Expanding CubeSat Capabilities with a Low Cost Transceiver

Scott Palo
Darren O'Connor, Elizabeth DeVito, Rick Kohnert
University of Colorado Boulder

Gary Crum and Serhat Altunc
NASA Goddard Spaceflight Center

The project

- Develop a cubesat transceiver compatible with the NASA Near Earth Network (NEN)
- Supported by 2013 NASA Small Satellite Technology Cooperative Agreement (CAN)
- SSTP CAN Program Objective
  - To award cooperative agreements to United States colleges and universities to develop and/or demonstrate new technologies and capabilities for small spacecraft <u>in collaboration with NASA</u>.

The Team

NASA SSTP
Greg Dorais
Chief Technologist

University of Colorado Boulder

Aerospace Engineering Sciences
Scott Palo PI

LASP

Darren O'Connor Co-I, RF Lead
Rick Kohnert Co-I, SE
Elizabeth DeVito RF Engineer

Student CAPSTONE Project Team
Mike Russell Savannah Schilling
Chris Borke Xingjie Zhong
Casey Pummel

GSFC Wallops & Greenbelt

Tom Johnson	Management
Brenda Dingwall	Management
Scott Schare	Management
Steve Bundick	RF Design/Test
Serhat Altunc	Antenna/Systems
Gary Crum	FPGA Lead
Thomas Winkert	FPGA Design

Goddard

Marshall Space Flight Center

Marshall Space Flight Center

Eric Eberly	Management
Leroy Hardin	Management
Herb Sims	RF Design
Kosta Varnavas	Digital Design

The Laboratory for Atmospheric and Space Physics (LASP)

- Founded in 1948 – 10 years before NASA
- Only research institute to have sent instruments to all eight planets and Pluto.
- LASP combines all aspects of space exploration in science, engineering, mission operations, and scientific data analysis.
- LASP also works to educate and train the next generation of space scientists, engineers and mission operators by integrating undergraduate and graduate students into working teams.

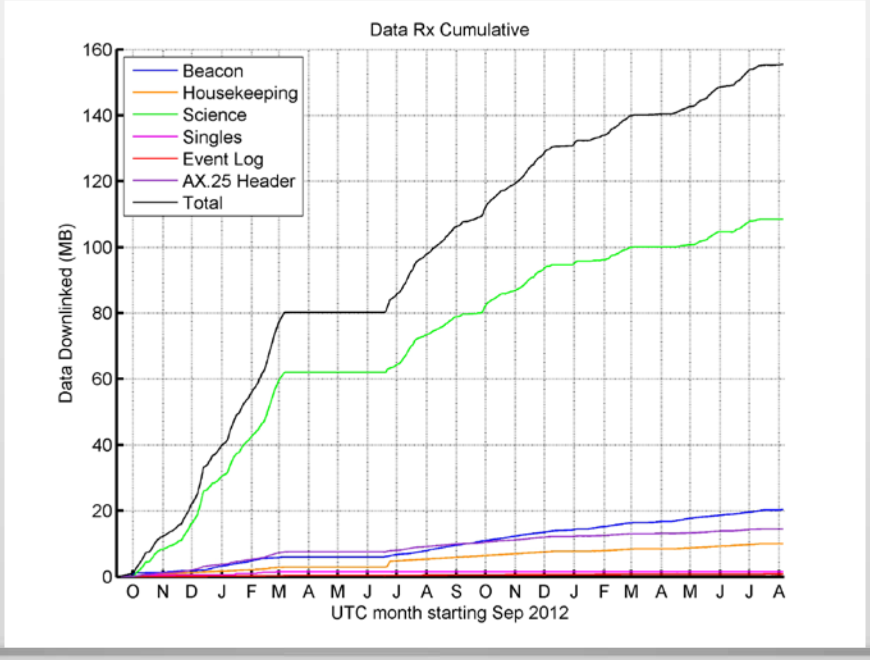
AeroSpace Ventures (ASV)

- Chancellor supported campus initiative with 4 academic departments (AES, ECE, APS, ATOC) and 2 research institutes (LASP, CIRES)
- Goals
  - Accelerate discoveries in Earth and space science with innovative engineering solutions
  - Broadly educate tomorrow's highly-skilled aerospace workforce
  - Develop technologies that create new commercial opportunities
  - Create collaborations that help industry grow
- Managing Director : Diane Dimeff (Diane.Dimeff@Colorado.edu)
- Small satellites and UAS are a key part of ASV
  - Founding member of the FAA COE on Commercial Space Transportation
- Collaborative with new campus Office of Industry Collaboration
- Founding industry partners
  - Ball Aerospace and Technology Corp
  - Blue Canyon Technologies
  - Braxton Technologies LLC
  - Lockheed Martin Space Systems
  - Sierra Nevada Corporation
  - Surrey Small Satellite Corporation

