



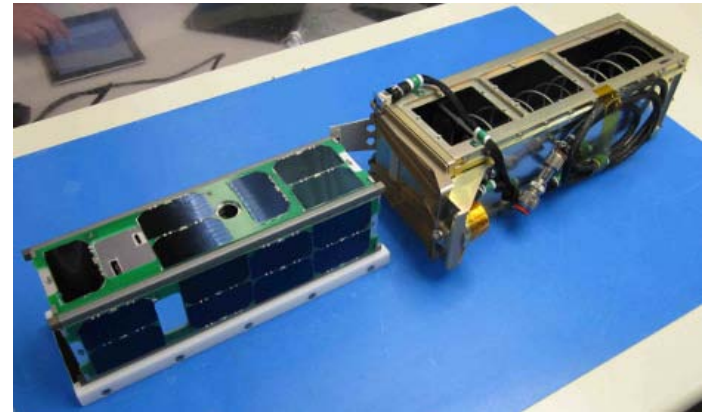
CubeSat Radios: From kilobits to Megabits

Bryan Klofas
SRI International
bryan.klofas@sri.com

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CubeSat Background

- CubeSat project started in 2000 as an international educational experiment
- Mechanical standard only: 10 x 10 x 10cm, up to 1.33kg is 1U
- Deployers typically hold 3U



- GeneSat (NASA Ames) was the first Government CubeSat in 2006
- NRO Colony program accelerated the building of Government CubeSats
- CubeSats launched to date:
 - 95 University CubeSats (NSF)
 - 11 Commercial CubeSats
 - 47 US Government (NASA and DOD)

CubeSat Launches (1 of 3)

Name	Vehicle	Date	# CubeSats	Total U
NLS-1	Rocket	06/30/2003	6	8
SSETI Express	Kosmos-3M	10/27/2005	3	3
M-V-8	M-V-8	02/22/2006	1	2
Minotaur-1	Minotaur 1	12/11/2006	1	3
Dnepr 2	Dnepr	04/17/2007	7	9
NLS-4	PSLV-C9	04/28/2008	5	9
Minotaur-1	Minotaur 1	05/19/2009	4	6
ISILaunch-01	PSLV-C14	09/23/2009	4	4
H-IIA F17	H-IIA	05/20/2010	3	3
NLS-6	PSLV-C15	07/12/2010	2	2

CubeSat Launches (2 of 3)

Name	Vehicle	Date	# CubeSats	Total U
STP-S26	Minotaur 4	10/19/2010	3	9
Falcon 9-002	Falcon 9	12/08/2010	8	18
PSLV-C18	PSLV-C18	10/12/2011	1	3
ELaNa-3/NPP	Delta 2	10/28/2011	5	9
Vega VV01	Vega	02/13/2012	7	7
ELaNa-6/NROL-36	Atlas 5	09/13/2012	11	24
ISS	HTV-3/ISS	10/04/2012	5	6
PSLV-C20	PSLV-C20	02/25/2013	2	4
ISILaunch-02	Soyuz	04/19/2013	5	7
Antares Demo	Antares	04/21/2013	4	6

CubeSat Launches (3 of 3)

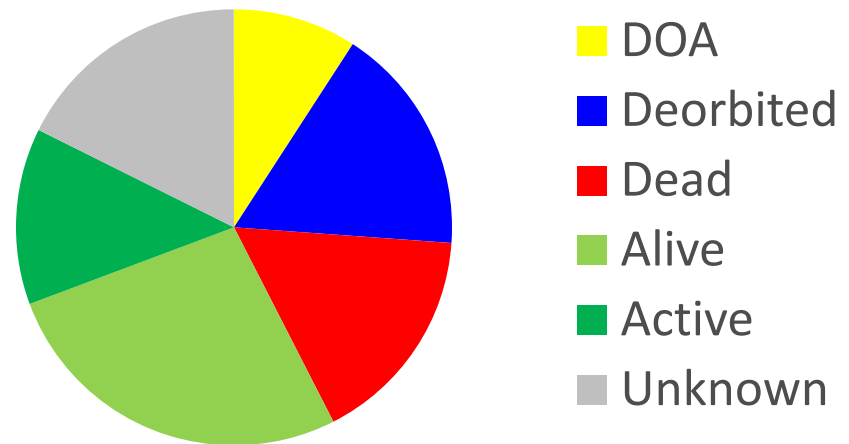
Name	Vehicle	Date	# CubeSats	Total U
Long March 2D	Long March 2D	04/26/2013	3	6
Vega VV02	Vega	05/07/2013	1	1
ISS	HTV-4/ISS	10/19/2013	4	6
ELaNa-4/ORS-3	Minotaur 1	10/20/2013	28	48
ISILaunch-03	Dnepr	10/21/2013	18	33
ELaNa-2/NROL-39	Atlas 5	12/05/2013	12	24
Totals:			153	260

