Electron Losses and Fields Investigation

Benjamin Domae

Communications Delta CDR
January 26, 2017
## Review Board Members

<table>
<thead>
<tr>
<th>Name</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryan Klofas</td>
<td>Planet Labs</td>
</tr>
<tr>
<td>Jacob Portukalian</td>
<td>Tyvak</td>
</tr>
<tr>
<td>Scott Tripp</td>
<td>JPL</td>
</tr>
<tr>
<td>Kyle Colton</td>
<td>Planet Labs</td>
</tr>
<tr>
<td>Sharlene Katz</td>
<td>CSUN</td>
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</table>
OBJECTIVES OF PEER CDR

Purpose: Demonstrate detailed design meets req’s, based on test data, and project is ready to proceed to full scale fabrication including flight model production. On track to complete ground system development and mission operations that meet the performance req’s on cost and schedule

Objectives:
- Show clear definition of personnel roles and responsibilities
- Show detailed subsystem design, and sub/system performance
- Expose design to experts with technical discussions in open environment
- Increase probability of success by taking corrective action on potential issues prior to full scale development and I&T
- Obtain feedback on the detailed design

Scope: ELFIN PM or delegate w/ Review Chair concurrence, declare:
- Requests for action (RFAs), to be closed after initiator concurrence
- Recommendations, to be considered without need for closure by initiator
- Observations, points of information to be noted in the review report
Table of Contents

Science Overview
Team Organization
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Design Overview
  - He-82 Radio
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  - Balun
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  - SWR/Tuning Tests
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  - Antenna Propagation Pattern Tests
Future Design and Test Plan
RFA’s
Science Overview
Radiation Belts: Discovered in 1958, Still Mysterious

Explorer 1, 1958

Time Magazine, May 4, 1959
**EXECUTIVE OVERVIEW**

- **The Challenge**
  - Geospace storms result in relativistic electron flux increases only half of the time – **unclear why**.
  - Electron fluxes result from competition of acceleration, transport and loss. The first two processes are measured well by many equatorial, high altitude NASA, NOAA and DOE missions, **but not loss**.

- **Goal**
  - To advance our understanding of dominant wave-loss mechanism of relativistic “killer” electrons.

- **Approach**
  - Measure, for the first time, if the angle and energy distribution of precipitating electrons bear the characteristic signature of scattering by the dominant wave scatterer, Electromagnetic Ion Cyclotron (EMIC) waves.

- **Science Closure**
  - ELFIN will compare the measured loss rates and electron properties during storms with theoretical models from EMIC wave scattering and from other mechanisms.
  - Storm recurrence once-per-month in the declining phase of solar cycle → 3 mo. minimum mission.
### Top Level Science Objectives

<table>
<thead>
<tr>
<th>Objective ID</th>
<th>Title</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>OBJ-01 Radiation Belt Loss Sources</td>
<td>Determine whether EMIC scattering is the primary loss mechanism of radiation belt “killer electrons”, or if other mechanisms are also important during the course of one storm.</td>
</tr>
<tr>
<td>Secondary</td>
<td>OBJ-02 Origin of Field-aligned Currents (FACs)</td>
<td>Determine location of FAC sources relative to plasma boundaries (dipole vs. tail; inner edge of plasma sheet vs. plasma sheet boundary)</td>
</tr>
</tbody>
</table>

