses, applicants must first obtain an FCC Registration Number at https://fjallfoss.fcc.gov/coresWeb/publicHome.do.

Then submit its license application through the Office of Engineering and Technology’s (OET) Experimental Licensing system; or,

For operations lasting less than six months..., an applicant should apply for Special Temporary Authority (STA) at https://apps.fcc.gov/oetcf/els/forms/STANotificationPage.cfm.

When is Coordination with Federal Governmental Agencies Necessary? An applicant’s proposed satellite operations may affect spectrum used by Federal Government entities. OET will determine [if it should ] coordinate with the NTIA [and/or be] subject to special conditions.
PSAT Power, Comm, Xponder & ADCS

Accredited Engineering majors now require hands-on Design-Build-Fly type projects

Figure 3: PSAT System Block Diagram
APRS Satellite Applications

- Wilderness Position and Status Reporting
- Off-shore Worldwide Position and Texting
- Remote Data Collection
- Comms Experiments (dual hop)
Licensed Radio Amateurs are Everywhere

"When you have no comms, 1200 baud text/data is great!"
CAPT Chas Richard
W4HFZ
The USNA Global Internet linked Amateur Data Network

APRS Packet Radio Network has evolved worldwide from USNA beginnings in 1993
Internet Linked for live Communications, telemetry and data
Global Wilderness Areas (90% of Earth)

- Live Global APRS Balloon Tracking Web Page