

Iris Transponder – Communications and Navigation for Deep Space

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ABSTRACT

The Jet Propulsion Laboratory has developed the Iris CubeSat compatible deep space transponder for INSPIRE, the first CubeSat to deep space. Iris is 0.4 U, 0.4 kg, consumes 12.8 W, and interoperates with NASA's Deep Space Network (DSN) on X-Band frequencies (7.2 GHz uplink, 8.4 GHz downlink) for command, telemetry, and navigation. This talk discusses the Iris for INSPIRE, its features and requirements; future developments and improvements underway; deep space and proximity operations applications for Iris; high rate earth orbit variants; and ground requirements, such as are implemented in the DSN, for deep space operations.

TRANSPONDERS

A deep space transponder is a radio system that transmits and receives simultaneously on diverse frequencies in support of coherent Doppler and range measurements, spacecraft commanding, and telemetry return. A highly stable signal is uplinked from Earth to the transponder which phase locks its downlink carrier to an integer ratio of the received uplink. The downlink is then received on Earth and measured against the uplink reference (two-way Doppler) or a different Earth station (three-way Doppler) against a coordinated time and frequency reference to produce high precision Doppler signatures for navigation processing.

The turnaround signal can also support modulated ranging signals, typically tones (sine waves) or pseudo-noise (PN) sequences to determine absolute range to the spacecraft, given calibration of the turnaround delay in the transponder.

The uplink also carries commands from Earth to the spacecraft and the downlink carries telemetry, including science and housekeeping data, from the spacecraft to Earth.

In deep space the distances are so vast and signals so weak that lengthy passes of interaction with Earth stations are conducted to support lengthy integrations, usually lasting for several hours. Relatively low data rates are also used. On most missions the transponder downlink is never turned off in order that the spacecraft can be located. The uplink is never turned off in order to enable constant accessibility for commanding.

IRIS TRANSPONDER [1]

The Jet Propulsion Laboratory provides equipment and operational services for both ends of the deep space link, in the form of flight transponders such as the Small Deep Space Transponder (SDST), the more modern and reconfigurable Universal Space Transponder (UST) and the Electra Proximity Operations UHF transceiver which is responsible for most of the data returned from the Mars Science Laboratory via Mars orbiting relays. The newest entry in this product line is the Iris CubeSat Compatible, Deep Space Network (DSN) compatible transponder that will be flown on JPL's INSPIRE "first CubeSat to deep space" mission and which is proposed for several future nanoSpacecraft missions to cis-lunar or solar system destinations.

Iris consumes 0.4 U of volume, 0.4 kg mass, and features a significant subset of standard deep space transponder features, largely inherited from UST and Electra in the form of complex digital signal processing code hosted in FPGA. Iris also shares the basic hardware architecture with these larger transponders but in a more compact form. The main limitation of Iris compared to its larger siblings is not data formats and measurement precision, which are similar, but the smaller amount of power consumed from the spacecraft bus and radiated on the downlink. Iris is a highly capable transponder that is compatible with the DSN in the same sense that all deep space transponders in use today are. The lower power sets an upper limit on the data rate that can be used for a given range.

Iris Architecture

The current Iris, Version 1, is a stacked set of four CubeSat-size boards interconnected with a Pumpkin standard PC-104 connector [2] and antennas. The spacecraft interface is Serial Peripheral Interface (SPI), also interconnected via the PC-104. See Figures 1 and 2. Per INSPIRE project policy, Iris V1 is assembled entirely from commercial off the shelf (COTS) parts, but the parts and architecture used have radiation hardened equivalents so that a more environmentally robust (and more expensive) model can be produced for a future customer. The INSPIRE approach to radiation events is to conduct a short mission and to tolerate radiation induced upsets through power-cycle resets as needed.

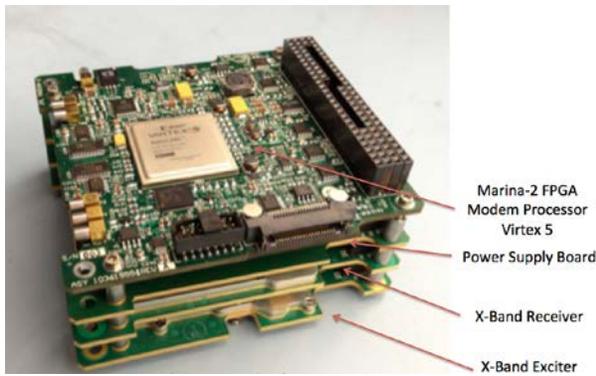


Figure 1: Iris Prototype Stack

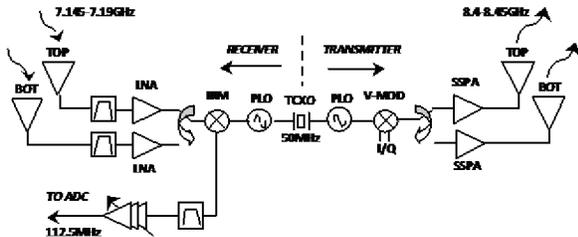


Figure 2: Iris High Level Block Diagram

Marina-2 Virtex 5 Board

On top of the Iris stack is the Marina-2 Field Programmable Gate Array (FPGA) board featuring a commercial grade Virtex 5, bus power conversion for digital electronics, and associated circuitry. Digital signal processing and data handling are performed here.