Secondary objectives do not drive mission design but do require additional instruments (magnetometer and ion sensor). Magnetometer also helps enhance the primary science with a tertiary objective.
<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Rationale</th>
<th>Parent(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCI-01</td>
<td>ELFIN shall measure the storm-time electron pitch angle distribution within the loss cone</td>
<td>Pitch angle distributions as a function of time at fixed energy provide a signature that can be used to determine whether 0.5 – 4 MeV electrons are scattered by EMIC waves</td>
<td>OBJ-01</td>
</tr>
<tr>
<td>SCI-02</td>
<td>ELFIN shall measure the storm-time electron energy spectrum within the loss cone</td>
<td>Energy spectra at fixed pitch angles can be used to determine the minimum resonant energy of precipitating electrons for comparison with EMIC waves</td>
<td>OBJ-01, OBJ-05</td>
</tr>
<tr>
<td>SCI-06</td>
<td>ELFIN shall measure the full angle/energy spectrum at every $\Delta L=0.5$ from $L=3$ to $L=5$ (minimum) or $\Delta L=0.25$ from $L=2$ to $L=9$ (baseline) once per orbit</td>
<td>Needed to determine if EMIC scattering is a dominant loss mechanism of relativistic electrons during geomagnetic storms</td>
<td>OBJ-01</td>
</tr>
<tr>
<td>SCI-03</td>
<td>ELFIN shall measure the storm-time ion energy spectrum within the loss cone</td>
<td>Observations of ions within the loss cone are used to identify the isotropy boundary</td>
<td>OBJ-02, OBJ-03</td>
</tr>
<tr>
<td>SCI-04</td>
<td>ELFIN shall measure the perpendicular and parallel components of the storm-time ion pitch angle distribution within the loss cone</td>
<td>Perpendicular and parallel components of the ion pitch angle distribution provide a signature that can be used to determine the isotropy boundary</td>
<td>OBJ-02, OBJ-03</td>
</tr>
<tr>
<td>SCI-05</td>
<td>ELFIN shall be capable of measuring magnetic field perturbations with a frequency of at least 5 Hz</td>
<td>Needed to measure the expected EMIC waves</td>
<td>OBJ-02, OBJ-04</td>
</tr>
</tbody>
</table>
**ELFIN Implementation Strategy**
- Polar orbit (>70°), on any initial MLT (except sun-synchronous at ±1hr from noon-midnight)
- Full angular distribution of electrons (100keV-4MeV) measured by **EPD instrument**
- Spin-axis ~ orbit-⊥ (for stability) and B-field-⊥ (allows full pitch angle coverage by EPD)
- Magnetic torque coils adjust spin-axis attitude
- EMIC waves and B field measured by **FGM instrument**

**ELFIN Operations and Data Use**
- Two Earth Stations (UCLA, TBD station #2)
- Amateur bands for communication
- Latency: < 1day including L0-L2 processing.
- Get >1 auroral/rad.belt crossing per 4 orbits (6 hrs).
- Record on-board multiple crossings, survey and select the ones to downlink later
- Open data policy, common data tools (SPEDAS)

**Complements many other missions**
- **Scientific**: VAP and THEMIS (HEO)ACE, WIND, DISCVR (L1) [NASA]; ERG (HEO) [JAXA]; DSX (MEO), VPM (LEO) [DOD];
- **Operational**: DMSP (LEO), GPS (MEO); LANL (HEO) [DOE]; POES (LEO), GOES (HEO) [NOAA]
Mission Overview

12 - 24+/- 1 hr LT:
β = 0-15°
Reduced science
(EMIC waves not often there)

13-1 hr (or 11-23) LT: β=±15°
Worst case power (science ON and low power input)
5 - 17 hr LT: β=±67°
Worst case thermal “hot”

6-18 hr LT:
Best case power:
science ON and high power input.
11/2008: ELFIN chosen as the top UCLA CubeSat concept
Selected by AFOSR/UNP NS8 12/2012, ended: 1/2015
11/2013 proposed for CLSI/ELaNa ride; selected 2/2014 Awaiting launch opportunity, likely mid-2017
Peer PDRs conducted between 10/2014 – 12/2014
Mission PDR conducted on 2/12/2015
Peer CDRs between 10/2015 – 1/2016
Mission CDR conducted on 2/17/2016
Anticipated ELFIN delivery: June 2018
TEAM ORGANIZATION
# Communications Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibility</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benjamin Domae</td>
<td>Team Lead</td>
<td>2</td>
</tr>
<tr>
<td>Michael Arreola-Zamora</td>
<td>Pattern Testing Lead</td>
<td>3</td>
</tr>
<tr>
<td>Akshaya Subramanian</td>
<td>-x Panel Layout</td>
<td>4</td>
</tr>
<tr>
<td>Bryan Chen</td>
<td>Pattern Testing Software</td>
<td>5</td>
</tr>
<tr>
<td>Alex Gonzales</td>
<td>He-82 radio tests</td>
<td>2</td>
</tr>
<tr>
<td>Ryan Caron</td>
<td>Mentor</td>
<td>-</td>
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COMMUNICATION SUBSYSTEM
Requirements
# COMM Requirements (1/3)

