Iris Deep-Space Transponder for SLS EM-1 CubeSat Missions

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Outline

• CubeSat Missions with Large Distances
• Iris Deep-Space Transponder
• Design and Architecture
• Typical Transponder Performance
• Future Work
CubeSat Missions with Large Distances

- **Lunar IceCube**
  - (1 Mkm)

- **CubeSat for Solar Particles**
  - (15 Mkm)

- **Near Earth Asteroid Scout**
  - (180 Mkm)

- **LunaH-Map**
  - (1 Mkm)

- **Lunar Flashlight**
  - (1 Mkm)

- **BioSentinel**
  - (84 Mkm)

- **MarCO**
  - (160 Mkm)

*IMAGES NOT TO SCALE*
Overcoming Large Distances

X-band Uplink

-83 dBm
-106 dBm
-121 dBm
-128 dBm

DSS-14 (Goldstone, CA)
70-m Aperture
20 kW X-Xmtr
EIRP: 145 dBm
Iris Deep-Space Transponder

<table>
<thead>
<tr>
<th>Iris Specification</th>
<th>Spec Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processor</td>
<td>Xilinx Virtex-6 w/ Leon-3FT</td>
</tr>
<tr>
<td>Uplink/Downlink Frequencies</td>
<td>7145 – 7235 / 8400 – 8500 MHz</td>
</tr>
<tr>
<td>Turn-around Ratio</td>
<td>880/749</td>
</tr>
<tr>
<td>Downlink Symbol Rates</td>
<td>62.5 bps – 6.25 Msps</td>
</tr>
<tr>
<td>Uplink Data Rates</td>
<td>62.5 bps – 8 kbps</td>
</tr>
<tr>
<td>Modulation Waveforms</td>
<td>PCM/PSK/PM w/subcarr,</td>
</tr>
<tr>
<td></td>
<td>PCM/PM w/ biphase-L, BPSK</td>
</tr>
<tr>
<td>Telemetry Encoding</td>
<td>Convolutional (r=1/2, k=7)</td>
</tr>
<tr>
<td></td>
<td>Reed-Solomon (255,223) l=1 or 5</td>
</tr>
<tr>
<td></td>
<td>Turbo (1/2, 1/3, 1/6)</td>
</tr>
<tr>
<td></td>
<td>Concatenated codes</td>
</tr>
<tr>
<td>Receiver Noise Figure</td>
<td>&lt; 3.5 dB</td>
</tr>
<tr>
<td>Carrier Tracking Threshold</td>
<td>-151 dBm @ 20 Hz LBW</td>
</tr>
<tr>
<td>RF Output Power</td>
<td>&gt; 3.8 W</td>
</tr>
<tr>
<td>Navigation Support</td>
<td>Doppler, Sequential/PN Ranging, Delta-DOR</td>
</tr>
<tr>
<td>Transmit Phase Noise</td>
<td>-110 dBc/Hz @ 100 Hz</td>
</tr>
<tr>
<td></td>
<td>-117 dBc/Hz @ 1 kHz</td>
</tr>
<tr>
<td></td>
<td>-126 dBc/Hz @ 10 kHz</td>
</tr>
<tr>
<td></td>
<td>-127 dBc/Hz @ 100 kHz</td>
</tr>
<tr>
<td>Oscillator Stability</td>
<td>0.001 ppm @ 1 sec</td>
</tr>
<tr>
<td>Mass / Volume</td>
<td>&lt; 1 kg (X/X only); 0.56 U (ex. SSPA/LNA)</td>
</tr>
<tr>
<td>Power</td>
<td>9 – 28 Vdc; 12.0 W Rx-only</td>
</tr>
<tr>
<td></td>
<td>16.0 W full Tx/Rx (No SSPA), 33.7 W (w/ 4W SSPA)</td>
</tr>
<tr>
<td>Environmental</td>
<td>AFT: -20°C to + 50°C</td>
</tr>
<tr>
<td></td>
<td>&gt; 23krad; 14.1 Grms RV</td>
</tr>
</tbody>
</table>

Key Updates in Iris V2.1

- FPGA with embedded processor
- 30% volume reduction
- Higher data rates
- Expanded encoding support
- Increased receiver sensitivity
- Radiation tolerant design
Hardware Design Considerations

- Modular hardware built of slice elements
  - NASA-STD-4009 (Space Telecom Radio System) guidelines
  - Slices are interconnected with stacking connectors
  - RF modules are generic to allow future designs with other frequency bands (UHF, S, Ka)
- Radiation tolerant up to 23 krads; no destructive SEL.
- EMI covers/shields to minimize radiated emissions
- Emphasized efficient thermal design

![Diagram of hardware design considerations]

- Thermal Path
- Nusil CV-2942 thermal compound (1.0 W/m-K)
- Aluminum covers (173 W/m-K)
- Thermal Vias
- Nusil CV2-2646 thermal compound (1.50 W/m-K)
- 1oz copper GND layers pulled to edge of PWB. (384 W/m-K)
- SN63 Solder (50 W/m-K)
**Top-Level Block Diagram**