Power Supply Board

The power supply board (PSB) (Figure 3) converts spacecraft bus voltage (nominal 7.4-8.3 VDC for a CubeSat such as INSPIRE) to the voltages required by the receiver and exciter boards. These are separate from the digital power rails on the Marina-2 board for noise control reasons. When powering Iris up, the Marina-2 board is powered first and the others are activated under its control. All power converters are designed to limit inrush to a CubeSat bus acceptable level of 3 Amperes peak.

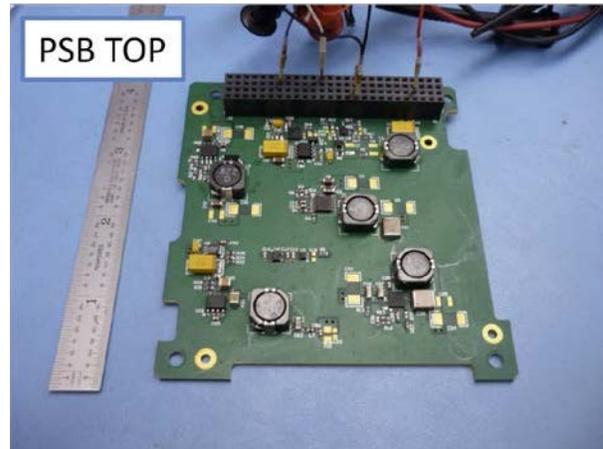


Figure 3: Power Supply Board (PSB)

Receiver Board

The receiver board (Figures 4 and 5) performs a single conversion of X-Band radio frequency (RF) at 7.2 GHz to a 112.5 MHz intermediate frequency (IF). The local oscillator (LO) for this down-conversion is provided by a phase locked loop (PLL) whose frequency is set under FPGA control. The IF is sub-harmonic sampled in quadrature and digitized at 12.5 Msp/s. These samples are then passed to the FPGA for baseband processing. The receiver has a demonstrated carrier acquisition sensitivity of better than -130 dBm and an RF passband suitable for use in any channel of the near Earth or deep space X-Band uplink allocations, that is, 7.14 – 7.24 GHz. The front-end noise figure is approximately 5 dB and the IF bandwidth is 15 MHz. Covers are used on the receiver board to provide RF isolation from other nearby electronics and to provide a thermal heat removal path.