<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Rationale</th>
<th>Parent(s)</th>
<th>Children</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMM-01</td>
<td>There shall be a minimum of 6dB margin in the telecommand link analysis for the uplink and downlink at the elevation mask necessary to complete the data volume requirements (currently set at 30 degrees). This margin will be in addition to assuming the worst case attitude presenting an antenna null toward the earth station.</td>
<td>Allow for clear communications even with unforeseen losses.</td>
<td>UNP-NS8-Userguide_IR (UNP 45)</td>
<td></td>
<td>T/A: Long range or balloon test and link budget analysis</td>
</tr>
<tr>
<td>COMM-02</td>
<td>Verify that spin-fading does not result in additional complications (AGC laging, packet corruption/truncation, etc)</td>
<td>Maintain the Link through maximum mission spin with margin</td>
<td>SYS-46</td>
<td></td>
<td>T/A: Simulation and field testing of antenna radiation pattern.</td>
</tr>
<tr>
<td>COMM-03</td>
<td>The comm subsystem shall use dynamic power stepping throughout a downlink pass to reduce total energy consumption</td>
<td>Lowest possible power load while closing the link to reduce load on spacecraft</td>
<td>SYS-46</td>
<td></td>
<td>T/A: Software simulation and ground based testing to verify emission strength.</td>
</tr>
<tr>
<td>COMM-06</td>
<td>Downlinks to auxiliary (community) earth stations shall be facilitated without requiring said stations to command the satellite. This is expected by scheduling blind downlinks aboard the satellite based upon prior demonstrations by the community station of its reliability and availability, likely from live telemetry beacon reception.</td>
<td>Simplifying auxiliary station downlink requirements</td>
<td>SYS-46</td>
<td></td>
<td>T: Flat Sat COMM beacon testing</td>
</tr>
</tbody>
</table>
## Comm Requirements (2/3)

<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Rationale</th>
<th>Parent(s)</th>
<th>Children</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMM-07</td>
<td>Command uplink to the satellite shall be secured against playback attack.</td>
<td>Prevent unauthorized command of the spacecraft</td>
<td>SYS-46</td>
<td></td>
<td>T: Software and transmission testing on development and flight hardware.</td>
</tr>
<tr>
<td>COMM-08</td>
<td>The satellite shall have two independent RF inhibits, enabling RF power output greater than 1.5W</td>
<td>Conform with LSP regulations to allow greater transmit capabilities</td>
<td>NASA LSP-REQ-317.01A (LSP 6.2.11)</td>
<td></td>
<td>T: Hardware in the loop testing.</td>
</tr>
<tr>
<td>COMM-09</td>
<td>The Comm subsystem shall be capable of accepting command uplink from earth stations within 3 weeks of deployment from the launch vehicle</td>
<td>Efficiently use the limited on-orbit time of the spacecraft</td>
<td>SYS-46</td>
<td></td>
<td>T: Tracking test with other Cubesats</td>
</tr>
<tr>
<td>COMM-12</td>
<td>The Communications subsystem shall not exceed the mass allocated by Systems</td>
<td>Limited spacecraft mass is available for communications</td>
<td>SYS-14</td>
<td></td>
<td>T: Radio, -X Panel, BETC, Antennas will be weighed</td>
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### COMM REQUIREMENTS (3/3)

<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Rationale</th>
<th>Parent(s)</th>
<th>Children</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMM-13</td>
<td>The Communications subsystem shall not exceed the power allocated in the ELFIN system power budget</td>
<td>Limited spacecraft power is available for communications</td>
<td>SYS-22</td>
<td></td>
<td>T/A: Measured power consumption data during component tests</td>
</tr>
<tr>
<td>COMM-14</td>
<td>The Comm subsystem shall not transmit any RF transmissions for the first 45 minutes after separation from the launch vehicle</td>
<td>Flow-Down</td>
<td>MSN-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM-15</td>
<td>The Comm subsystem shall not exceed the data allocated in the ELFIN system data budget</td>
<td>Flow-Down</td>
<td>SYS-42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM-16</td>
<td>The Comm subsystem shall be designed for a 6 month lifetime</td>
<td>Flow-Down</td>
<td>SYS-37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM-17</td>
<td>The Comm subsystem shall be designed to operate at a dose of 5 krad/yr or greater</td>
<td>Flow-Down</td>
<td>SYS-38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM-18</td>
<td>The Comm subsystem shall be SEU tolerant</td>
<td>Flow-Down</td>
<td>SYS-39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMM-19</td>
<td>The Comm subsystem shall not transmit any RF transmissions during the launch</td>
<td>Flow-Down</td>
<td>SYS-35</td>
<td></td>
<td>T: Inhibits testing</td>
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</table>
**Mass Requirement - Communications**

<table>
<thead>
<tr>
<th>REQ ID</th>
<th>Requirement</th>
<th>Parent(s)</th>
<th>Verification</th>
<th>Verification Document</th>
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</thead>
<tbody>
<tr>
<td>COMM-12</td>
<td>The Communications subsystem shall not exceed the mass allocated by Systems</td>
<td>SYS-14</td>
<td>T: Instruments will be weighed</td>
<td></td>
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</table>