Future CubeSat Launches

Name	Vehicle	Date	# CubeSats	Total U
Orb-1/ISS	Antares/ISS	Feb 2014	33	96
ISILaunch	Soyuz	Feb 2014	1	3
ELaNa-5/CRS-3	Falcon 9	Mar 2014	5	12
ELaNa-7/ORS-4	Super Strypi	Fall 2014		24
ELaNa-10/SMAP	Delta II	Nov 2014	3	9
GRACE/NROL-55	Atlas 5	Dec 2014		24
ULTRASat/AFSPC-5	Atlas 5	Feb 2015		18
STP-2	Falcon 9 Heavy	Fall 2015		27
Totals:			42+	213

Summary of CubeSats 2003 to 2014

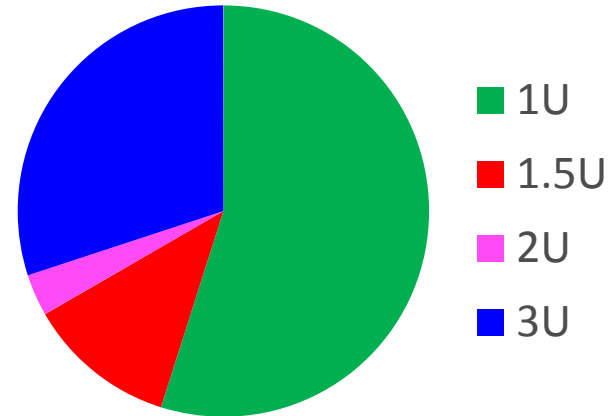
- 153 CubeSats Launched (not including latest Orb-1/ISS)
- Launch Failures:
 - Dnepr-1 launch (14)
 - Falcon-1 (2)
 - ELaNa-1/Taurus XL (3)
- Status of CubeSats as of Feb 2014:
 - DOA: 14
 - Deorbited: 26
 - Dead: 25
 - Alive: 41
 - Active: 20
 - Unknown: 27 (just launched)



CubeSat Details: Size and Transmitters

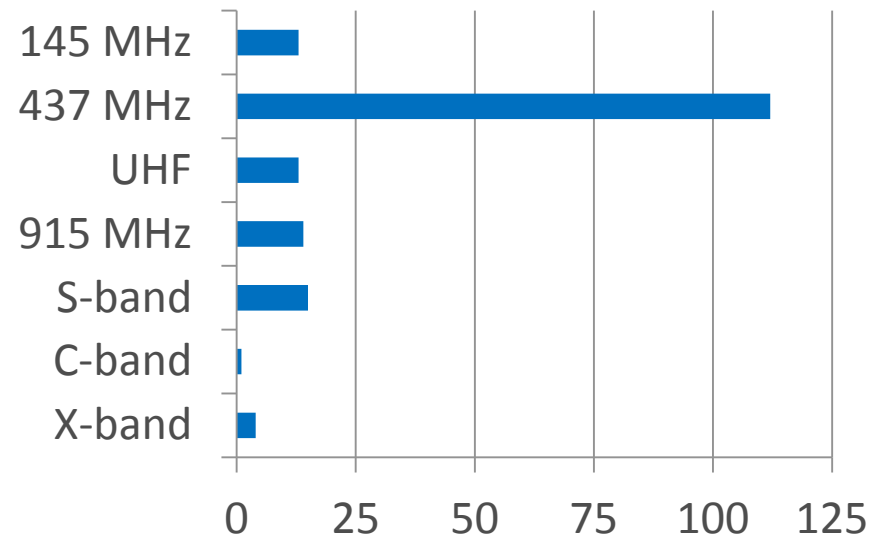
- Size of CubeSat (Total 153 CubeSats):