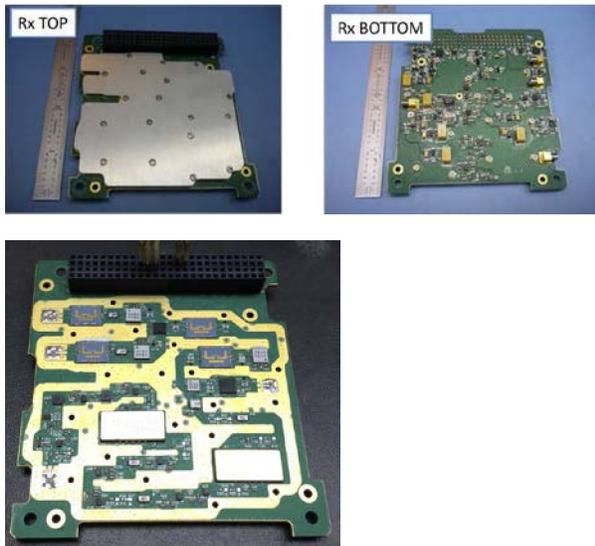


Figure 4: Receiver Board

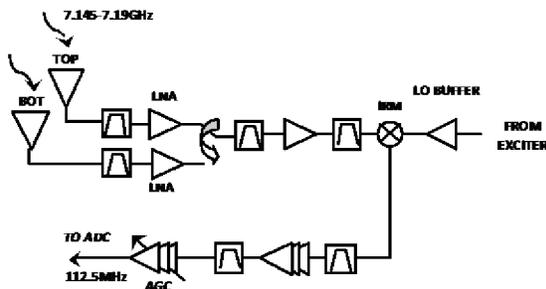


Figure 5: Receiver Block Diagram

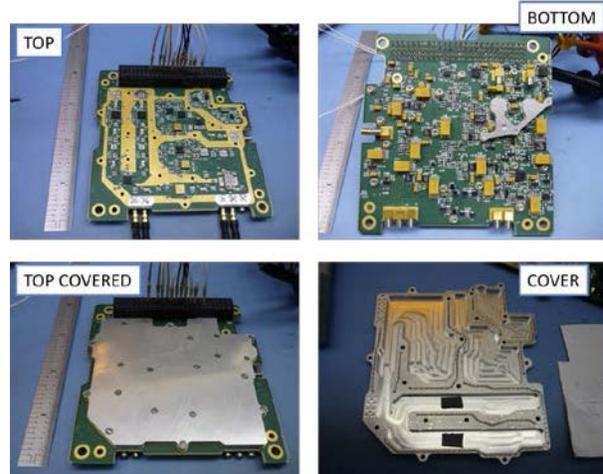


Figure 6: Exciter Board

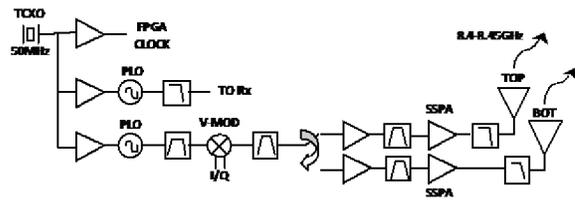


Figure 7: Exciter Block Diagram

Exciter Board

The exciter (or “transmitter”) board (Figures 6 and 7) generates a carrier frequency using a PLL under FPGA control that is about 2 MHz away from the intended transmission channel. This carrier is then quadrature modulated with baseband samples produced in the signal processing firmware of the FPGA to produce carrier, subcarrier, modulation as required for the mode selected, and shifting to the assigned carrier channel. A balanced vector modulator is used to suppress the original carrier frequency and images, 2 MHz and 4 MHz away from the intended signals respectively, to acceptable levels.

The exciter board also hosts the 50 MHz Temperature Compensated Crystal Oscillator (TCXO) that provides the reference frequency for all onboard operations: transmit and receive PLLs, digital to analog (DAC) and analog to digital (ADC) conversion, and FPGA clocking. All digital processing operations are therefore coherent to this oscillator.

A metal cover is used on the exciter board to provide RF isolation to other nearby electronics and to provide a heat sink for the board, particularly the power

amplifier (PA) parts that dissipate approximately 3 Watts of heat when operating.

The PA used in this version of Iris is a solid state power amplifier capable of 1 W (30 dBm) RF output but, for the INSPIRE mission, was biased to approximately 0.2 W (23 dBm) so as to reduce overall DC power draw.

Power is supplied to Iris at a nominal 7.4 VDC from the spacecraft power system. Iris consumes 12.75 W in full transpond operation, 6.4 W receive only, and 2.6 W when operating only the Marina-2 board.

Low Gain Antennas

The INSPIRE Iris uses a low gain antenna (LGA) printed on CubeSat sized circuit boards (Figure 8).

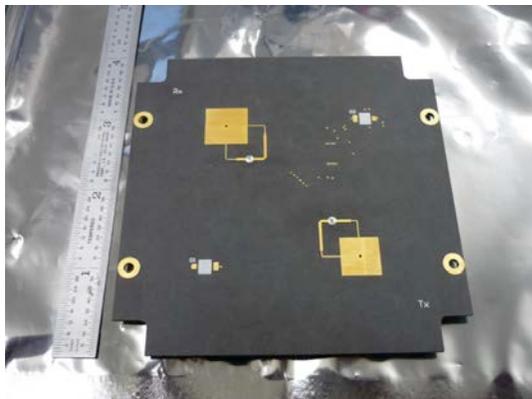


Figure 8: Low Gain Antenna Board

Each antenna board features two independent patch antennas, one for transmit at 8.4 GHz (lower right) and the other for receive at 7.2 GHz (upper left). They each have a 3 dB bandwidth of about 300 MHz and are right hand circularly polarized (RHCP). Each has a peak gain of approximately 5 dB and a beamwidth of 80 degrees.

The antenna board pictured also hosts INSPIRE spacecraft sun sensors and associated electronics.

Iris on INSPIRE does not use a diplexer for simultaneous transmit and receive. The printed antennas have over 35 dB of isolation from each other and bandpass filtering in their respective circuits produces sufficient total isolation for simultaneous transmission and reception at the stated power output and sensitivity levels.

An antenna board is mounted on each end of the INSPIRE spacecraft (Figure 9) so that two roughly hemispherical views of the sky are supported, enabling communications from any spacecraft orientation. The favored direction is broadside to the board, that is, off

one end or the other of the spacecraft, for maximum gain and circularity. A PA is provided on the exciter board for each transmit antenna and a low noise amplifier (LNA) is provided on the receive board for each receive antenna. Antennas are selected by providing DC power to the corresponding amplifier under FPGA control. This approach eliminates the need for troublesome RF switches or relays (either for antenna selection or transmit/receive) and provides some operational redundancy.