### Mass Allocated and CBEs

**Subsystem: Communications**

<table>
<thead>
<tr>
<th>Component</th>
<th>Maturity</th>
<th>Qty</th>
<th>Unit mass</th>
<th>CBE</th>
<th>Margin</th>
<th>CBE + Margin (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio</td>
<td>P</td>
<td>1</td>
<td>78.00</td>
<td>78.0</td>
<td>15%</td>
<td>89.7</td>
</tr>
<tr>
<td>Antenna PCB, -X</td>
<td>P</td>
<td>1</td>
<td>46.40</td>
<td>46.4</td>
<td>15%</td>
<td>53.4</td>
</tr>
<tr>
<td>Antenna</td>
<td>P</td>
<td>4</td>
<td>0.69</td>
<td>2.8</td>
<td>15%</td>
<td>3.2</td>
</tr>
<tr>
<td>Radio, etc board (BETC)</td>
<td>L</td>
<td>1</td>
<td>40.44</td>
<td>40.4</td>
<td>20%</td>
<td>48.5</td>
</tr>
</tbody>
</table>

Mass allocated for Communications: **208 g**

Current best estimate (CBE): **167.6 g**

Margin: **16% (27.2g)**

CBE + Margin: **194.8 g**

Contingency: **6.3% (13.2 g)**
3rd party licensee, amateur 2m uplink, amateur 70cm downlink
   • Prof. Corbin in Physics dept is the W6YRA trustee
   • Open data policy, both on the science and on the comm & ESN design

1. UHF Downlink  437.450 MHz telemetry
2. VHF Uplink  145.960 MHz command
   • FCC licensing through launch coordinator (Tyvak), will start Nov 2017
     • Possibly last satellite with VHF uplink
   • ELaNa-18, Delta II with ICESat-2, launch Sept 2018
     • Three P-PODs: IT-SPINS, CHEFsat (NTIA), and ELFIN
DESIGN OVERVIEW
**PRIMARY COMPONENTS**

- He-82 Radio
- -X Panel
  - Chip baluns (Uplink and downlink)
- Antennas
  - Interfaces to -X panel through tuna can
  - Stored in tuna can
- BETC Board: Provides power to the radio
  - Designed to mate with He-82

-x Panel, Tuna Can, and Antennas

BETC Interface Board
INTERFACING OF COMPONENTS

- VHF Dipole
- UHF Dipole
- Tuna Can
- -X Panel
- Balun
- Balun
- RG-178
- VHF MCX
- UHF MCX
- He-82
ASTRODEV HE-82 RADIO

- 3.3V UART data interface
- 9V amplifier
- Independent temperature sensor (I2C TMP275)
- MCX antenna RF interface
- Physical form factor: 82x82x15mm
- AX25 may be removed for downlink, replaces with custom “byte level” interface
  Lower priority for CDH team
- Control and Flag Output lines
- Over the air reset
• 19k2, 9V, shield temps 24C, 3 second bursts, waited for radio to cool down if temps exceeded 24C
ANTENNAS

- **Test:** Copper Rod (1/8” diameter)
  - Similar circumference to flight antennas
  - 120° bent half wavelength dipole

- **Flight:** Fiberglass beryllium copper tapespring antenna
  - 120° bent half wavelength dipole
- “Rattail” conductor “tail” without fiberglass to allow electrical connection
- Excess length fiberglass without conductor to prevent incomplete deployment
ANTENNA DEPLOYMENT

IMG_3804.MOV
Anaren Xinger Baluns (BD0205F5050AHF)
- 2W rated RF input power limit -> 1.2W (60%) derated limit
- Insertion Loss:
  VHF - 1.3 dB
  UHF - 0.8 dB
- 4.10 x 2.10 x 0.84mm
-X Panel v3

- X v3 Panel (EM)
  - Interface board between Antennas and Radio
  - Attached balun ICs for TX and RX
  - Contains Striplines to carry RF signal
    - Internal Transmission line

Top View

Bottom View
- BETC + SBPCBs + FC + Antennas (via -X panel)
  - Goal:
    - Antennas should deploy when given enough power
    - Achieved proper communication via testing through Flight Computer
  - Problems:
    - Issues with 9V Switching Regulator Chip on BETC
    - Not consistent voltage
    - Experiences undervoltage
    - Could be a problem with SBPCB output voltage
- Same general board design
  - Identical RF (baluns, rat tail pads, etc)
  - Using two chip baluns only
- Improved burn resistor pads
- Updated chassis fastener positions and annulus
- Finalize antenna attachment method
Tests
Tests Performed

