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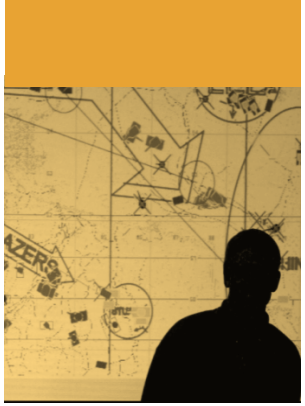

CubeSat Radios: From kilobits to Megabits

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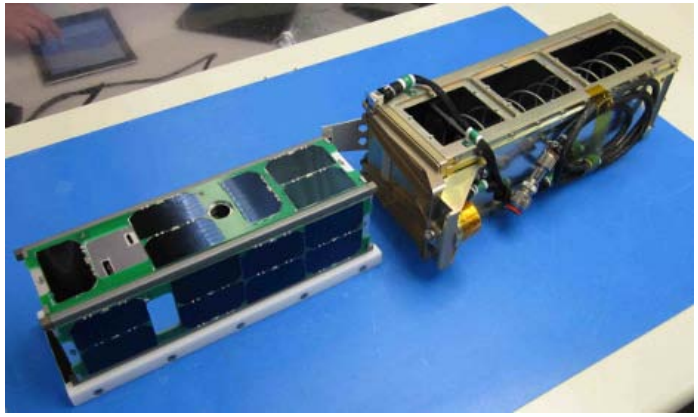
Ground System Architectures Workshop
Los Angeles, California
26 Feb 2014

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	Rockot	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

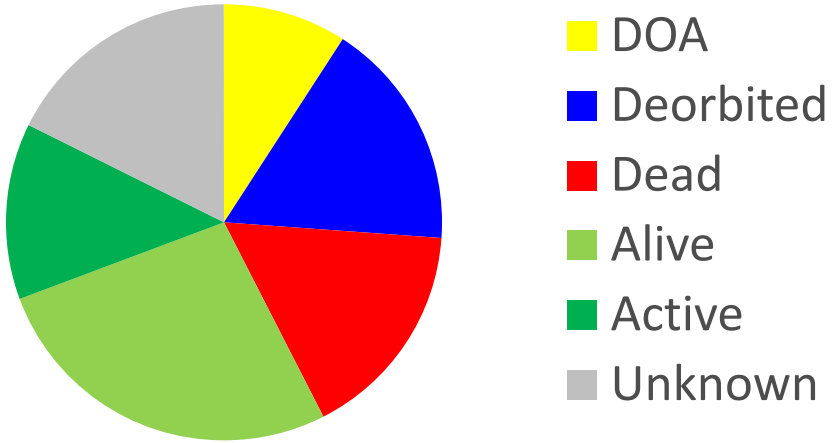
Name	Vehicle	Date	# CubeSats	Total U
Orb-1/ISS	Antares/ISS	Feb 2014	33	96
ISILaunch	Soyuz	Feb 2014	1	3
ELaNa-5/CRS-3	Falcon 9	Mar 2014	5	12
ELaNa-7/ORS-4	Super Strypi	Fall 2014		24
ELaNa-10/SMAP	Delta II	Nov 2014	3	9
GRACE/NROL-55	Atlas 5	Dec 2014		24
ULTRASat/AFSPC-5	Atlas 5	Feb 2015		18
STP-2	Falcon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

Summary of CubeSats 2003 to 2014

- 153 CubeSats Launched (not including latest Orb-1/ISS)

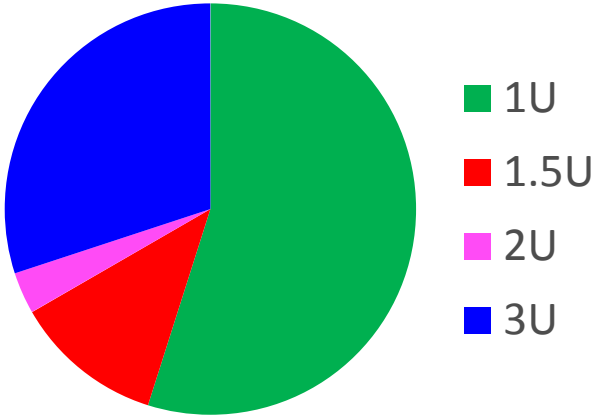
- Launch Failures:
  - Dnepr-1 launch (14)
  - Falcon-1 (2)
  - ELaNa-1/Taurus XL (3)

- Status of CubeSats as of Feb 2014:
  - DOA: 14
  - Deorbited: 26
  - Dead: 25
  - Alive: 41
  - Active: 20
  - Unknown: 27 (just launched)