The overall system as designed, analyzed, and tested, does not have significant, self-degrading intermodulation products.

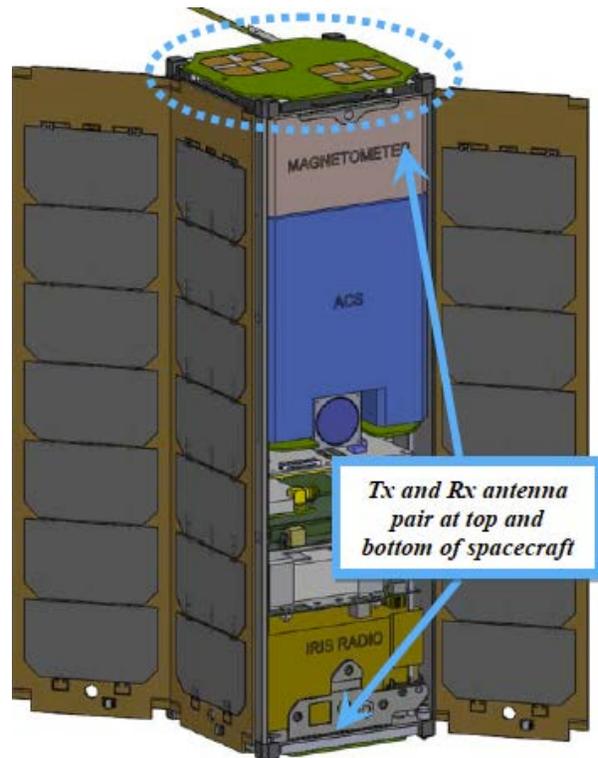


Figure 9: INSPIRE Spacecraft Showing Low Gain Antenna and Iris Transponder Placement

C&DH Interface and Duties

Iris V1 does not feature a sequential processor although a CPU is planned for future Iris versions. The FPGA interacts directly via SPI with the spacecraft Command and Data Handling (C&DH) processor which reads and writes appropriate command values to FPGA registers. Data to and from Earth is stored in MTIF buffers implemented in the MTIF module in FPGA. The Multimission Telecommunications Interface (MTIF) is FPGA code that implements data handling (buffers), rate selection, encoding and decoding (Reed Solomon, Convolutional) “FireCode”, and related features.

Uplink and downlink buffers are double, ping pong style. Spacecraft science and telemetry data are written by C&DH into downlink MTIF buffers from which they are clocked into the FPGA modems for downlink to Earth. Commands received via FPGA modems from the uplink are buffered into MTIF uplink buffers and read by C&DH. MTIF supports a special “FireCode” command that causes the FPGA to latch a spacecraft reset line that cycles power on the entire spacecraft. This FireCode is OR combined with FireCodes from the AstroDev Lithium [7] UHF crosslink radio and the spacecraft watchdog timer so that the spacecraft can be reset from any of these sources.

Concept of Operations

From the spacecraft C&DH point of view, Iris is the Marina-2 FPGA board on the SPI bus. When Iris is first powered, only the Marina-2 board is active. Receiver and exciter boards can then be activated by command values written into FPGA interface registers.

The nominal sequence of events when interacting with the Deep Space Network (DSN) is for Iris to begin a pass by transmitting, on the Earth direction antenna, an unmodulated carrier at its “Best Lock Frequency” (BLF) which is nominally at its assigned X-Band channel. The DSN station (DSS) points at the predicted spacecraft location in the sky and listens on the predicted Doppler corrected frequency. The spacecraft is located in space and frequency and DSN antenna pointing is refined for best signal. An uplink carrier is then initiated and swept across what is expected to be the Doppler corrected spacecraft receive frequency (Figure 10). When this carrier is detected at the spacecraft, the receiver locks on it and the downlink frequency then locks, by means of signal processing in the FPGA, to exactly 880 / 749 times the uplink frequency. This causes the downlink to jump from BLF to the new “coherent” downlink frequency and so it must be reacquired in the DSN receiver.

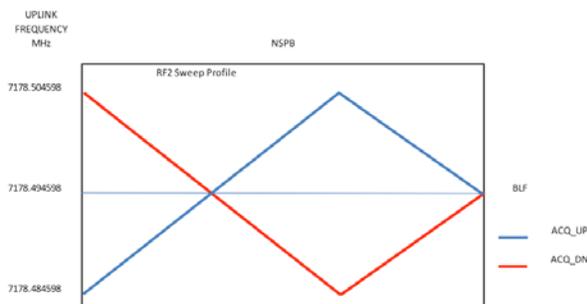


Figure 10: Example DSN Uplink Acquisition Sweep Pattern, Ascending and Descending

Once these steps are complete, navigation measurements and two-way data transfer commence.