http://www.colorado.edu/aerospace/cu-aerospace-ventures

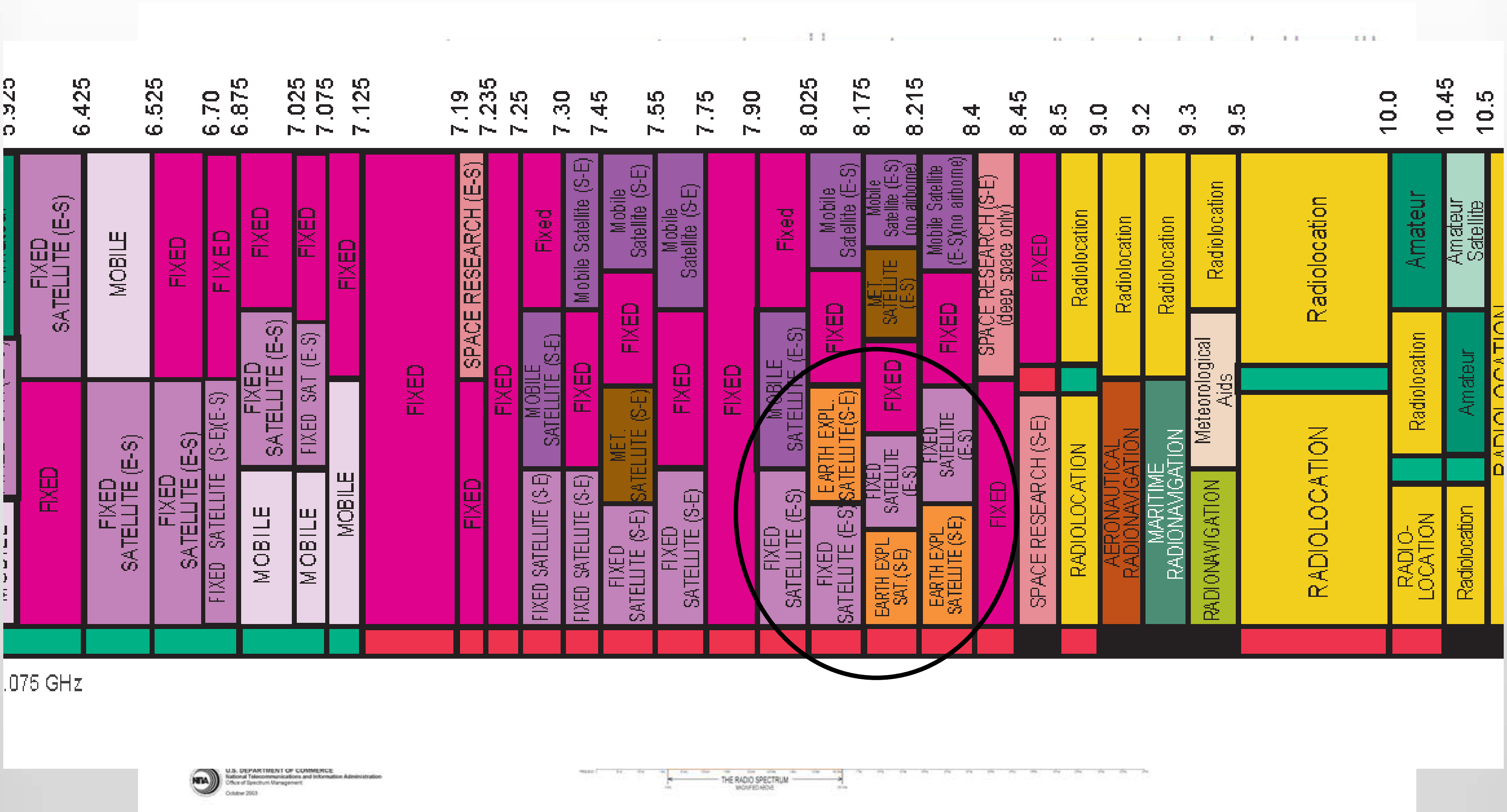
Jump To X-Band Will Mean 1000 X Data Rate Increase

- LASP's CSSWE is communicating in the 70 cm band using antennas on the roof at 9.6 Kbps (most common data rate). Has collected ~160MB of data to date.
- X-Band communications in the Earth Explorer Satellite Service (EESS) band would yield 1000 X data rate increase



