Iris Transponder
Communications and Navigation from Deep Space

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Transponders

• Transmit and receive simultaneously
  – 100% duty cycle for hours during navigation passes
  – No GPS in deep space, users participate by receiving and transmitting
• Coherent turnaround – Doppler and Ranging
  – Long navigation passes (hours)
• Commands up / Telemetry down
• Subcarriers and residual carrier
• Data rates vary with range

• Note the differences between transponders and more familiar data-only transceivers

• When navigating on Earth or in Earth orbit using GPS
  – Transmit and receive are 100% duty cycle, but
  – GPS users are receive-only, not needing much power
Iris Transponder for Deep Space

• JPL and others build transponders for deep space missions
  – Not small or low power enough for a CubeSat or nanoSat form factor
  – Until now
• Iris is CubeSat Compatible – 0.5 kg, 0.5U
  – Four stacked boards in current version, 0.4U
• Iris is DSN Compatible – CCSDS, transponder
  – Also intended for proximity operations – (planned)
Iris Architecture

RF Block Diagram:

All functions and PLOs under FPGA control
All signal processing at baseband in FPGA
- generation of transmit I/Q
- processing of 112.5 MHz receive IF

Commercial Parts for INSPIRE mission
Receiver

- Converts 7.2 GHz uplink to 112.5 MHz IF
  - X-Band channel/frequency selection under FPGA control
  - 15 MHz IF bandwidth
  - -130 dBm sensitivity
  - 5 dB noise figure
- Two selectable low noise amplifiers
  - Top and bottom antenna
- Quadrature (subharmonic) sampled at 12.5 Msps
Exciter

- 8.4 GHz carrier PLL
  - X-Band vector modulator
  - Quadrature baseband at 2 MHz
- 50 MHz TCXO
- DACS for PLLs (TX and RX)
- Two selectable power amplifiers
  - Top and bottom antenna
- 30 dBm (1 W.) output possible
  - Can be biased back depending on mission needs
  - For INSPIRE, 23 dBm selected
- PA Heat dissipation
  - 3 W thermal at final amplifier (but only one at a time)
- “Exciters” usually drive high power amplifiers
  - This is CubeSat compatible, 1-2 W is “high” power
Power Supply Board

• Converts CubeSat bus to voltages used internally
  – 7.4-8.3 VDC nominal input
  – Separate RF and digital rails
  – Inrush limited to 3 A
  – FPGA, RX, and TX boards separately powerable

• Because *transponders* run nominally for hours at 100% duty cycle for navigation passes, an ultra low power “cellphone-like” receive mode is not as useful
  – But receive-only is still lower power

• To be upgraded to “radiation tolerant”

<table>
<thead>
<tr>
<th>DC Input Table, W.</th>
<th>INSPIRE V1</th>
<th>INSPIRE V2 (WC)</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPGA &amp; PSB</td>
<td>2.6</td>
<td>2.6</td>
<td>1.5</td>
</tr>
<tr>
<td>plus Receive</td>
<td>6.4</td>
<td>6.4</td>
<td>4.0</td>
</tr>
<tr>
<td>Full Transpond @ 0.3 W</td>
<td>12.75</td>
<td>12.75</td>
<td>10.0</td>
</tr>
<tr>
<td>Full Transpond @ 1.0 W</td>
<td>15.2</td>
<td>15.2</td>
<td>11.0</td>
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<tr>
<td>Full Transpond @ 2.0 W</td>
<td>18.9</td>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td>Ka-Band @ 2.0 W</td>
<td>&gt; 21.0</td>
<td></td>
<td>&lt; 20.0</td>
</tr>
</tbody>
</table>
Low Gain Antenna

RHCP, each:
- 300 Mhz 3 dB bandwidth
- 80 degree 3 dB beamwidth
- 5 dB boresite gain

Receive Patch, 7.2 GHz  >35 dB isolation

Transmit Patch, 8.4 GHz

Antenna placement on top and bottom of INSPIRE spacecraft
Baseband Functions, Common

- All baseband functions are implemented digitally in FPGA code and can be modified
  - In-flight modification capability planned
- Phase Lock Loop (PLL) programming, Tx and Rx
- Automatic Gain Control (AGC)
  - RF chain analog using PWM to op amp
  - Digital in later stages in baseband
- C&DH interface: Serial Peripheral Interface SPI
  - Command and telemetry dictionary planned for softcore in FPGA
Baseband Functions, Navigation

• Phase coherence downlink with uplink
  – 880/749 for standard X-Band – others possible

• Ranging tone or PN code passthrough
  – Non-regenerative
  – Regenerative (planned)

• Delta DOR tones (planned)
  – 19 MHz
Baseband Functions, Modems

• Uplink
  – Carrier
  – Subcarrier, 16 KHz
  – BPSK bit sync
  – Buffering
    • Multimission Telecommunications Interface (MTIF) SDST heritage
  – Deframing (in C&DH on INSPIRE, planned for softcore in FPGA in V2)
    • 2072 bit frame (smallest CCSDS frame size) on INSPIRE (other frame sizes planned)
Baseband Functions, Data & Modems

• **Downlink**
  – **Carrier**
  – **Subcarrier** (25 KHz, 281.25 KHz, others possible)
  – **Framing** (in C&DH on INSPIRE, planned for softcore in FPGA in V2)
    • 2072 bit frame on INSPIRE (other frame sizes planned)
  – **Buffering and Coding in MTIF**
    • Reed Solomon RS (255,223)) other schemes and interleave depths available
    • Convolutional (R=1/2, K=7), two symbols per bit
    • Turbo Coding available: 1/2, 1/3, 1/6
    • PN Coding available
  – **BPSK**
  – **Direct carrier modulation**
    • Suppressed carrier (π/2 mod. index)
    • Residual carrier (π/3 mod. index)
Iris Data Specifications