Doppler Navigation Data

The uplink carrier frequency is precisely referenced to a maser clock at the DSN station. The downlink carrier from the spacecraft is then precisely phase referenced to the same maser to produce the Doppler data type. This is a measure of how fast the DSN station and spacecraft are moving with respect to each other and can be measured with a precision equivalent to a fraction of a millimeter per second. In processing this data, navigators compare the measured carrier phase to the “predicted” or “model” carrier phase and use this information to correct the assumed state vector of the spacecraft. Doppler data is most useful when there is a measurable change in the value such as is experienced when a spacecraft is in orbit about or passing near Earth, moon, or a planet. The Doppler signature from INSPIRE as it drifts slowly away from Earth is expected to be comparatively benign.

Ranging Navigation Data

During a tracking session, it is possible to make an absolute range measurement of distance from the DSN station to the spacecraft. The station modulates a series of sinusoidal ranging tones onto the uplink carrier. This modulation is detected at baseband in Iris and re-modulated onto the downlink non-regeneratively. The highest frequency ranging tone used is about 1 MHz and has a wavelength of about 300 meters. Other tones at longer wavelengths are used in sequence, the returned phase of each being measured precisely on Earth. The resulting collection of phase measurements is then used to find the absolute distance to the spacecraft with an ambiguity of several tens of kilometers. As the predicted position of the spacecraft is typically within several tens of kilometers of correct, this data is adequate to refine range knowledge to around a meter.

A “pseudo noise” ranging type is also available at the DSN that can be used in similar fashion.

Future versions of Iris will support “regenerative” ranging in which the uplink modulation is used as a reference to generate a clean ranging tone onboard for modulation on the downlink, without inclusion of the receiver noise in the uplink passband.

A nano-second level “transponder delay” calibration is needed to reach the highest accuracy available from ranging. Such a calibration measurement is performed during DSN compatibility testing.

Delta-DOR Navigation

The Delta-Differential One-Way Ranging (Delta-DOR) data type is used to find highly accurate plane-of-sky locations for spacecraft. The spacecraft transmitter modulates a high frequency signal onto the carrier (usually around 19 MHz) that is measured, broadband, at the DSN site. The station slews back and forth between the spacecraft and nearby quasars, making similar broadband measurements of both, to differentially determine the plane of sky location of the spacecraft. Delta-DOR will be supported on future versions of Iris.

Navigating with the DSN

DSN station locations are known to a few centimeters and are corrected for many observable errors including media (ionosphere and atmosphere), instrumental signal delays, chaotic terms in Earth rotation, and even plate tectonics! These accurate locations and world-class atomic clocks (masers) are the foundation for the accuracy of these navigation processes. Since the navigation techniques depend on highly accurate equipment on Earth, equipment onboard the spacecraft does not need to be so high performance.

Navigation data types used are selected based on project navigation requirements and budget. INSPIRE will use Doppler and ranging types.

As all data types are more precise if averaged or “integrated” over long uninterrupted periods. A typical tracking pass for a deep space object at low signal levels lasts for one to eight hours. It is also possible to hand off to other DSN stations (as the Earth rotates) for longer tracking arcs.

To support these tracking arcs, Iris must remain in full transpond mode, drawing full power, for hours at a time. This requires the spacecraft power budget to maintain the 12.75 W load steady state and the spacecraft thermal design to reject much of that power as heat, also in steady state.

Although the CubeSat paradigm for Earth orbit is to only operate the transmitter continuously for brief periods (several minutes) over ground stations, deep spacecraft must operate their transmitters for hours at a time. Typically, the spacecraft transmitter and receiver remain on and operating at 100% duty cycle throughout the mission life of years or decades. This facilitates recovery of the spacecraft for tracking and communications sessions.

On the INSPIRE Iris, although INSPIRE and Iris individually had adequate thermal designs, they were not initially connected in a way that removed the heat

from Iris boards efficiently enough. It was necessary to redesign the transmitter and receiver covers and the associated spacecraft mechanical interface to reduce the steady state operating temperature into an acceptable range. Further thermal and electrical efficiency improvements are planned for future versions of Iris.

Communication

During passes, uplink and downlink communication are also supported at the rates and modulations discussed in the next section. In communication modes where carrier is present, either where data is modulated onto a subcarrier or where the modulation index of data modulated directly onto the main carrier is such that there is residual carrier for Doppler tracking, it is possible to navigate and communicate at the same time. Iris for INSPIRE supports simultaneous navigation and communication except at the highest data rate, which is direct carrier modulated with fully suppressed carrier (modulation index of 90 degrees).