- UHF/VHF SWR Tests
- Range 1 Test
- Propagation Pattern Tests
v3 –X panel attached with conductive tape
- Copper rod test antenna elements
- Pumpkin chassis with stacer mockup
- AA600 inside Pumpkin chassis
  - Controlled via RJ45 extended USB to UPS powered laptop
- Fiberglass “military mast” tripod
  - Base of model @ 14ft (4 sticks)
  - Sometimes as high as 17ft (5 sticks)
- On the roof of the Geology Building (away from metal vents)
UHF/VHF SWR Test

- Test the -X v3 panel system (Baluns and Antennas) at the desired frequencies
  - UHF: 437.45MHz
  - VHF: 145.96MHz
- Looking for impedance matching between 50 Ohm Coax, Stripline, and antennas.
  - SWR = 1.0
- Cut copper antennas to tune to desired frequency.
- Most recent tests conducted:
  - Post-Range 1 with copper rod elements
  - Tapespring antenna tuning
- Block diagram:
VHF SWR (Copper Rod) Test

Peak: 143.000 MHz
SWR: 1.28

145.000 MHz
SWR: 1.33
VHF SWR (Copper Rod) Test

145.000 MHz
SWR: 52.9 - j14.4

Peak: 143.000 MHz
Z = 63.4 + j3.7
VHF SWR (TAPESPRING) Test

Peak: 143.500 MHz
SWR: 1.29

145.960 MHz
SWR: 1.

Fq = 143.500 MHz
SWR = 1.29
Return loss = 17.92 dB
Z = 58.5 + j11.0 Ohm
|Z| = 59.5 Ohm
Phase = 10.6°
L = 12 nH
Zpar = 60.5 + j322.1 Ohm
Lpar = 357 nH
Cable: Length(1/4) = 0.44 m, Length(1/2) = 0.89 m
VHF SWR (TAPESPRING) Test

146.000 MHz
SWR: 69.4 - j2.5

Peak: 143.500 MHz
Z = 58.5 + j11.0
Peak: 444.975 MHz
SWR: 1.11

436.975 MHz
SWR: 1.23
UHF SWR (Copper Rod) Test

436.975 MHz
Z = 41.9 + j4.9

Peak: 444.975 MHz
Z = 45.0 + j0.4
UHF SWR (Tapespring) Test

Peak: 431.400 MHz
SWR: 1.24

437.400 MHz
SWR: 1.29
UHF SWR (Tapespring) Test

Peak: 431.400 MHz
Z = 58.1 + j8.2

437.400 MHz
Z = 55.9 + j12.3
Tune antennas based on test copper rod antenna lengths

Trimming test antennas:
  - Score copper element to electrically disconnect lengths of the antennas
  - Backup – remove copper pieces without destroying the fiberglass backing
    - Most recent tuning tests inconsistent
    - Potential connection problems due to cured epoxy

New SWR and propagation pattern tests
Attaching the antennas to the -x panel:

- **Initial method:** Silver conductive epoxy used for solar cells
  - Method attempted; unsuccessful
  - Requires a special new aluminum jig to complete properly
  - Antennas not removable

- **Proposed method:** Spring connectors
  - More reliable assembly procedure
  - Antennas removable
  - -x panel revision already in progress
  - Design in backup method to attach using epoxy
  - Tuna can design modifications required
**Future: Tapespring Antennas**

- **Proposed method:** Spring connectors
**Goal:** Test the viability of our current communications and ESN designs
  - Find the minimum power setting to maintain link

**Transmit:**
  - Pumpkin chassis with mockups of the stacer and solar panels
  - He-82 radio: 438.975 MHz with Baud Rate 19200
  - -X panel v3 with chip baluns
    - Standard copper rod test antenna elements
  - Computer-controlled transmissions: Beaglebone computer board
    - UART interface via FTDI breakout board

**Receive:**
  - Full ESN antenna setup on Knudsen Hall
Arrows:
Black = data + power (USB)
Red = power
Brown = RF coax
Yellow = wireless comm
**Range 1 Results**

- **Successful Link!**
  - ~17 mW minimum output RF power
  - 93% packet receive rate at the lowest reliable power setting
  - 98% highest receive rate for any power setting

![Graph showing packets received vs. RF power into -X Panel [dBm]](image)

The graph shows the percentage of packets received as a function of RF power into -X Panel [dBm]. The equation for the plotted line is:

\[ f(x) = -8.583E-6 \cdot x^4 + 7.372E-4 \cdot x^3 - 2.342E-2 \cdot x^2 + 3.244E-1 \cdot x - 6.903E-1 \]

with \( R^2 = 9.980E-1 \).
**Range 1 Results**

- **Link not representative**
  - 14 dB extra path loss required
  - Planned Range 1b in a few weeks for a better representation
  - Similar setup but more path loss and tapespring antennas