### Iris LNA
- Modular MIC assembly
  - Reduce noise figure by shortening cable length from antenna
  - Separate gain cavities between LNA and Rx (risk of oscillations)

### X-Band LNA
- Pre-Select
- Image Reject
- SAW Filter
- VVA
- RX PLO

### Iris Transponder Stack
- X-band Receiver
  - X-band Exciter
  - DDS Generator
  - DDS Input Filter
  - TX PLO

### Digital Processor
- Xilinx Virtex-6 FPGA
- SRAM
- Leon3FT Softcore Processor
- U/L DATA
- AGC
- Command Decoder
- Tracking Loops
- D/L DATA
- I-DAC
- Q-DAC
- DDS

### Iris SSPA
- Modular MIC assembly
- Provide superior heat dissipation path to structure/radiator
- Chip-and-wire assy to reduce losses for higher efficiency

### X-Band SSPA
- Isolator
- RX PLO
- 50 MHz

### X-Band Uplink
- 7145 – 7235 MHz
- -130dBm to -70dBm

### X-Band Downlink
- 8400 – 8500 MHz
- 3.8W BOL

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Digital Processor

**Xilinx Virtex-6 FPGA**
- Leon-3FT softcore processor
- SEL tested up to 37 MeV-cm2/mg
- TMR logic and EDAC protected
- Reprogrammable/Reconfigurable

**Rad-Hard Memory**
- 2 MB SRAM program memory
- 32 MB NVM for multiple software images and configuration files

**14-bit DDS DAC**
- Doppler carrier tracking for transponder functions

**Modem Processor**
- **Telecom Interface**
- **Tyco-160 Bus connector**
- 1 MHz Serial-Peripheral I/F
- Expandable for SpaceWire

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Previous Iris models were for low radiation environ. (Mars ~2.9 krad). Design update necessary for EM-1

<table>
<thead>
<tr>
<th>Part No.</th>
<th>High Dose Rate Radiation Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>LMZ34002</td>
<td>Hard failures at 14-16 krad (biased)</td>
</tr>
<tr>
<td>LT1964</td>
<td>Total functional failure by 50 krad</td>
</tr>
<tr>
<td>LT3082</td>
<td>No degradation/failures up thru 50 krad</td>
</tr>
<tr>
<td>LT3433</td>
<td>Functional failures at 17-21 krad (biased)</td>
</tr>
<tr>
<td>LT8570</td>
<td>Output degraded 2% at 7 krad</td>
</tr>
<tr>
<td>LT8610</td>
<td>No degradation/failures up thru 50 krad</td>
</tr>
<tr>
<td>LT8613</td>
<td>No degradation/failures up thru 50 krad</td>
</tr>
</tbody>
</table>

Key Power Supply Board Specs

- Bus input range 8 – 28 Vdc
- 36 Watts full-load capability
- High converter efficiency > 86%
- 13 secondary analog/digital voltages
**X-band RF Boards**

- **X-band Exciter**
  - Tx-Out
  - Rx-PLL
  - 50MHz TCXO

- **I/Q Modulator**
  - Image-Rejection Mixer
  - Tx-PLL

- **X-band Receiver**
  - Rx-In
  - IF Amps
  - SAW Filters
  - VVAs

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**Transmit carrier phase noise at X-band**

**IF Spectrum at high SNR input**

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**X-band RF Modules**

- **GaAs MMIC Power Amps**
- **X-band SSPA**
  - Isolator
- **Ceramic printed BPFs**
- **X-band LNA**
  - GaAs MMIC LNAs

**Graphs:**
- **SSPA Output Power (dBm)**
  - High Saturated Power for 30% Eff.
  - SSPA Input Power (dBm)
  - Curves for +25C, +50C, -20C

- **LNA Gain (dB)**
  - > 100 dB transmit rejection
  - Typ. NF: 2.5 dB

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Typical Transponder Performance

- Receiver characterization shows stellar performance comparable to commercial transponders.
- Low loop bandwidth is desirable for low signal levels, but sensitive to frequency dynamics.

- Typical uplink receiver Bit Error Rates on a 16 kHz sine-wave subcarrier at 1.5 radian mod index.
- Further performance improvements can be made with modem processor parameter optimization.

- High-rate testing shows spectrum of a direct-carrier modulated 6.25 Msps waveform with Manchester encoding.
- I/Q imbalance seen as spurious outputs at nulls can be eliminated by software tuning.
Future Work

• Upcoming Iris V2.1 Qualification Tests
  – Complete ambient characterization
  – Environmental tests: TVAC, Vibe, EMI/EMC
  – DSN Compatibility Testing at DTF-21 Facility

• Future Enhancements
  – Delay/Disruption Tolerant Networking
  – Pseudo-noise regenerative ranging support
  – Advanced higher-order modulation (QPSK, 8PSK, etc.)
  – State-of-the-art FEC algorithms (LDPC)
  – Other frequency bands (UHF, S, Ka)
Conclusion

• Upcoming EM-1 CubeSat missions face challenging deep-space telecom system requirements.

• Thorough slice-by-slice design description of the Iris Transponder was presented.

• Comparable transponder performance demonstrated.

• Software defined radios as “smart radios” are leading the pathway to enable rapid technology infusion.