Iris Specifications

The uplink to Iris is 1000 bits per second bi-phase modulated onto a 16 KHz subcarrier modulated on the uplink carrier. Receive frames are buffered on Iris and sent to C&DH for deframing.

Other uplink rates are supported by Iris modems, but only the 1000 bps is used and tested for INSPIRE.

Only one frame size (2072 bits) is used on INSPIRE for developmental and testing simplicity. The Iris transponder itself will support other Consultative Committee for Space Data Systems (CCSDS) [3] frame sizes and formats as needed. Uplink frames are Reed Solomon (255, 223) encoded. Decoding is provided by MTIF.

Downlinks from Iris are supported at multiple rates. 62.5, 250, 1000, and 4000 bps are BPSK modulated onto a 25 KHz subcarrier. Rates of 16000 and 64102 bps are modulated onto a 281.25 MHz subcarrier, and 260,416 bps is modulated directly onto the X-Band carrier. (The two highest rates are slightly non-standard. This will be corrected in future versions of Iris.) Downlink frames are convolutional encoded ($r=1/2$, $k=7$) meaning that the modulated *symbol* rate is twice the *bit* rate. When using the highest rate, for example, 520,832 symbols per second are modulated onto the carrier.

Standard modulation rates proceed in factors of 2 up and down from 1000 bps. Although Iris signal processing supports all standard rates, only half of them were tested for INSPIRE in order to reduce DSN compatibility test time.

Selection of a data rate depends on signal strength and signal to noise ratio (SNR) at the receiver. Early in the mission when the spacecraft are near Earth, the higher rates will be used to return higher volumes of data, such as pictures. Later, as the requirements distance of 1.5 M km is reached and passed, the rate will be slowed accordingly. INSPIRE is expected to operate at 250 bps or greater at the requirement distance.

As there is ample power available for DSN transmitters and as there is no re-configurability built into the INSPIRE Iris that would require a large upload of program data, the uplink rate on INSPIRE does not need to be large or adjustable.

In-flight re-configurability will be added in future Iris versions.

Signal Processing in FPGA

All of the modulation schemes are implemented as baseband signal processing in the Virtex 5 FPGA, including the correct carrier frequency shift of the downlink carrier to match the uplink carrier frequency at the 880/749 turnaround ratio, to within a few microHertz. Only two frequencies are generated by PLL onboard, the receive down-conversion frequency and the transmit frequency. After down conversion, the FPGA operates on the uplink signal at a frequency of several MHz, detecting and locking on the carrier, measuring its phase to feed frequency adjustments into the downlink frequency and phase generation algorithm, detecting and removing the subcarrier, and finally detecting, decoding and sequentially buffering uplink bits. The signal processing involved provides internal, digital automatic gain control (AGC) to several of these demodulation stages and also provides an analog AGC output signal in the form of a variable width pulse train that is smoothed in an op-amp integrator and applied to analog RF gain stages.

Similarly all of the carrier and subcarrier modulations described above are performed on the downlink signal at an IF of about 2 MHz (as adjusted for coherence with uplink) and are provided as modulation to the PLL generated downlink carrier about 2 MHz away from the intended frequency. All of these signal processing manipulations result in a stream of “I and Q” (“inphase” and “quadrature”) signals that proceed to the X-Band vector modulator.

The 50 MHz TCXO used on Iris V1 (an inexpensive computer crystal) does not have sufficiently low phase noise to be a good reference for phase referencing the ultimate X-Band downlink signal. This is mitigated by several factors. First, the absolute frequency of the non-coherent downlink (that is, before a DSN uplink is

not present) is unimportant as long as it is within the 200 KHz search window (Figure 10). The drift of the crystal is unimportant as long as it is sufficiently slow, comparable to Doppler signatures. The close-in stochastic phase noise, however, is problematic in terms of downlink acquisition at the high performance and narrow bandwidth DSN receivers. Fortunately, this close in phase noise is minimal when the temperature is very stable, as it will be when operating in the vacuum of space. It is also possible to adjust the DSN receiver parameters to accommodate a noisier non-coherent downlink signal if necessary, at some cost in SNR.

Once Iris is acquired by the DSN and coherence with an uplink is established, the uplink signal is extremely stable (modified only by media effects and Doppler) and the signal processing in FPGA easily tracks out local reference oscillator instabilities, substantially removing them from the downlink.

PROJECTED CAPABILITIES

Potential Missions

Several deep space CubeSat and nanoSpacecraft missions now in study have baselined Iris as their communications and navigation transponder. Most of these would go greater distances and all of them would need to last in space longer than the 90 day baseline mission of INSPIRE. One improvement needed for longer duration missions is radiation hardening. Although the Iris transponder for INSPIRE was built from COTS parts, these parts have radiation hard versions and a new more hardened version of Iris is now in the design phase. Several other improvements, including electrical and thermal efficiencies, and power output, are also in the new design, as discussed above.