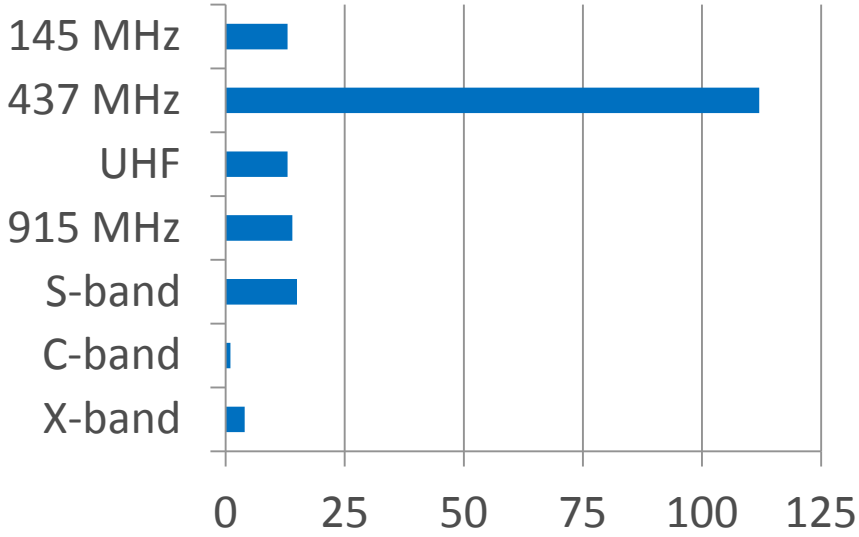


CubeSat Details: Size and Transmitters

- Size of CubeSat (Total 153 CubeSats):
  - 1U: 84
  - 1.5U: 18
  - 2U: 5
  - 3U: 46

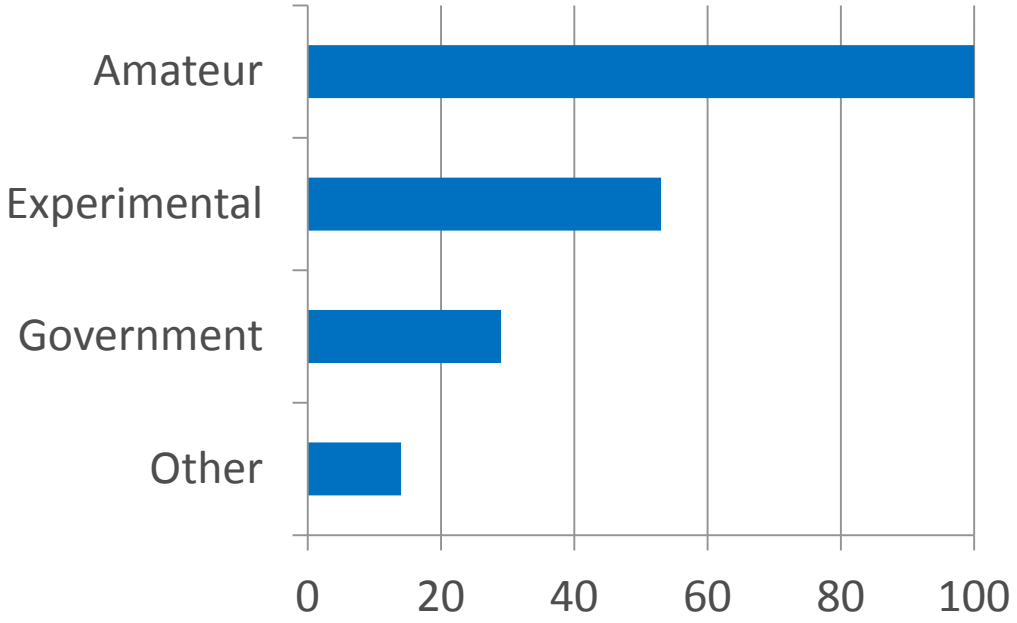


- Transmitters (Total 172 transmitters):
  - 145 MHz amateur radio: 13
  - 437 MHz amateur radio: 112
  - Other UHF spectrum: 13
  - 915 MHz experimental: 14
  - S-band: 15
  - C-band: 1
  - X-band: 4