2 years of CSSWE data could be downloaded in 3.4 minutes using a 12.5Mbps radio

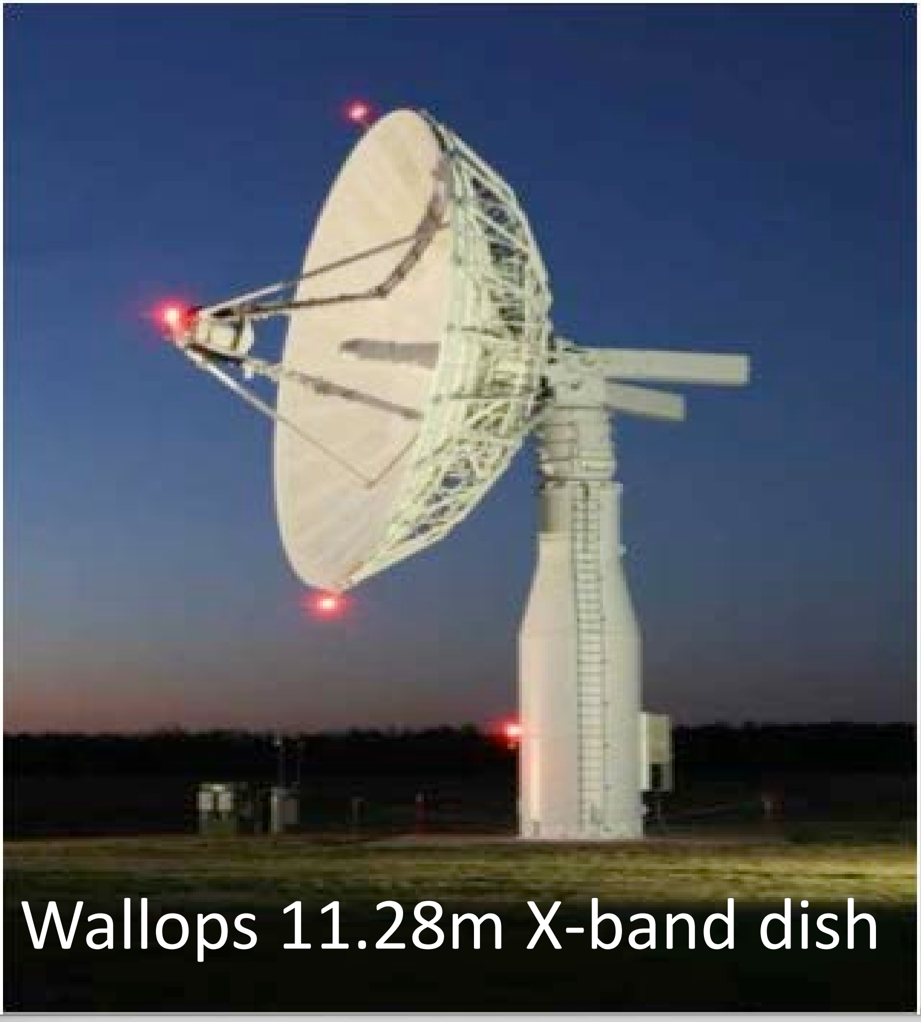
Spectrum is a challenge



Project

- Develop a radio that is compatible with NEN and can be accommodated by a cubesat
  - 200kbps S-band command uplink
  - 12.5Mbps X-band data downlink
- Approach
  - Use COTS parts
  - Minimize complexity and features
    - Push complexity to software where possible (SDR approach)
  - Use RF software design tools to expedite process
  - Build, test and iterate (3-4 mo. cycle)
- Schedule
  - Year 1
    - Develop and mature X-band TX from TRL-3 to TRL-5
    - Engage students in the preliminary design of S-band receiver
  - Year 2
    - Develop and mature S-band RX from TRL-3 to TRL-5

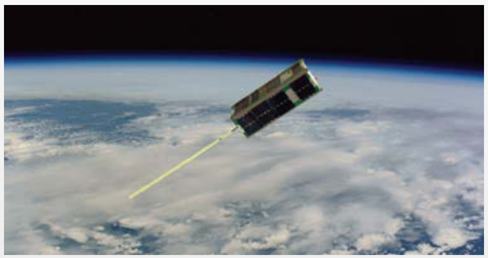
Near Earth Network Compatibility


Wallops 11.28m X-band dish

Characteristic	Value
Frequency	8000-8500 MHz
G/T	≥ 34.50 dB/K
System Noise Temperature	170 K
Polarization	RHC or LHC
Antenna Beamwidth	0.23°
Antenna Gain	56.8 dBi

Link Budget (101): NEN to LEO

Space Segment



$$EIRP\ (dBW) = P_t + G_t + L_{sys}$$

$T = 170K$

$k = 1.38E\text{-}23\ J/K$

$B = 12.5MHz$

$P_{noise} = -136\ dBW$

Communications Channel

$$L_{prop}\ (db) = L_{space} + L_{atm} + L_{pol}$$

$$L_{space}\ (db) = 10\log_{10}(\lambda^2/(4\pi R^2))$$

R is range not altitude (a)

$R \sim 2500km$

for $a = 700km$ and $\Theta = 5^o$

$L_{space}\ (db) = -179dB$

$L_{atm}\ (db) = -1.5dB$

$L_{pol}\ (db) = -0.5dB$

$L_{prop}\ (db) = -181dB$

Ground Segment

$$P_{rx}\ (dBW) = EIRP + L_{prop} + G_r$$

$$P_{noise}\ (dBW) = 10\log_{10}(kTB)$$

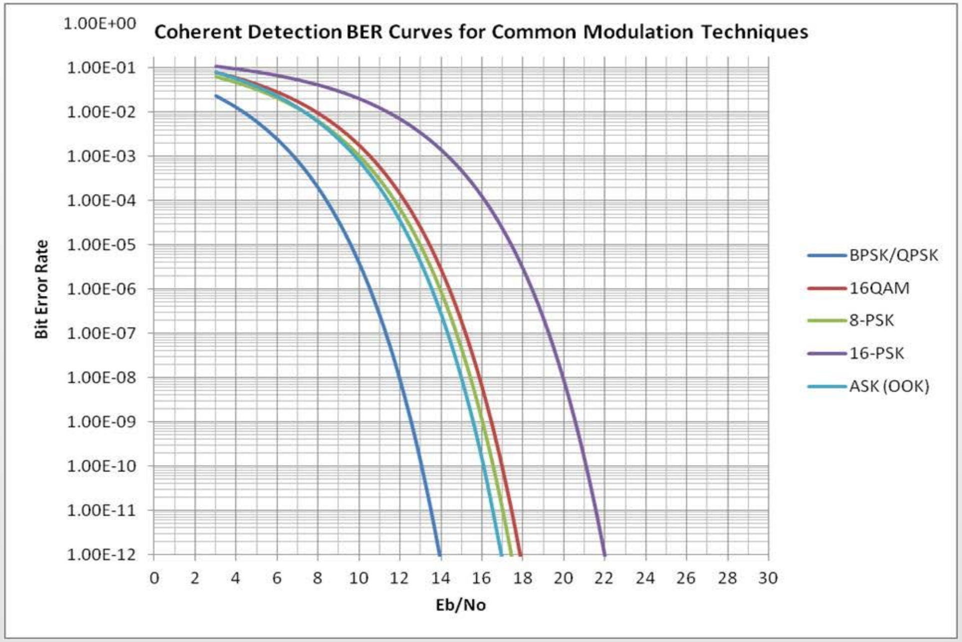
$$SNR(dB) = P_{rx} - P_{noise}$$

$$\text{Required } P_{rx}\ (dBW) = P_{noise} + SNR$$

What SNR (Eb/No) is required?