For the next design iteration, we intend to use a higher power PA as standard, but to bias its output, and therefore control its power *input*, according to mission needs as determined in mission specific trade studies.

The possibility of even higher RF power has also been considered. Iris could be used as a true “exciter” putting out about one milliWatt (0 dBm) that would be used to drive a travelling wave tube (TWT) to tens or even hundreds of watts output. These tubes operate at higher efficiency (40% DC to RF or better). Of course, a CubeSat using such a system would have to supply tens or hundreds of watts of power to the transponder / TWT combination and reject the resulting heat. If one is really considering a mission that would need higher power, see the section, “You May Not Want an Iris...” below.

Not just X-Band

Although Iris V1 was developed for X-Band, a Ka-Band exciter and receiver are in development and RF boards for UHF and S-Band are planned. The Ka-Band development is in concert with JPL's KaPDR work, which is to extend the AENEAS [4] CubeSat S-Band deployable parabola and RF feed to Ka-Band capability. Iris will also be compatible with the Ka-Band reflectarray to be demonstrated on the ISARA mission.

A UHF-capable Iris is intended as a proximity operations transponder which could interoperate with JPL developed Electra radios [5] currently at Mars (on Mars Reconnaissance Orbiter (MRO) and Mars Science Laboratory (MSL); in route to Mars on the Mars Atmosphere and Volatile Evolution spacecraft (MAVEN); and in preparation for the European Space Agency's (ESA) Trace Gas Orbiter (TGO) mission (launch in 2016) and the Mars 2020 lander. They could also interoperate locally at other planetary destinations with JPL-developed Universal Space Transponder (UST) or similarly compatible systems, both for local communication *and* navigation.

Exploring the Solar System

Figure 11 contains some estimated downlink data rates supported at various solar system destinations for various projected Iris and antenna configurations. Note that where high gain antennas (HGA) would be used, pointing requirements on the spacecraft would be comparably stringent. For example, for an antenna with a gain of 30 dB (factor of 1000), roughly speaking, a well-made and fed half-meter diameter parabola, pointing accuracy must be on the order of one degree in both dimensions to achieve most of this gain at X-Band and a quarter of that at Ka-Band.

A careful reading of this chart could lead one to believe that the "sweet spot" for a system of this type would be lunar or cis-lunar space, or proximity operations where ranges wouldn't exceed a million or a few million kilometers. But, low data rates could be returned from much greater distances and sometimes small amounts of data are all that would be required. A Mars sample return canister, for example, would only need navigation (which requires tracking but not high SNR) and a small amount of payload health data as it proceeded along its return trajectory toward Earth.

Navigation can be supported at any range shown on the chart including those below 62.5 bps, as tracking is a more robust process than data recovery.

Beginning at the left of the chart, it is estimated that an Iris with LGA could return a million bits per second to

a modest (2-meter) ground terminal from low earth orbit, 10,000 bps from Geosynchronous Earth Orbit (GEO) or about 50 bps from the moon. INSPIRE itself is expected to return data from at least 5 million km to 34 meter DSN stations and some amount of data from lunar and further distances to a smaller university based ground station (see "The DSN and Earth Station Partnerships" below.)

A 2-Watt Iris with a medium gain antenna (on the order of 20 dB or a factor of 100) could return 1000 bps from a near Earth asteroid or 62.5 bps from Mars.

Finally, using the half meter KaPDR antenna, all the best coding techniques, and the 70 meter DSN stations, an Iris could return a few hundred bps from Jupiter and beyond.

Data rates below 62.5 bps are also possible by using "tones" or "semaphores", one of many possible low data rate techniques that can easily be implemented in Iris baseband signal processing.

In all of these cases, the uplink capability of the DSN is not considered a limitation. Plenty of power (many kilowatts) is available on Earth and command data rates can be quite low and still be effective.

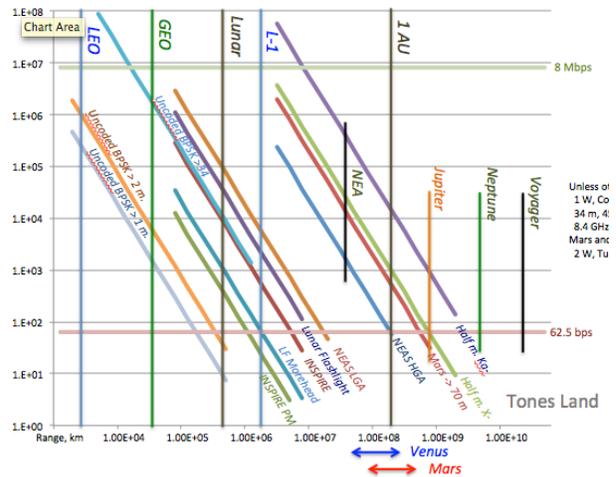


Figure 11: Estimated Link Rates for Various Iris Configurations in Various Solar System Locations

But, You May Not Want an Iris....