<table>
<thead>
<tr>
<th></th>
<th>Range 1</th>
<th>Orbit (30deg el mask, 2015 pointing loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TX PWR [dBm]</td>
<td>12.5</td>
<td>30.8</td>
</tr>
<tr>
<td>TX pointing loss</td>
<td>0</td>
<td>-9</td>
</tr>
<tr>
<td>RX pointing loss</td>
<td>0</td>
<td>-2.7</td>
</tr>
<tr>
<td>Free-space path loss</td>
<td>-117.17</td>
<td>-143.6</td>
</tr>
<tr>
<td>Gas &amp; Ionosphere loss</td>
<td>0</td>
<td>-0.8</td>
</tr>
<tr>
<td>Terrain path loss</td>
<td>-1.47</td>
<td>0</td>
</tr>
<tr>
<td>25m urban ground clutter</td>
<td>-10.96</td>
<td>0</td>
</tr>
<tr>
<td>Margin</td>
<td>0</td>
<td>-6</td>
</tr>
<tr>
<td>Received power</td>
<td>-117.1</td>
<td>-131.3</td>
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<tr>
<td>Range 1 margin</td>
<td></td>
<td>-14.20</td>
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</table>
Range 1 with a more realistic ELFIN model
- Flight computer control; BETC power interface
- Antenna deployment
- Very realistic RF model (electronics stack, panels, chassis)
- Larger distance/transmit attenuator

Testing:
- Uplink, downlink, remote command, antenna deployment
- Finer test power resolution
- Better antenna pointing with several orientations

Steps to Range 2
- Characterize new He-82
- Integrate with CDH, avionics stack, EM chassis, v3 –x panel with tapespring antennas
- Roof-to-Roof pre-Range test

Planned for late Feb
Similar Setup to the SWR Test Setup with v3 –X panel
- Triple-axis Accelerometer + Magnetometer (Compass) Board - LSM303
- SparkFun RFM22 Shield
- Adafruit Arduino Uno
- Cross Polarized Yagi Antenna
- Electric Turntable
  - Smooth slow spin
- “Military mast” tripods
  - Base of model @ 14ft (4 sticks)
  - TX fiberglass, RX aluminum
- Tests done on the roof of the Geology building
- SparkFun RFM22 Shield 439 MHz
- Metal enclosure to contain undesired stray RF signals
- Receiver and transmitter include the same hardware (just different code)
- RFM Calibration
  - Observe the change in dBm at different Transmit settings
  - Use loss calculations to get our transmit power calculation
  - Do this with both a short and long coax cable
  - Measure the power delivered to the RFM
  - Use this information to create the Linear fit equation for dBm
- 3-axis accelerometer
- Magnetometer
- Use python code made in-house which uses PyQt Graph to graph in 360 degrees
- LSM Calibration
  - Set-up in test configuration
  - Output Magnetometer data with min and max for each axis
  - Rotate the in every orientation
  - Obtain calibration variables through excel and upload
**XZ Plane with Cross Polarized Antenna**

<table>
<thead>
<tr>
<th>Margin</th>
<th>Number</th>
<th>Null</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 dB</td>
<td>1</td>
<td>10 dB</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>15 dB</td>
<td>50°</td>
</tr>
<tr>
<td>12 dB</td>
<td>1</td>
<td>7 dB</td>
<td>35°</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12 dB</td>
<td>40°</td>
</tr>
</tbody>
</table>
### YZ Plane with Cross Polarized Antenna

<table>
<thead>
<tr>
<th>Margin</th>
<th>Number</th>
<th>Null</th>
<th>Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 dB</td>
<td>1</td>
<td>3 dB</td>
<td>25°</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5 dB</td>
<td>25°</td>
</tr>
<tr>
<td>12 dB</td>
<td>1</td>
<td>1 dB</td>
<td>10°</td>
</tr>
<tr>
<td>Margin</td>
<td>Number</td>
<td>Null</td>
<td>Width</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>9 dB</td>
<td>1</td>
<td>14 dB</td>
<td>95°</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11 dB</td>
<td>105°</td>
</tr>
<tr>
<td>12 dB</td>
<td>1</td>
<td>11 dB</td>
<td>75°</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8 dB</td>
<td>85°</td>
</tr>
</tbody>
</table>