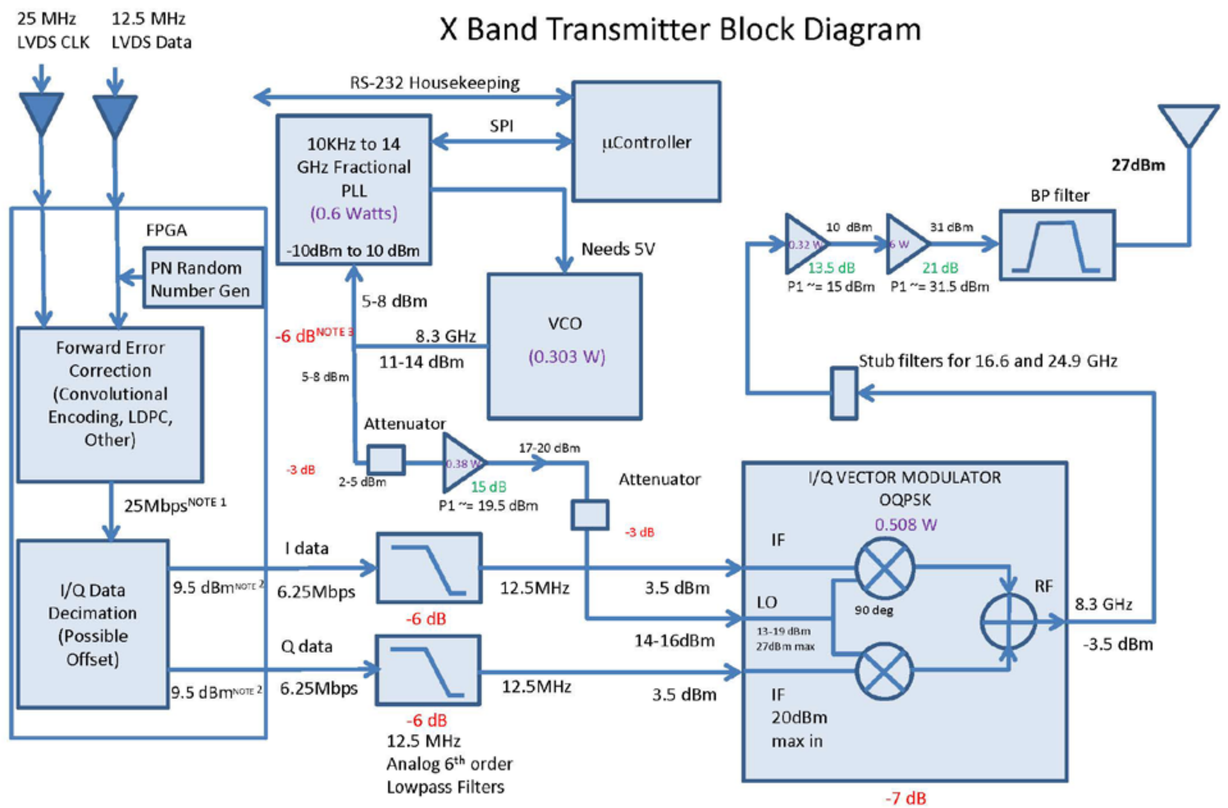
- Eb/No depends on
  - Bit Error Rate (BER)
  - Modulation scheme
  - FEC
- Eb/No = 5.5dB
  - OQPSK
  - 1E-7 BER
- Using 170K receiver at 12.5Mbps P_{rx} required is -130.5dBW

EIRP_min = -6.5 dBW



- 1 W TX (0 dBW) + omni antenna (0dB) provides 6dB link margin
- 6m dish would provide 0.5 dB link margin. Increased margin could come from patch flight antenna