Missions going much beyond the inner solar system would not be made dramatically less expensive by the P-POD (Poly PicoSatellite Deployer) that has enabled access to Low Earth Orbit (LEO) for many university and small commercial projects. Space is nearly unimaginably vast, and any attempted trip to a truly distant location, like Jupiter or Saturn would probably

only be attempted with larger missions for some time to come. These missions do not require the tight volume, mass, and power requirements enabled by Iris and they should use the larger, harder transponders available for such missions, in particular the Universal Space Transponder (UST), now in development at JPL. UST is about ten times as large and massive as Iris and uses roughly ten times the power. Most importantly, UST is hardened for long duration in truly deep space, years of transit followed by years of science, continuously operating throughout.

On the other hand, Iris and UST share all the same signal processing schemes and, with respect to DSN compatibility, have comparable capabilities.

The DSN and Earth Station Partnerships

While Iris was designed for compatibility with the existing DSN (Figure 12), other large aperture capabilities, either for high data rates in the Earth vicinity, or for deep space tracking apart from the DSN, are planned or contemplated.

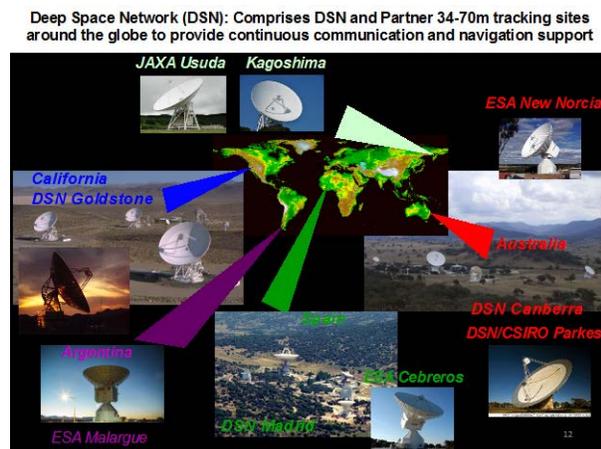


Figure 12: DSN Overview Information

The DSN is eager to support all missions of any type that go to deep space and is working at this time to make the process for support of non-NASA small spacecraft projects more tractable. While the DSN is a world-class facility pushing the state of the art in every important parameter, its capacity may prove to be limited if small spacecraft for deep space become very popular. [6]

As institutions contemplate joining the world of deep space tracking, we highly encourage them to do so in a Deep Space Network compatible way. This has several advantages. First, DSN and DSN compatible users would be able to aid each other as needed, in emergencies or otherwise. They would also be able to compare operational techniques and results. The

spacecraft implementer will only have to support the established standard rather than that *plus* something different.

While university based or commercial facilities may never rival the DSN for position and timing precision, low gain over temperature figure of merit (G/T) or high uplink power, there will be missions that can function adequately on less.

One likely paradigm now in contemplation is to have missions be DSN compatible and controlled from DSN uplinks, but to have them download large amounts of data slowly (i.e., from great distance) to apertures with less schedule competition, such as already exist at universities. Such stations may also be able to participate as additional downlink sites for navigation tracking, geometrically strengthening solutions for near Earth operations.

To build a station toward DSN compatibility, we recommend the following broad steps:

Receive 8.4 GHz, including antenna feeds, LNAs, and downconverters. At IF use software defined radios (SDR) to implement demodulators and CCSDS protocols.

Add a “good” frequency reference and participate in 3-way navigation. Share data with JPL navigators to determine system performance.

Uplink. Set up antennas, amplifiers, upconverters, and an SDR IF for transmitting at 7.2 GHz. In addition, this will require licensing and safety evaluations. Again, cooperate and collaborate with DSN and JPL as needed for scheduling and data analysis.

SUMMARY

Iris is the first DSN Compatible, CubeSat Compatible transponder. Something like this would be needed by anyone sending a CubeSat or small spacecraft to deep space.

Transponders in deep space have much higher duty cycles (perhaps 100%) than radios or transceivers on CubeSats in earth orbit. This has significant power budget and thermal implications to the host spacecraft.

Navigating in deep space is done with the same equipment that is used for communications – a transponder. GPS and NORAD are not available very far from Earth.

Earth stations should be DSN compatible to the extent possible for collaboration and mission safety reasons.

Your mission may be bigger than a CubeSat. You might really want or need a UST.

Based on INSPIRE development and, later, operational experience, numerous improvements are planned for Iris that would improve its capacity to support longer, more distant missions.

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