A Deep Space Radio Communications Link for Cubesats: The CU-E³ Communication Subsystem

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The Challenge!

CU's Earth Escape Explorer (CU-E³)

The University of Colorado's - Earth Escape Explorer (CU-E³) is a **6U cubesat** being designed and built to compete in **NASA's Cube Quest Challenge - Deep Space Derby**. CU-E³ will be attempting communication from ≥ 4,000,000 km, requiring us to "escape" the influence of the "Earth" and "explore" deep space.

NASA's Cube Quest Challenge

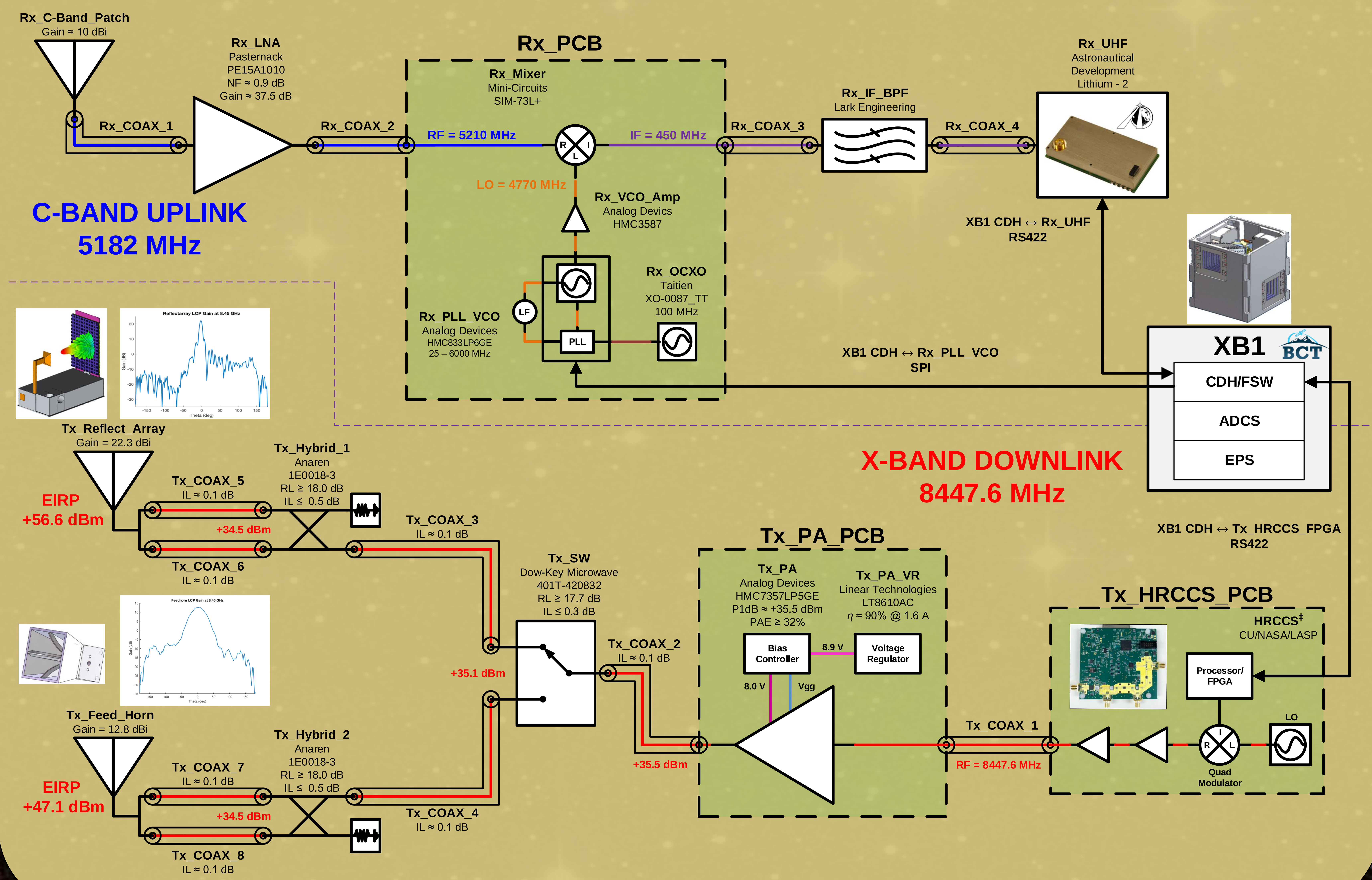
- The **Cube Quest Challenge** has two phases:
  1. Ground Tournaments (GT-1 thru GT-4)†:
     - Maximum of $100,000 for any one team.
     - Phase completed in June 2017.
  2. The "In-space Prizes":
     - 365-day competition period.
     - a) **Lunar Derby**
       - Up to $3 million in prizes.
       - Technical objectives in propulsion & communications.
     - b) **Deep Space Derby**
       - Up to $1.5 million in prizes.
       - Focus on deep space communications using small spacecraft.
       - Competition starts at **4,000,000 km**:
         - i. Best Burst Data Rate - **$250,000**
         - ii. Largest Aggregate Data - **$750,000**
         - iii. Spacecraft Longevity - **$250,000**
         - iv. Farthest Communication - **$250,000**

† CU-E³ placed 2nd during the Ground Tournament phase, earning $80,000, and has been offered a position on the SLS's EM-1 mission!!!