- 1U: 84
- 1.5U: 18
- 2U: 5
- 3U: 46



- Transmitters (Total 172 transmitters):

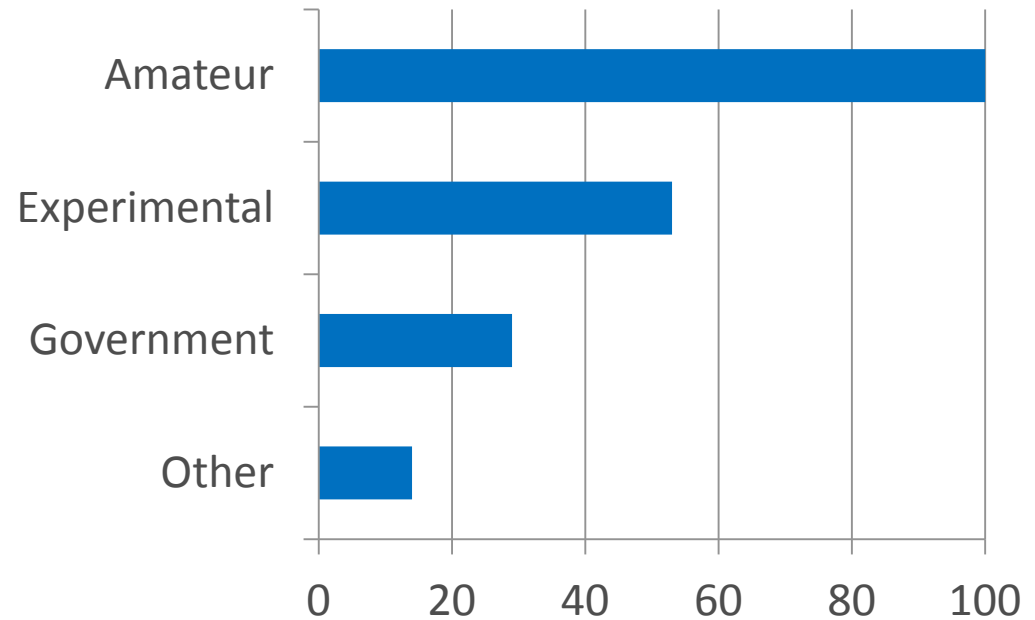
- 145 MHz amateur radio: 13
- 437 MHz amateur radio: 112
- Other UHF spectrum: 13
- 915 MHz experimental: 14
- S-band: 15
- C-band: 1
- X-band: 4



CubeSat Details: Satellite Service Used

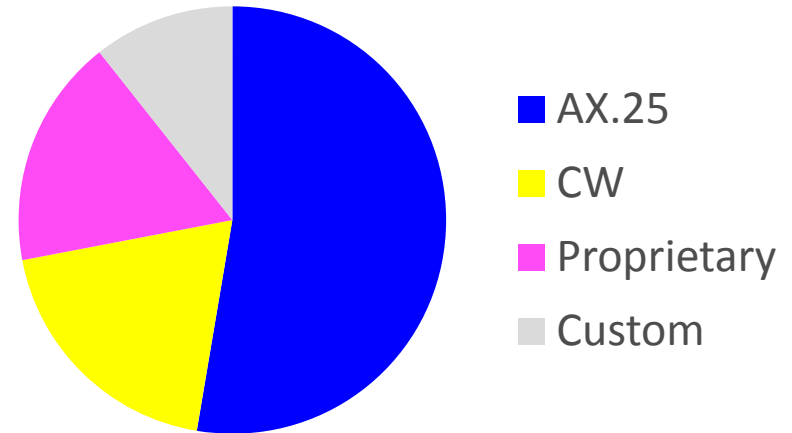
- Satellite Service (Total 196 transmitters):

