Bistatic Radar Receiver for CubeSats: The RAX Payload

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Mission: High-resolution Mapping of Auroral Ionospheric Irregularities

Payload: UHF Radar Receiver

Transmitter: Ground-based MW-Class IS Radar

Support: NSF CubeSat Program (NSF08-549)

Selected: September 2008

Delivered: February 2010

Launch: TBD 2010, DoD Minotaur-4 from KLC

Orbit: 650 km circular, 72 deg. inclination

Lifetime: 1 year primary + 5 year secondary
RAX Experiment Description

- RAX is bistatic - Receiver located far from Transmitter
- Maps irregularities with high spatial & angular resolution
- Ground-based ISR also measures background plasma state & E-Field

Poker Flat Advanced Modular Incoherent Scatter Radar (Alaska)
# RAX Compatibility with Global ISRs

<table>
<thead>
<tr>
<th>Name</th>
<th>Loc</th>
<th>Lat</th>
<th>Freq. MHz</th>
<th>MW</th>
<th>Beam width</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFISR</td>
<td>Alaska</td>
<td>78</td>
<td>449</td>
<td>2.0</td>
<td>1º</td>
</tr>
<tr>
<td>RISR*</td>
<td>Canada</td>
<td>81</td>
<td>442</td>
<td>2.0</td>
<td>1º</td>
</tr>
<tr>
<td>MUIR</td>
<td>Alaska</td>
<td>62</td>
<td>446</td>
<td>0.25</td>
<td>10º</td>
</tr>
<tr>
<td>MHO</td>
<td>Massachusetts</td>
<td>53</td>
<td>440</td>
<td>2.5</td>
<td>0.6º</td>
</tr>
<tr>
<td>Arecibo</td>
<td>Puerto Rico</td>
<td>34</td>
<td>430</td>
<td>2.5</td>
<td>0.2º</td>
</tr>
<tr>
<td>ESR</td>
<td>Norway</td>
<td>75</td>
<td>500</td>
<td>1.0</td>
<td>0.6º</td>
</tr>
</tbody>
</table>
Challenges for RAX Radar Receiver Design

Traditional (monostatic) Radar

- Synchronizes TX pulses with RX range gate timing
- Shares local oscillator (LO) with TX and RX subsystems

Bistatic Radar

- Requires accurate independent synchronization scheme
- Requires LO stability - especially during ISR flyover

Additional Requirements (in addition to CubeSat SWAP)

- Quick recovery from direct-path ISR illumination
- Extremely large dynamic range
- Immunity from bus-generated EMI (shared COMMS antenna)
- Efficient dissipation of thermal loads
- Avoidance of radiation sensitive components
- Tunability, gain control, housekeeping status
Synchronization Scheme

GPS Based

• Receiver
  Sample clock is allowed to free-run
  Receiver samples I & Q data at 1 MHz
  Samples time-stamped via onboard GPS PPS

• Transmitter
  Timing standard is free-running
  Time-stamp first TX pulse to GPS time
  Time and drift values sent to spacecraft

Overflow Based

Direct-path TX signal saturates receiver every second
Record ADC overflow bit on satellite
TX signal time-stamp and drift values sent to spacecraft
Frequency Stability Considerations

- Transmitter and Receiver oscillators are free-running
- Short-term stability is very good
- A small frequency offset between TX and RX is okay
- Measure TX signal offset using Receiver
RAX Payload Receiver

- Primarily Analog Industrial Components
- Pulse (>2μS) or CW operation
- 426 – 510 MHz (1 MHz steps)
- 4-bands
- Adjustable Gain
- Internal Voltage Regulation
- Continuous Sampling at 14-bit Resolution
- In-phase and Quadrature (I/Q) Signals
- Internal 500 MHz Calibration Source

Enclosure

- Provides EMI Shield
- Thermally Dissipative
- 9.7cm x 9.7cm x 3.6cm
- Weight 320 g
- Power 2.6 W
I/Q Receiver Board

Calibration
Internal 500 MHz source

Preselector
SAW Bandpass Filters
4 Bands:
- 426 – 434 MHz
- 437 – 445 MHz
- 443 – 452 MHz
- 483 – 510 MHz

Gain
-4 to +58 dB (2 dB steps)

Mixer
Active – I & Q outputs
High Dynamic Range
2X LO input

I/Q Filter
Passive LC, 250 kHz BW
10-pole Bessel function

ADC
Dual Interleaved I/Q
14-Bit, 1 MHz Sampling

Homodyne Design - Direct Conversion (No IF)