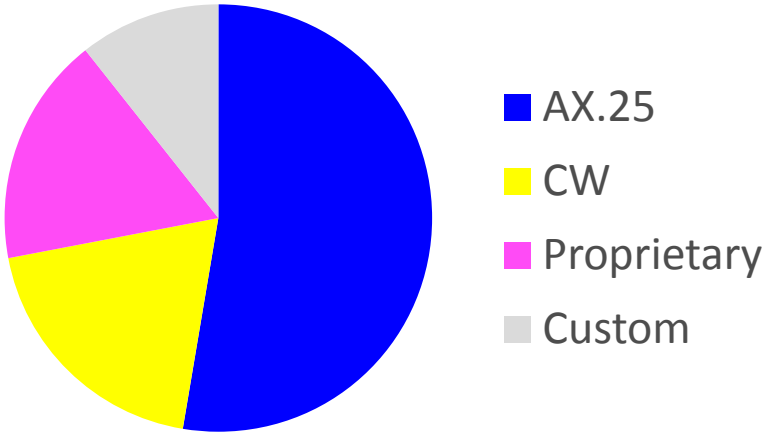
CubeSat Details: Satellite Service Used

- Satellite Service (Total 196 transmitters):
  - Amateur: 100
  - Experimental: 53
  - Government: 29
  - Other:
    - Earth exploration: 2
    - Meteorological: 2
    - Space research: 4
    - Unlicensed/unknown: 6

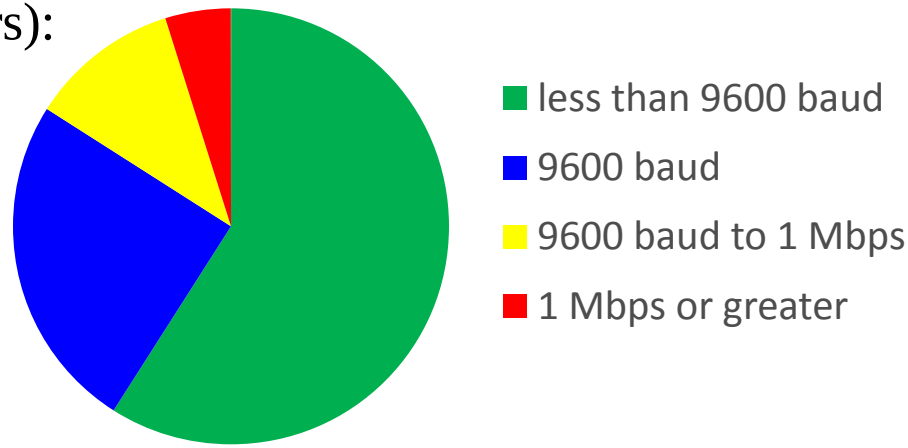


CubeSat Details: Protocols and Data Rates

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

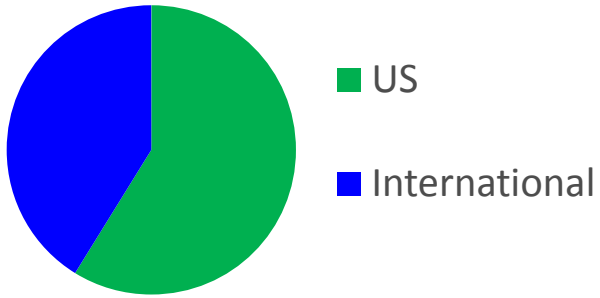


- Max data rates (Total 144 transmitters):
  - < 9600 baud or CW: 85
  - 9600 baud: 36
  - 9600 baud to < 1 Mbps: 16
  - 1 Mbps or greater: 7
    - Hayato, DICE, CINEMA, Dove+



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

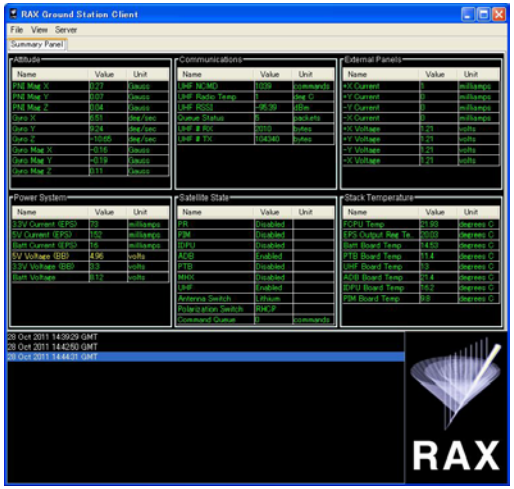
- First CubeSat radios were modified handheld amateur radios
  - Alinco DJ-C5
  - Yaesu VX-2R
- In schools with RF experience, single-chip transceivers were used
  - Designed for keyless entry systems
  - CC1000
  - RF2905
- By 2010, basic radios built for CubeSats were commercially available
  - AstroDev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

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