- Amateur: 100
- Experimental: 53
- Government: 29
- Other:
 - Earth exploration: 2
 - Meteorological: 2
 - Space research: 4
 - Unlicensed/unknown: 6

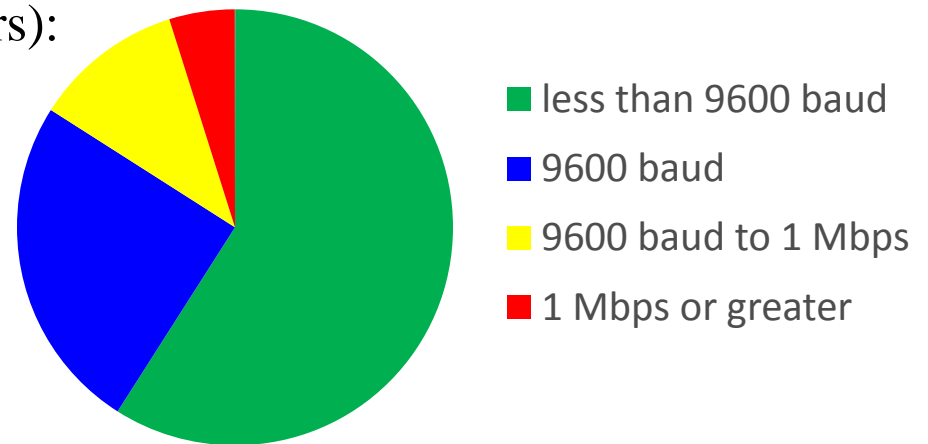


CubeSat Details: Protocols and Data Rates

- Protocols (Total 150 transmitters):
 - AX.25: 79
 - CW: 29
 - Proprietary: 26
 - Custom: 16 (CCSDS, Mobitex, DVB-S2, etc)

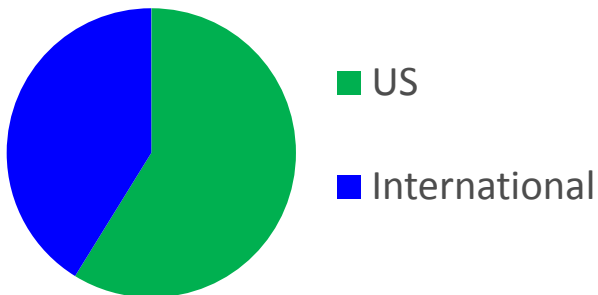


- Max data rates (Total 144 transmitters):
 - < 9600 baud or CW: 85
 - 9600 baud: 36
 - 9600 baud to < 1 Mbps: 16
 - 1 Mbps or greater: 7
 - Hayato, DICE, CINEMA, Dove+



CubeSat Details: Countries

- Countries (Total 27 countries, 153 CubeSats):
 - USA: 90
 - Japan: 11
 - Germany: 9
 - Denmark: 4
 - Netherlands: 3
 - South Korea: 3
 - Spain: 3
 - Argentina: 2
 - Canada: 2
 - Ecuador: 2
 - England: 2
 - India: 2
 - Italy: 2
 - Norway: 2
 - Switzerland: 2
 - Turkey: 2
 - Vietnam: 2
 - Colombia: 1
 - Estonia: 1
 - France: 1
 - Hungary: 1
 - Pakistan: 1
 - Peru: 1
 - Poland: 1
 - Romania: 1
 - Singapore: 1
 - South Africa: 1



Satellite and Ground Segment Classes

- Mission funding determines communications system
 - No funding for ground segment infrastructure
 - Very little thought given to the next mission, except using the same hardware
- In most cases, there is little funding for the ground segment
 - The satellite is more interesting
- Two classes of communications systems
 - Basic or low-speed
 - Advanced