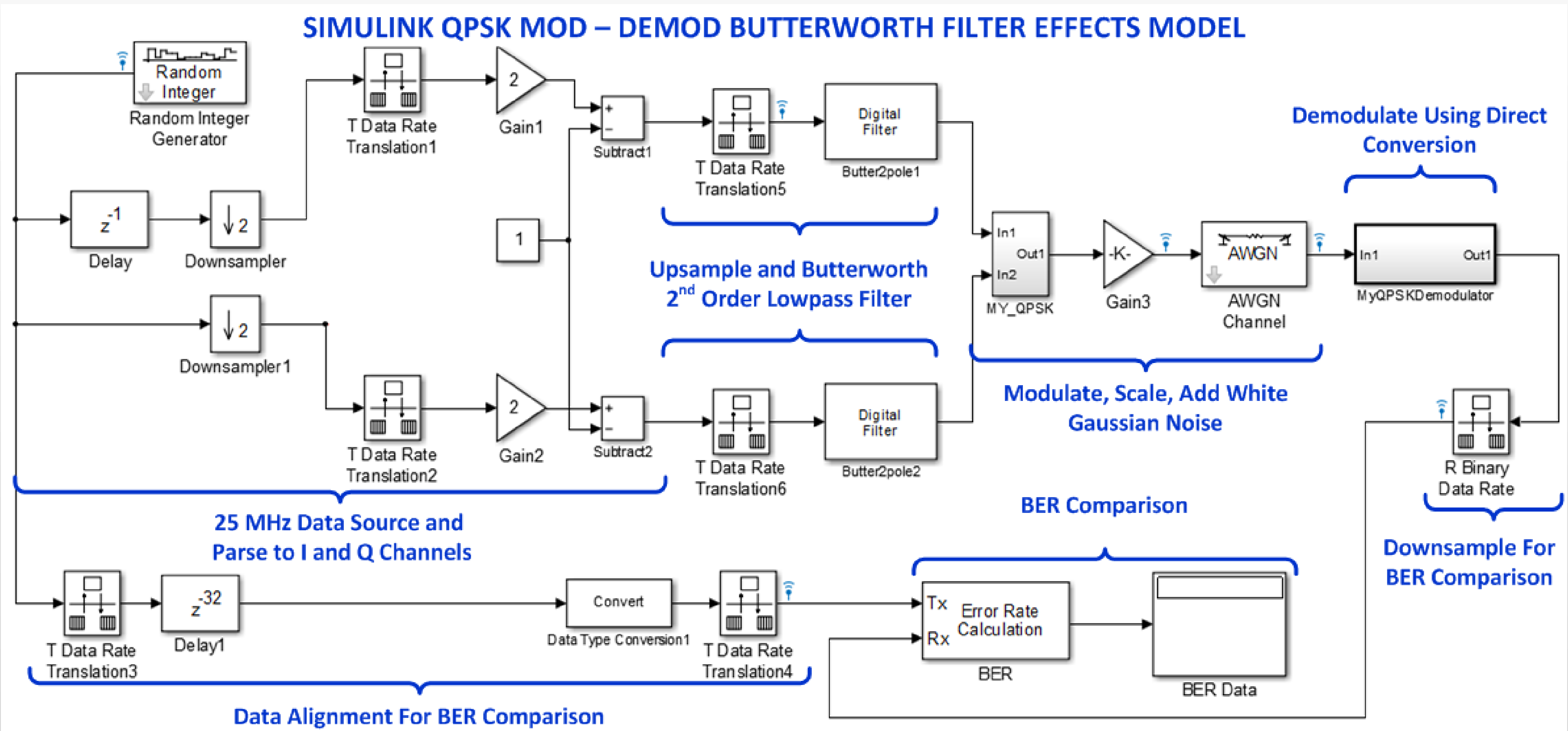
X-Band transmitter design approach



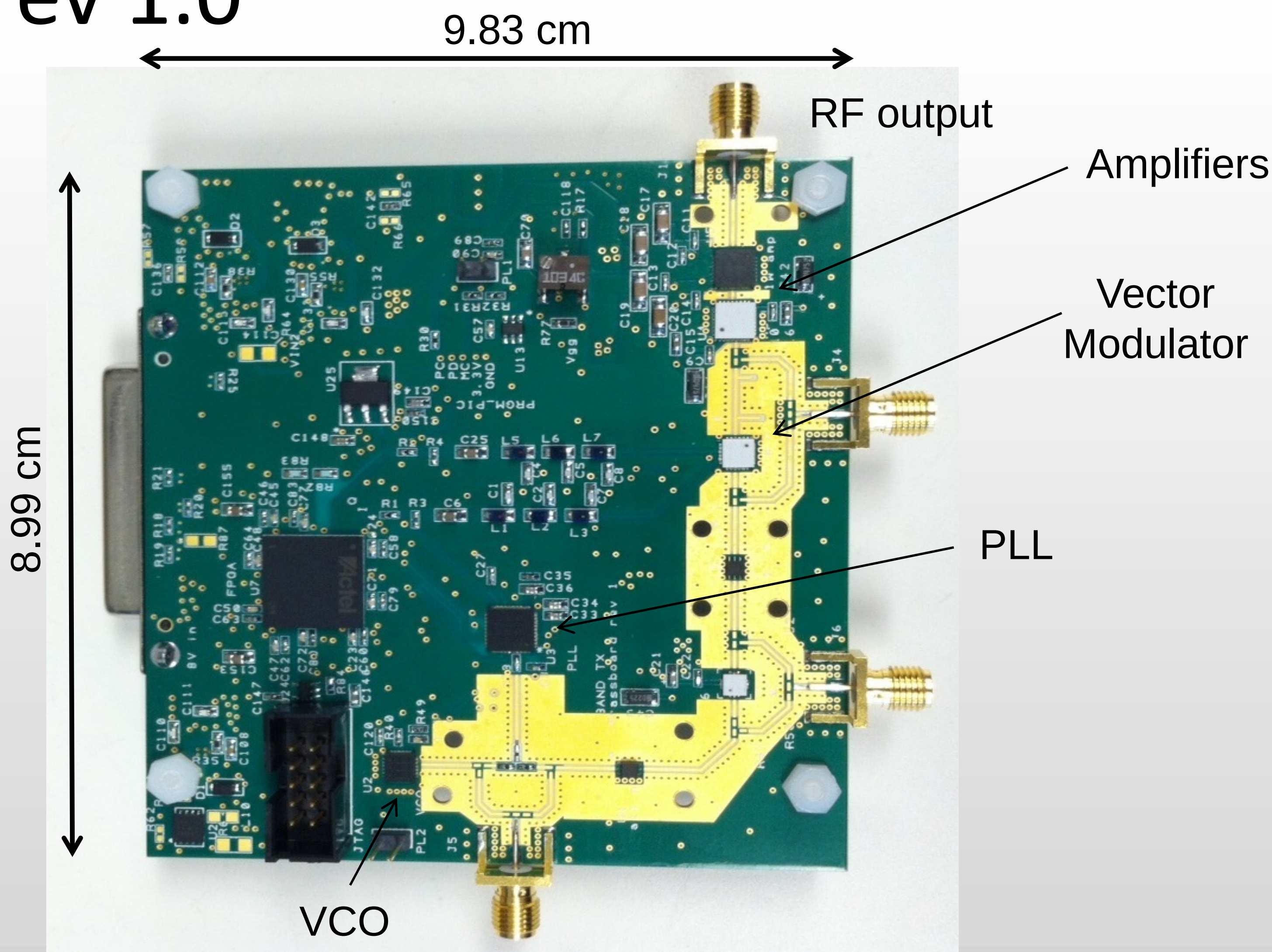
Note 1: Assuming Convolutional Encoding
Note 3: Power is divided using a resistive divider