PCB
4-layer
FR-4 construction
Thermal Transfer Perimeter
8.6cm x 8.6cm
## I/Q Receiver Performance

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise figure</td>
<td>3.8 dB (400° K)</td>
</tr>
<tr>
<td>Noise Floor</td>
<td>-114 dBm</td>
</tr>
<tr>
<td>Gain Range</td>
<td>-4 dB to +58 dB</td>
</tr>
<tr>
<td>Single Frequency Dynamic Range (DR)</td>
<td>60 dB</td>
</tr>
<tr>
<td>Dual Frequency Spurious Free DR</td>
<td>54 dB</td>
</tr>
<tr>
<td>LO Radiation</td>
<td>&lt; -80 dBm</td>
</tr>
<tr>
<td>Max RF Input (no damage)</td>
<td>+20 dBm</td>
</tr>
<tr>
<td>Max Recovery Time</td>
<td>30 μS</td>
</tr>
<tr>
<td>Recovery to 1 dB</td>
<td>10 μS</td>
</tr>
</tbody>
</table>

![100-microsecond Pulse Saturation Response](image)

\[
\text{SQRT}[ I^2 + Q^2 ]
\]
I/Q Receiver Selectivity
Local Oscillator Board

10 MHz Reference Oscillator
TCXO
Digital compensation ±0.28 ppm, -40C to +85C
Stabilization time ~200 sec. (cold start)
I2C monitor for crystal temp
I2C control for freq push/pull (1ppb or 0.01Hz)

ADC Clock
Buffered 10 MHz from TCXO
Conversion to sinewave to reduce EMI

Mixer Local Oscillator
Phase-locked system
852 - 1020 MHz
2 MHz control resolution

Cal Oscillator
500 MHz – free running
I2C on/off control

PCB
4-layer
FR-4 construction
Thermal Transfer Perimeter
7.6cm x 7.6cm
PWM DC/DC Buck Regulators
High efficiency (>90%)
Wide input range (3 - 17V)
Regulated outputs: +5V, +3V
Integrated design – low radiated EMI

LC Filtering on Input and Outputs

Voltage and Temperature Monitoring

Shielding
Continuous external ground plane
Compartment in housing

PCB
2-layer
FR-4 construction
Thermal Transfer Perimeter
8.6cm x 8.6cm
Temperature Cycling in (Moderate) Vacuum

**Equipment**
14L Enclosure with 0.6 T Pump
10cm X 10cm liquid coolant thermal Plate
Temperature range (-60°C to +60°C)

**Setup**
RAX Receiver in 1U Pumpkin frame
Multiple thermal sensors

**Procedure**
Baseline receiver operation
RX OFF: Cold-soak @ -40°C for 30 min
RX ON: Start logging data
Temperature ramp-up (240 min. to +55°C)
Post-test operational check

**Results**
TCXO drift <0.24 ppm (spec: +/-0.28ppm)
PLL maintained lock
RF gain variation ± 1.5 dB
Internal DC voltages stable
Crystal Oscillator Thermal Response
Board-Level Thermal Response
Vibration Testing

**Pre-Test Sine-Sweep**
Baseline all resonances
Range: 20-2000 Hz @ 0.5G
Rate: 3 Oct/Min
One sweep per axis

**Random Vibration Test**
20-2000 Hz
10.4 G rms
1 minute/axis

**Post-Test Sine-Sweep**
Same as pre-test
Compare pre/post resonances

**Results**
No change in resonances
Pass - Visual inspection
Pass - Post electrical tests
**Functional Testing**

**Radar Simulator**
Generates radar direct and scattered signals
Variable timing (Pulse Width, IPP)
Adjustable transmit frequency

**Payload Interface Module (PIM) Simulator**
Direct interface to payload receiver
Supplies power and control to payload
Collects and stores I & Q samples

**Integrated Testing with Cubesat BUS**
PIM interface
Antenna Interface
I2C checkout
Full-up EMI validation

![Diagram of Radar Simulator and Payload Interface Module (PIM) Simulator](image)
The Path Ahead

RAX Science Planning at 2010 NSF CEDAR Workshop

Future Applications
- Antenna pattern measurements for large GB Radars
- Other bistatic radar experiments in the UHF band
- Global UHF LEO Noise Survey

Ongoing life tests
- 11-week (24/7) operational burn-in
- No failures

Future design modifications
- Investigate Digital down-converters
- Lower-power techniques
- Lighter materials
- Integrate PIM Functions within Structure
- Explore PnP Capabilities