- Flight rotation axis
## Summary of Nulls

<table>
<thead>
<tr>
<th>Plane</th>
<th>9 dB Margins</th>
<th>12 dB Margins</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Null</td>
<td>Width</td>
</tr>
<tr>
<td>XY Plane</td>
<td>14 dB</td>
<td>95°</td>
</tr>
<tr>
<td></td>
<td>11 dB</td>
<td>105°</td>
</tr>
<tr>
<td>XZ Plane</td>
<td>10 dB</td>
<td>80°</td>
</tr>
<tr>
<td></td>
<td>15 dB</td>
<td>50°</td>
</tr>
<tr>
<td>YZ Plane</td>
<td>3 dB</td>
<td>25°</td>
</tr>
<tr>
<td></td>
<td>5 dB</td>
<td>25°</td>
</tr>
</tbody>
</table>
Test setup build in progress

- Provide a realistic view of our propagation patterns in all axes
- Similar rooftop setup with added elevation control
- Cross-polarized Yagi antenna for better coverage

**Future:**

**3D Antenna Pattern Tests**
FUTURE DESIGN AND TEST PLAN
Future Design and Test Schedule

- X v4
- Tapespring element tuning
- Stowed and deployed SWR tests
- Range 2 test
- 3D propagation pattern tests
- Pass duration (continuous transmission for 10 min with power stepping)
- TVAC tests (frequency stability, power output)
- More...
Test the radio for realistic transmission times
  - ~10 min. data transmissions
Also testing the flight computer/radio interface for data handling
  - Collaborative test with the Command and Data Handling and Earth Station Team
Planned for after Range 2
TVAC Comm Tests

- Produce two separate tests one with low power and one with high power
  - Conduct low power test with stowed antennas
  - Conduct high power test with antennas on the outside or dummy load/high power resistors attached to the -X Panel
- Planned for late Winter Quarter
Reviewing RFA’s
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>113</td>
<td>Characterize the power efficiency of the He-82 radio. Must be done manually</td>
<td>Complete</td>
<td>Have yet to open and configure the He-82. The manual for the He-100 had incorrect power characterizations.</td>
</tr>
<tr>
<td></td>
<td>through the testing of the radio.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>114</td>
<td>Assume 200mW average power for receiving on the He-82 radio.</td>
<td>Complete</td>
<td>Must be implemented into the power budget.</td>
</tr>
<tr>
<td>118</td>
<td>Finding a Balun Alternative that works for the specifications we are hoping</td>
<td>Complete</td>
<td>Chip baluns to be used on both frequencies. (Eliminated: No Balun, Ferrite Tube, SMT Balun, and Coax Balun options)</td>
</tr>
<tr>
<td></td>
<td>to achieve magnetically, mechanically and in terms of the link budget.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>121</td>
<td>He-82 Firmware Request: Ask for no He-100 auto tracking for uplink command</td>
<td>Complete</td>
<td>Requested when the He-82 was ordered.</td>
</tr>
<tr>
<td></td>
<td>in firmware (locks on to strongest signal).</td>
<td></td>
<td></td>
</tr>
<tr>
<td>122</td>
<td>Effective noise temperature in the Link Budget for both ground and spacecraft</td>
<td>In Progress</td>
<td>Need EM to test RFA#142 Combined into this.</td>
</tr>
<tr>
<td></td>
<td>side must be reevaluated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>123</td>
<td>Downlink Baud rate should be changed to 19k2.</td>
<td>In Progress</td>
<td>More research to be done in the amount of sites that support 19k2</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Status</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>124</td>
<td>Radio temperatures are unreliable and completely off.</td>
<td>Complete</td>
<td>Will use an additional TMP275 and then assume 10C higher.</td>
</tr>
<tr>
<td>128</td>
<td>RF Connector Trade study for use in the Balun design.</td>
<td>Complete</td>
<td>MCX was chosen due to size constraints</td>
</tr>
<tr>
<td>133</td>
<td>Consider using Half Duplex still. Very few satellites have ever had a stuck transmitter, and the radio would drain the battery and force a reset.</td>
<td>Complete</td>
<td>The radio will have Full Duplex. C&amp;DH need to confirm.</td>
</tr>
<tr>
<td>143</td>
<td>Test the avionics stack in a Faraday cage with an antenna for link budget noise estimates</td>
<td>Not Complete</td>
<td>To be scheduled.</td>
</tr>
<tr>
<td>269</td>
<td>Consider link test between earth station and comm while the spacecraft is at high elevation, Ideally a mountain.</td>
<td>Complete</td>
<td>Range 1</td>
</tr>
</tbody>
</table>