• Data Rates
  – Uplink
    • 1000 bps on 16 KHz subcarrier
    • Full range (planned) subcarrier and non subcarrier
    • FIRECODE (special but valid CCSDS frame)
  – Downlink
    • 62.5, 250, 1000, 4000 bps on 25 KHz subcarrier
    • 16000, 64102 bps on 281.25 KHz subcarrier
    • 260416 bps direct on carrier
    • Full range in factors of 2 (planned)
      – Up to > 4 Mbps
      – < 62.5 bps using tones
DSN Compatibility

• ConOps
  – Keep in mind two way light time delays of seconds to minutes (Earth orbit light time is milliseconds)
  – Find the downlink in plane of sky and frequency
  – Sweep the uplink across expected acquisition range
    • Up and/or Down (diagram)
  – Watch downlink frequency move to coherence with uplink
  – Reacquire downlink
  – Record navigation measurements
    • Doppler only for carrier coherence
    • Tones or PN code for ranging
  – Downlink Telemetry
  – Uplink Commands
Deep Space Navigation Data Types

• **Doppler**
  – Most useful when there is Doppler “signature” as orbiting or passing a planet or moon
  – Easiest – nominal transponder operation

• **Ranging**
  – Gives absolute range from station to spacecraft
  – Sequential tones or PN (pseudo-noise)
  – Non-regenerative (implemented) or regenerative (planned)

• **Delta DOR (planned)**
  – Gives plane-of-sky location of spacecraft
  – Involves multiple ground stations slewing between spacecraft and quasars with spacecraft sending “tone” modulation

• **Iris supports all**
Projected Capabilities

• Frequency Bands
  – Ka-Band – more bandwidth available, higher gain antennas possible
  – UHF / S-Band – proximity operations
• Digitally implemented feature upgrades
  – As presented
• 2 W RF out baseline
  – Thermal design cooperation with spacecraft
  – Consideration of driving a higher power tube
    • But remember, these are CubeSats / nanoSats
    • You may really have a bigger mission and need a bigger comm/nav system
Iris Downlink Rates

<table>
<thead>
<tr>
<th>Range, km</th>
<th>LEO</th>
<th>GEO</th>
<th>Lunar</th>
<th>L-1</th>
<th>1 AU</th>
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<tbody>
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<td>1.00E+06</td>
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<td>1.00E+07</td>
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<td>1.00E+08</td>
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<td>1.00E+09</td>
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<tr>
<td>1.00E+10</td>
<td></td>
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</tbody>
</table>

Unless otherwise noted:
1 W, Conv. K=7, r=1/2
34 m, 45K
8.4 GHz
Mars and beyond:
2 W, Turbo 1/6 1728

8 Mbps

62.5 bps

Venus

Mars

L-1

LEO

GEO

Lunar

1 AU

NEA

Voyager

Venus

Mars

8 Mbps

62.5 bps
Missions Planning on Iris

• INSPIRE – delivered 6/30/14
  – Earth escape, operate to 1.5 M km (0.01 AU)
  – Waiting on Earth Escape manifest
• Baseline for EM-1 launch in 2017
  – Lunar Flashlight*
    • Lunar south pole science with solar sail
  – NEAScout*
    • Fly by Near Earth Asteroid with solar sail
  – Bio Sentinel*
    • Interplanetary radiation effects on yeast
  – Heliophysics CubeSat*
    • LCAS AO out now

*Mission Concept – Pre-decisional – for Planning and Discussion Purposes Only
DSN

- DSN wants to support all deep space missions
  - Business and technical issues being worked in the community now
  - Don’t assume it’s too expensive or inaccessible
  - JPL contact is Kar-Ming Cheung

- DSN is the earth station partner that makes deep space operations possible
  - 34 and 70 m apertures – high gains
    - Precision pointing
  - Quiet front ends – 45K system noise temperature
  - High uplink power – 20 KW
  - High performance coding and other modulation schemes, > 10 dB of further improvements
Deep Space Network (DSN): Comprises DSN and Partner 34-70m tracking sites around the globe to provide continuous communication and navigation support.
The Big Picture

DSN Antenna

DSCC Signal Processing Center (SPC)

WAN

JPL Deep Space Operations Center (DSOC)

Mission Support Area (MSA)

Spacecraft Operations
DSN Collaborators

• Non DSN ground stations should be DSN compatible for interoperability
  – Small number of missions to deep space, multiple standards don’t make sense
  – Community needs to be able to help / rescue each other, at least technically

• Steps towards compatibility
  – X-Band, receive 8.4 GHz data
    • CCSDS back-ends (can be implemented in digital IFs)
  – Good clock on ground to participate in navigation
    • Ideally collaborate with JPL navigators
  – 7.2 GHz uplink for command / navigation
    • Licensing
  – Ka-Band 32/34 GHz
Summary

• Iris is a DSN Compatible, CubeSat Compatible transponder intended for deep space mission communication and navigation
  – Support for at least inner solar system missions on nanoSats
    • Different missions will need different antennas – stabilization strategy
  – Evolving product, improved capabilities in progress as discussed
  – Commercialization is in progress for lower cost, higher availability

• Deep Space missions should use or be compatible with DSN
  – Including non DSN ground stations intended for this purpose