Basic Satellite Radios

- First CubeSat radios were modified handheld amateur radios
 - Alinco DJ-C5
 - Yaesu VX-2R
- In schools with RF experience, single-chip transceivers were used
 - Designed for keyless entry systems
 - CC1000
 - RF2905
- By 2010, basic radios built for CubeSats were commercially available
 - AstroDev
 - ISIS
 - Gomspace



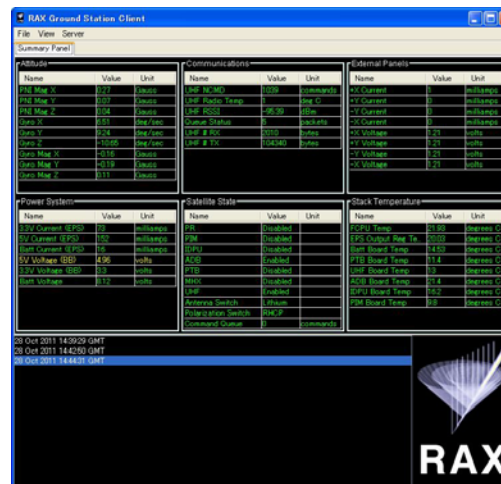
Basic Ground Stations

- Typically use UHF amateur radio spectrum
 - Easy to obtain a frequency license
 - Hardware is very inexpensive
- Amateur radio transceivers and TNCs
 - Icom 910 or Yaesu TS-2000 hardware radios
- Yagi antennas
- 9600 baud or less
- AX.25 packet formatting
 - No encryption or error correction
- Total cost \$10k or less



Basic Ground Station Networks

- With very slow data rates, the only way to increase the amount of data downlinked is to use multiple ground stations
- Many teams have built software programs that interested people can install on their ground station to upload data
- If implemented well, these ad hoc networks can provide hundreds of MBytes to the PI
- These programs are usually closed-source and work with only one mission
 - University of Michigan Java decoder is open-source, and used across their three missions and CSSWE



Advanced Satellite Radios

- As CubeSat missions get more advanced, the amount of data to downlink is increasing dramatically
- First publically-acknowledged high-speed radio was DICE, October 2011
 - L3 Cadet-U radios on 465 MHz at 2.6 Mbps
 - Wallops 18-m UHF dish for free
 - Total downloaded: 8.4 GBytes
- CHDC working group looking into this issue
- No current radios support NEN, DSN, or other existing commercial ground station networks
- Each radio at least \$10k



Advanced Ground Segments

- Except for Government CubeSats, most teams do not have the resources to build or use advanced ground stations
 - Satellite radio and ground station hardware is cost-prohibitive
 - Latest NSF teams have more resources from other university programs
- NASA Wallops trying to build a network with L3 Cadet
- University of Michigan designing a USRP network



Advanced Ground Station Networks

- Most university teams can't even support a single advanced ground segment, and can't support a network
- For those teams that would like to rent time on a network, there are several hurdles:
 - Commercial networks (USN) are cost-prohibitive
 - No cost model to support single satellites
- No standard downlink protocols or data rates
 - The future is software-defined radios, so lack of standards is not a factor
- No established low-cost networks, so most teams create their own
 - Planet Labs (COTS DVB-S2 hardware)
 - NanoSatisfi (USRP)
- Government ground station networks do exist
 - Naval Postgraduate School and MC3 network
 - USAF
 - NASA Ames/SCU

Future

- Hundreds more CubeSats will be launched in the next few years
- For universities and small teams, existing ground segment solutions and frequencies will dominate for the near future
- Constellations will break the small ad hoc ground segment networks
 - More dispersed ground segments must be built
 - Ground station networks must be fully automated
- Organizations are building CubeSat constellations
 - Perseus
 - Planet Labs
 - QB50
- Cost is the driving factor for all missions (except US government-funded)

Thank You



Headquarters: Silicon Valley

SRI International

333 Ravenswood Avenue
Menlo Park, CA 94025-3493
650.859.2000

Washington, D.C.

SRI International

1100 Wilson Blvd., Suite 2800
Arlington, VA 22209-3915
703.524.2053

Princeton, New Jersey

SRI International Sarnoff

201 Washington Road
Princeton, NJ 08540
609.734.2553

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