Digital Direct Convert

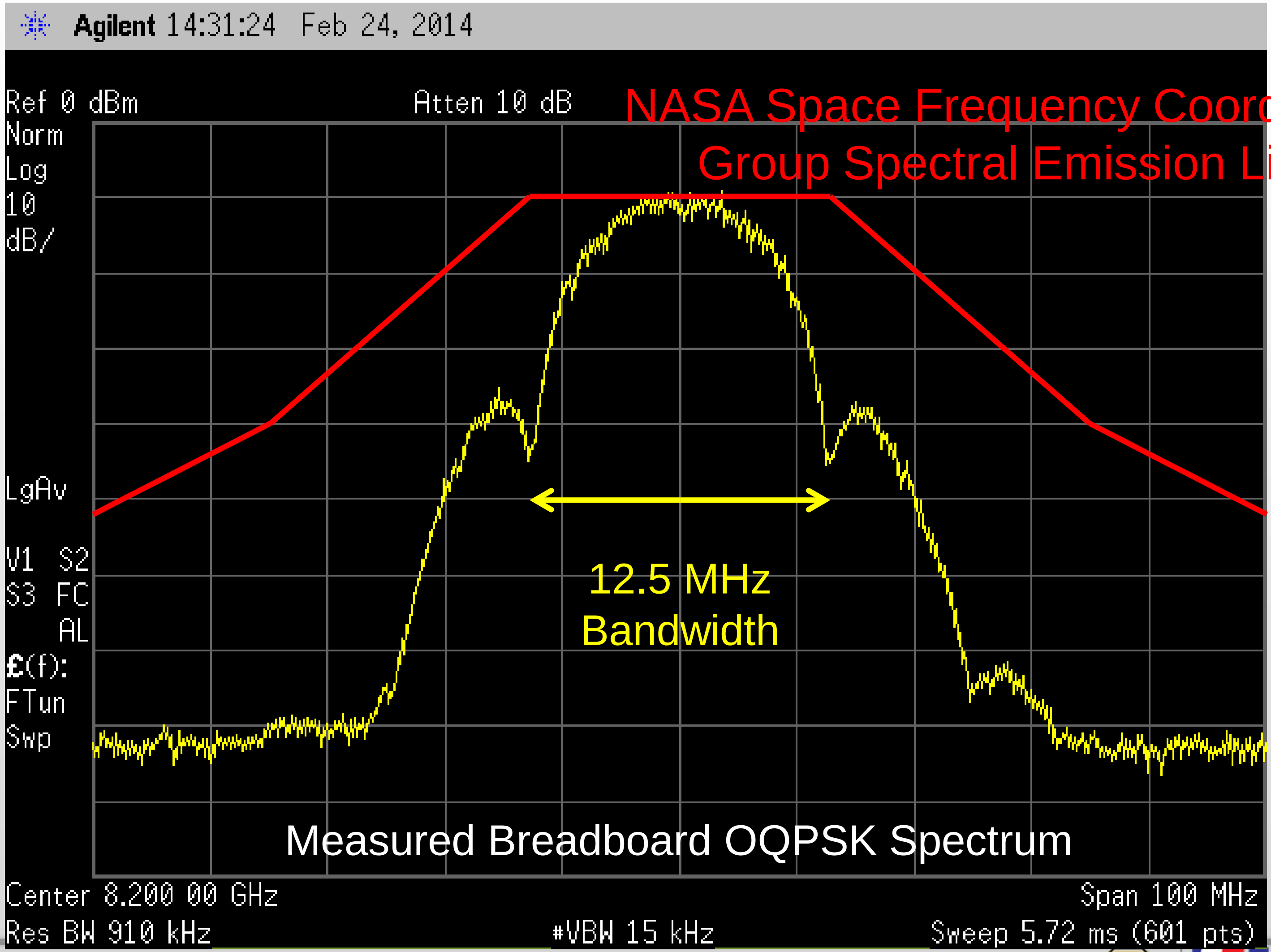
- Modeling at system level with Matlab Simulink
- Circuit and board level simulations done in AWR Microwave Office and Mentor Graphics 3D EM Tools