Complete: 8  
In-Progress: 2  
Not Complete: 1
<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1677</td>
<td>Do power and efficiency tests with boost converter at different settings for DC power consumption. This involves doing power tests with the radio at different input voltages.</td>
<td>In Progress</td>
<td>Data for 7-10V at every 0.5V using a spectrum analyzer and bench power supply. Need to conduct tests using BETC.</td>
</tr>
<tr>
<td>1679</td>
<td>Create a plan for a Full Comm System Test. Includes: Betc, He-82, Antennas,-X Panel, as well as Batteries and Power Boards.</td>
<td>In Progress</td>
<td>Range 2 test; similar to Range 1 but using more realistic hardware. Formalized plan to be completed in the next few weeks.</td>
</tr>
<tr>
<td>1680</td>
<td>Create block diagrams for each test and send it out to reviewers so that they can suggest the proper equipment to use.</td>
<td>In Progress</td>
<td>Block diagrams created for past tests to record methodology; block diagrams for future tests will be created before conducting the test.</td>
</tr>
<tr>
<td>1681</td>
<td>Investigate what derating AstroDev is using for the radio. Get more numbers from Kevin.</td>
<td>Complete</td>
<td>Power: AstroDev ~5W; using up to 1.2W (24% derating) Voltage: AstroDev 12V max, 16V peak; using 9V (56% derating) Balun derating: 1.2W = 60% derating</td>
</tr>
<tr>
<td>1682</td>
<td>Rethink the -X board. Involves rattail pads, use of striplines, chip baluns, lack of ground plane between pads.</td>
<td>In Progress</td>
<td>-X panel v3</td>
</tr>
<tr>
<td>1683</td>
<td>Investigate the ability to use chip baluns. Suggested to chip uplink and sleeve balun the downlink.</td>
<td>Complete</td>
<td>Chip baluns tested on -X panel v3 and will be used on -X panel v4 for both uplink and downlink antennas.</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>Status</td>
<td>Notes</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------------</td>
<td>----------</td>
<td>-----------------------------------------------------------------------</td>
</tr>
<tr>
<td>1716</td>
<td>Begin working with the launch provider ASAP on obtaining the FCC license.</td>
<td>Complete</td>
<td>Working with Tyvak.</td>
</tr>
<tr>
<td>1717</td>
<td>There is a limit for how much you can radiate. The limit is set by a maximum power density at Earth's surface due to the satellite transmission.</td>
<td>Complete</td>
<td>Not an issue for AMSat bands (only an issue for NOAA bands).</td>
</tr>
<tr>
<td>1727</td>
<td>Perform a bench top test to measure the downlink and uplink sensitivities of the radios (just using cables).</td>
<td>Not complete</td>
<td>See item 143 (MPDR RFA)</td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS

Thank you to all of our sponsors, stakeholders, and contributors

Shaun Murphy @ Northrop Grumman
Katharine Gamble @ UT Austin
Jim White WD0E @ Colorado Satellite Services
Mark Spencer WA8SME @ ARRL
Tony Monteiro AA2TX & Bob Davis KF4KSS @ AMSAT-NA
Questions?
Backup slides
## Review Recommendations Status

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Status</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1685</td>
<td>Investigate the robustness of the radio. Related to derating parameters used.</td>
<td>Complete</td>
<td>See PCDR 1681</td>
</tr>
<tr>
<td>1686</td>
<td>Use a an analysis method to compare benefits and disadvantages for decision trades like the amount of power provided to the radio. i.e. if we use extra power does it cut down on the amount of science? What is the loss?</td>
<td>In progress</td>
<td>See Pattern test results</td>
</tr>
<tr>
<td>1687</td>
<td>Investigate how long Nulls may last in the antenna pattern as it spins. Allows us to assess the impact it has.</td>
<td>In progress</td>
<td>See Pattern test results</td>
</tr>
</tbody>
</table>
- He-82 Physical Inspection performed
  - Look for scratches, damages, poor solder joints, document condition
- Power up
  - Check for LED’s, read basic telemetry
- Verify Downlink capabilities (old firmware)
  - AX25, 19k2 and 9k6
- Verify Uplink capabilities (old firmware)
  - AX25, (ICOM + TNC)
- Power curves for He-82
  - Standby power, short duty cycle, long duty cycle, temperature, efficiency, power stepping
- He-82 + BETC + Power Board integration
- Verify Downlink capabilities (byte level interface)
  - SDR
- Verify Uplink capabilities (new firmware)
  - ICOM + TNC
- Verify Over The Air reset (new firmware)
- Verify Power Stepping (new firmware)
ASTRODEV He-100 AND He-82 RADIO