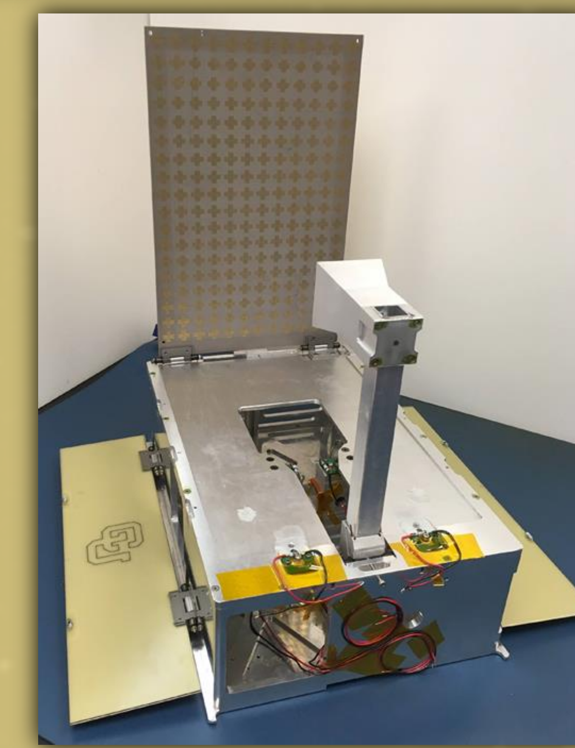
Challenges Faced by CU-E³

- Size – restricted to 6U dimensions.
  - Limits power generation and heat dissipation.
  - Limits transmitter power.
  - Limits use of classic high-gain antennas.
  - → **Limits possible radiated signal strength (EIRP)!**
- Limited time & money!
  - GTs' schedule very short & tight.
  - Rad-hardened parts too expensive.
  - → **Could not design everything from scratch.**
  - → **Use COTS components as much as possible.**
  - → **Prototype circuits quickly for P.O.C & testing.**
- Distance – *extremely* long range.
  - → *EVERY dB COUNTS!!!*

The CU-E³ Solution



Key Notes



Reflectarray & Horn Antennas

- CU-E³ utilizes a novel, student-designed, *reflectarray* antenna and *feed horn.*
  - Planar design → fits 6U cubesat form factor.
  - Utilizes standard PCB microstrip technology.
    → easy and relatively inexpensive to fabricate.
  - High gain → 22.3 dB at X-band Tx frequency.
- CU-E³'s design includes a second *feed horn* antenna.
  - Provides back-up communication link in the event primary reflectarray antenna does not deploy.
  - Lower gain → 12.8 dB, but can still close link.

High-Rate CubeSat Communication System (HRCCS)‡

- CU-E³ will provide the maiden launch for the HRCCS.
  - Designed for deep space X-band frequencies.
  - Provides a flexible communications platform.
  - Compatible with NASA's NEN & DSN.

Downlink Budget Analysis Summary

TX ANTENNA	-	Reflect Array	Feed Horn	Reflect Array	Feed Horn	Reflect Array	Feed Horn
SLANT RANGE	km	4,000,000		6,000,000		27,000,000	
TRANSMITTED EIRP	dBm	56.6	47.1	56.6	47.1	56.6	47.1
TOTAL SIGNAL POWER @ OUTPUT OF LNB (S)	dBm	-82.4	-91.9	-85.9	-95.4	-99.0	-108.5
NOISE POWER DENSITY OF RX @ OUTPUT OF LNB (No)	dBm/Hz	-123.0	-123.0	-123.0	-123.0	-123.0	-123.0
NOISE POWER OF RX (N)	dBm	-94.3	-103.8	-97.9	-107.4	-111.0	-112.2
USEFUL BIT RATE	bits/s	608	68	270	30	13	1
ENERGY PER BIT (Eb)	W/bit	-110.3	-110.2	-110.3	-110.2	-110.1	-108.5
Received SNR (@ OUTPUT OF LNB)	dB	11.9	11.9	11.9	12.0	12.0	3.7
Resulting Eb/No	dB	12.7	12.7	12.7	12.8	12.8	14.5
Link Margin	dB	6.10	6.12	6.11	6.15	6.22	7.86

‡Palo, S.E., "High Rate Communications for CubeSats", Proc. of the IEEE International Microwave Symposium, Phoenix, AZ, 2015.

‡Palo, S.E., D. O'Connor, E. DeVito, R. Kohnert, G. Crum and S. Altunc, "Expanding CubeSat Capabilities with a Low Cost Transceiver", Proc. of the AIAA Small Satellite Conference, Logan, UT, 2014.