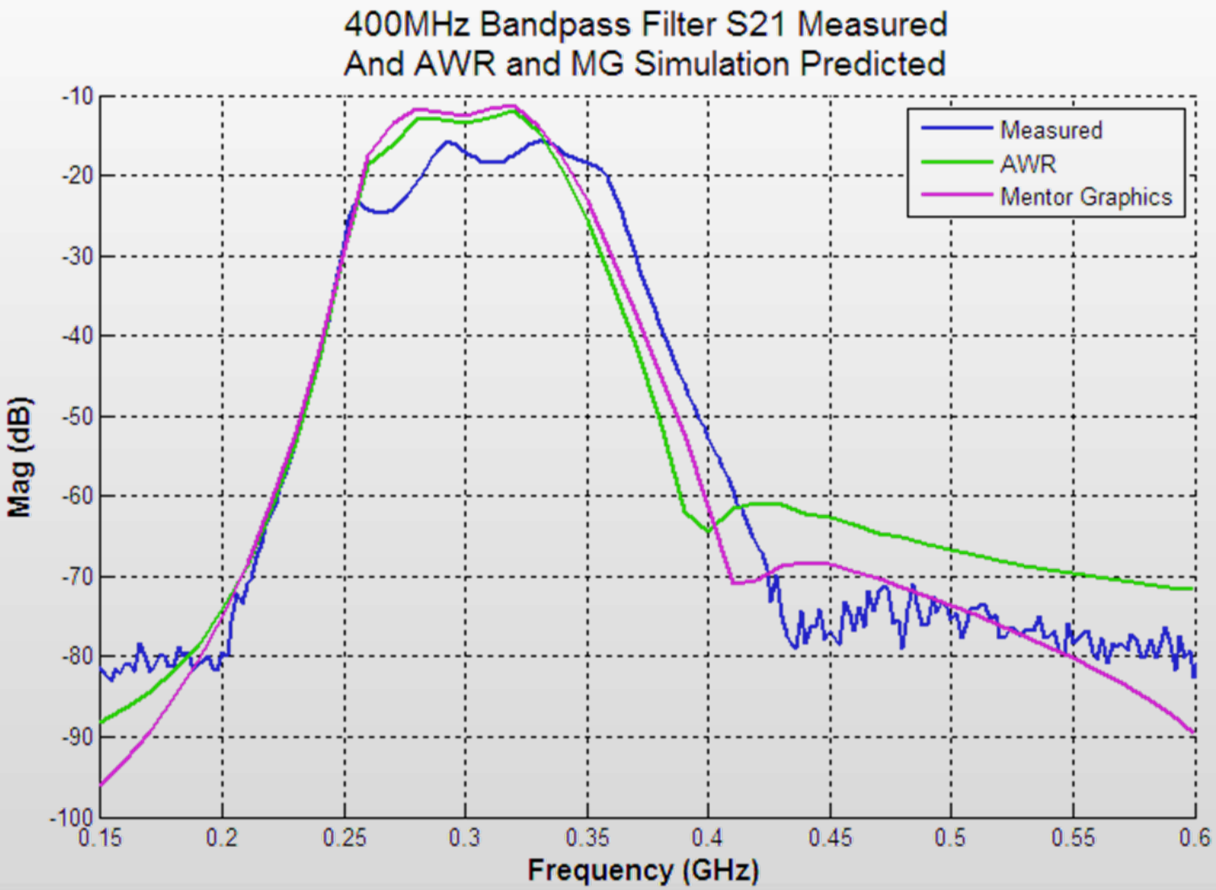
HRCCS rev 1.0



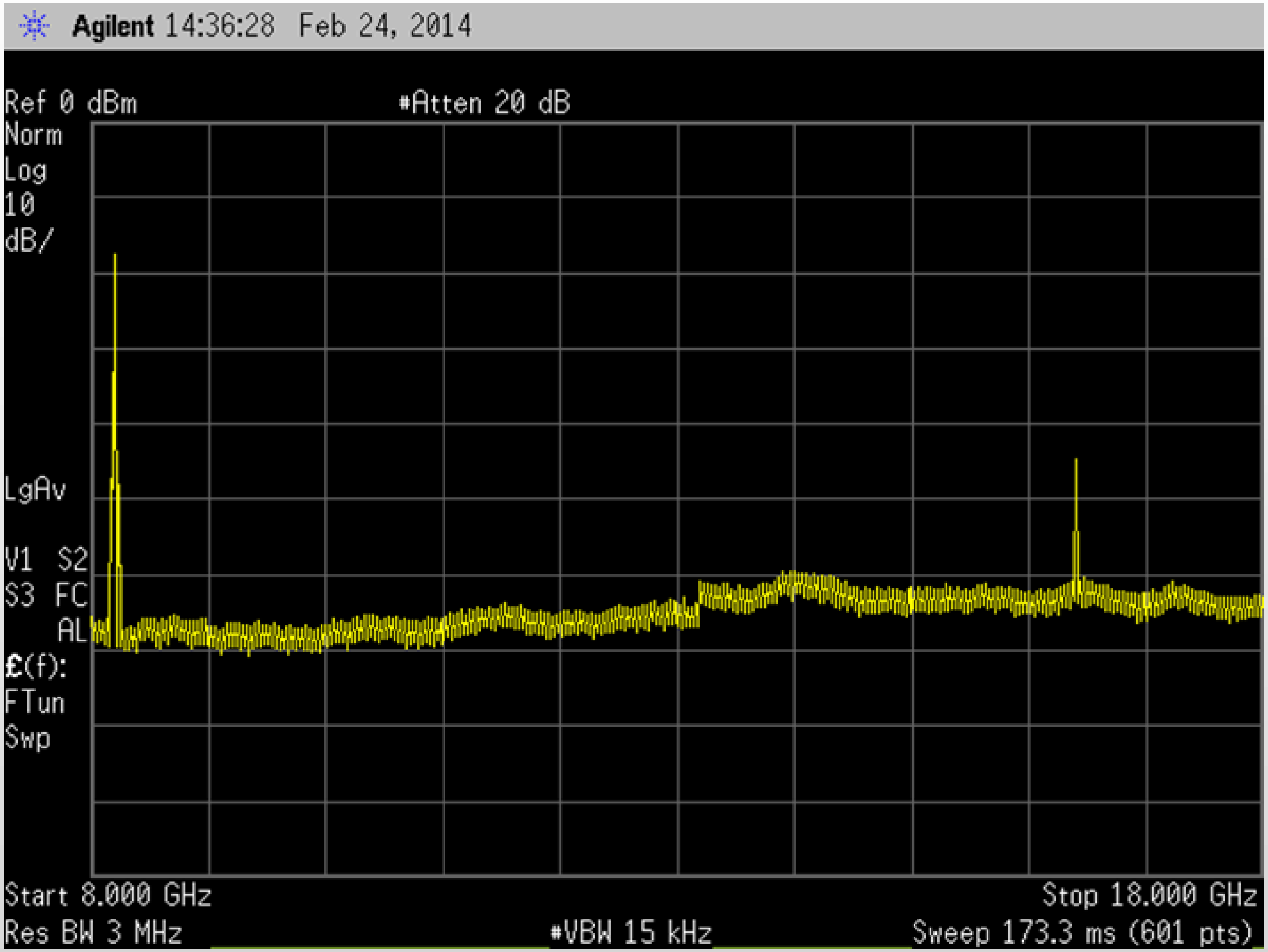
X-Band OQPSK, 12.5 Mbps Spectrum



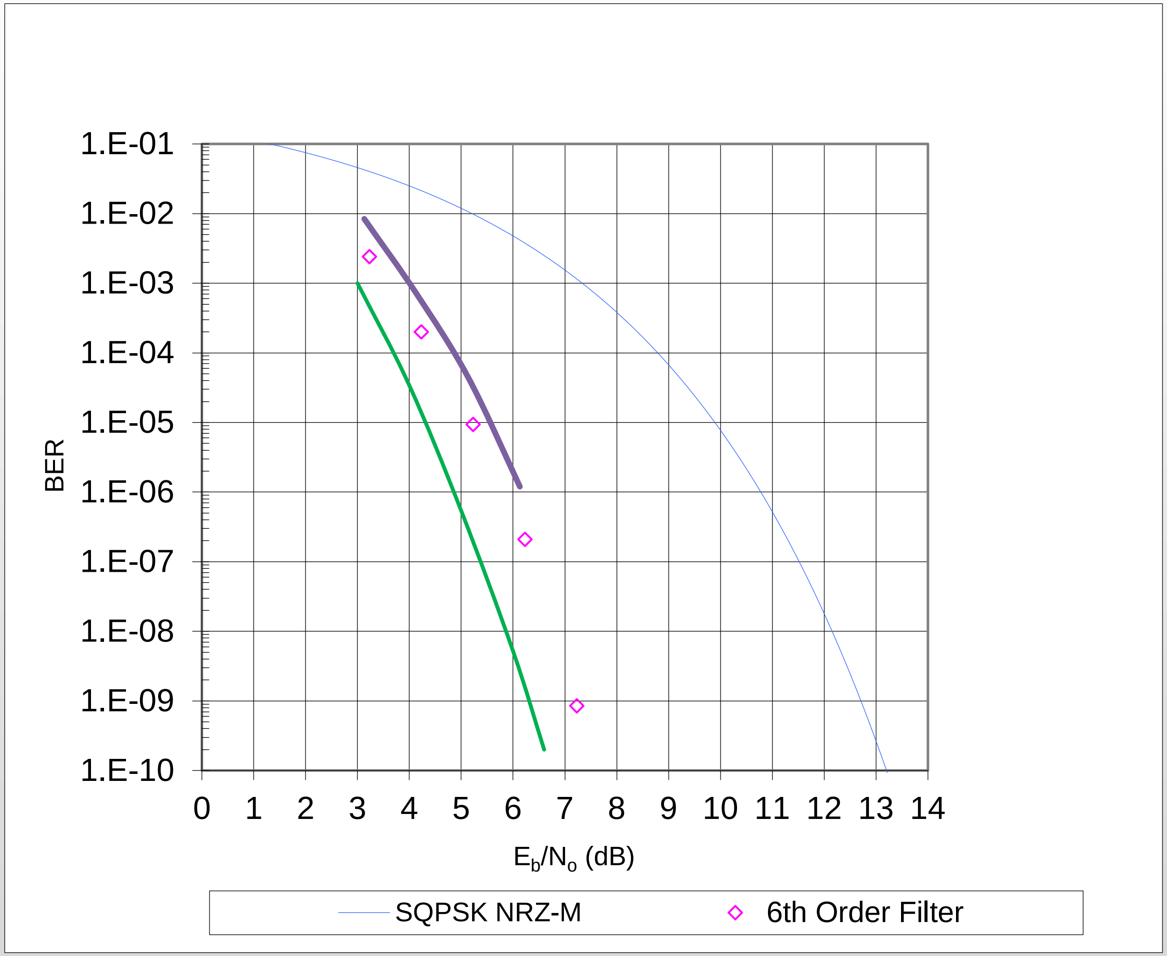
Comparison of RF development tools and fabricated hardware



Output spectrum from 8 to 18 GHz



BER results with 6th order filter



Next Steps

- Complete functional testing of X-Band transmitter (Aug 2014)
- TRL-5 verification in September 2014
  - BER testing at GSFC
  - T-VAC testing at LASP
- GSFC IRAD proposal for balloon testing in late 2014
- Discussions about ground station compatibility testing
- Discussion about future flight opportunities in 2015 (TRL-9)
- Discussions about commercialization
- S-Band receiver development in FY 2015