INTRODUCTION:

Title of the candidate technology: X-Band Phased Array Antenna (XPAA)

ADT Lead: Kenneth Perko, GSFC, 301-286-6375

Sponsoring IPDT: Communications

Category of proposed use: Category II

Supplying organization: Boeing Defense and Space Group

Primary technology candidate contact: Dr. Gary E. Miller, 206-773-2963

Useful secondary contacts: Dr. Geoffrey O. White, Boeing, 206-657-5801
Stephen A Townes, JPL, 818-354-7525

BACKGROUND:

Characterize the candidate technology: (What is it; how does it work; where does it go, etc.)

Phased array antennas with electronically scanned beams and associated high-efficiency RF power amplifiers are seen as a solution to the problems associated with providing high gain for science downlinks without the deployable structures, moving parts and torque disturbances that are associated with current mechanically steered high-gain antennas.

The phased array antenna for this application is composed of a flat grid of many radiating elements whose transmitted signals combine spatially to produce the desire antenna directivity (gain). The phases of each of these radiating elements is varied by computer to point its beam in the desired direction. This antenna takes the place of the traditional parabolic antenna, which is used on many satellites. For EO-1, the radiating elements are combined with low power, high-efficiency solid sate amplifiers (as mentioned above) to achieve the required RF power output level. The antenna is nadir mounted to allow communications with ground stations.

How will the utilization of this technology enhance science in the 21st Century?

When compared to many past and current missions, future science spacecraft will be extremely compact, and will have limited resources available in terms of weight, space, and DC power for the communications subsystem. This departure from past designs necessitates a re-evaluation of all aspects of the mission, including the enabling space and ground systems. One part of this re-evaluation concerns the use of higher frequency band systems, such as X and Ka-bands, that represent a major shift in NASA's space
communications frequencies. Despite their small size, these spacecraft will generate multi-terabit daily data streams of science data which must be returned to Earth. It is also anticipated that increasing numbers of end users such as universities will desire direct access to spacecraft instruments using low-cost ground stations, which will increase the burden on the spacecraft end of the communications link.

These operations will require peak data rates of tens to hundreds of megabits/second and must be accomplished with high-gain onboard antennas of a size dictated by the small dimensions of the new spacecraft. These size restrictions and the increasing international competition for RF spectrum will ultimately force all users to utilize current allocations more efficiently and develop the technology to use frequencies such as X-band (8 GHz) and Ka-band (25-27 GHz).

Why is this considered a revolutionary technology development?

The X-band phased array antenna offers significant mass and volume reductions over current systems of equivalent performance at similar or lower costs. Flying this type of antenna on EO-1 would represent a major capability step for NASA and other satellite designers/users.

In addition, demonstration of spacecraft operations with phased array transmit antennas at X-band using existing ground facilities will serve as a pathfinder toward ultimate use of Ka-band arrays for science downlinks.

Why is a space flight necessary to validate this technology?

Necessary validation of this technology goes beyond the demonstration that the hardware will perform in space. The significant benefits of phased arrays, besides reducing spacecraft impacts of flying high performance communications links, involve operational benefits of simultaneous instrument data collection and downlink communication, reduced contact times and minimized ground station requirements, as well as reduced I&T costs due to the elimination of articulating mechanisms. In sum, these benefits have the potential major cost savings during the life of a project. The phased array technology proposed is based on an aeronautical system that has significantly different operating environment than that of space. Space
flight testing and validation is crucial to the adoption of this potentially high payoff/lower cost technology.

PROPOSED INTEGRATION & VALIDATION APPROACH

Describe your proposed approach to incorporating this candidate technology into the NMP/EO-1 flight and justify your categorization:

This technology is proposed for Category II flight.

The phased array antenna system (XPAA) is a part of an X-band transmitting system which will provide a high rate downlink channel for the return of science data.

Engineering model phased array designs currently existing at Boeing will be used as the baseline for a flight phased array having 64 elements and an effective isotropic radiated power of 22 dBW or greater. This Boeing effort uses a modification of existing element module GaAs MMICs as well as an existing basic design for the antenna. Interfaces are a low level modulated X-band excitation, 28 Vdc power, and 1773 command and telemetry interface using the ESN.

Mechanical designs are modified as required for the spacecraft thermal and vibration environment.

Describe the approach presently in the budget:

Current plans call for the S-band GSTDN transponder to be used to downlink science data at rates of approximately 4 Mbps to an 11-meter class ground station located at Spitzbergen, Norway. The five watt transmitter will radiate through an omni-directional antenna similar to that used most LEO science missions. No antenna pointing is required. The communications link budget obtained with this hardware is satisfactory to meet the minimum mission science data return requirements.

Describe how your approach affects the current approach:

This approach does not directly affect or detract from the existing S-band approach as it provides an additional communication channel. X-band modulation and excitation functions are required in addition to the IPDT supplied XPAA. The hardware to implement these functions would be supplied by the spacecraft mission team. The low-level X-band signal from the exciter is fed to the phased array via a coaxial cable where it would be amplified and radiated. The higher gain of the phased array as compared to the S-band system enables operational quality communications links to the ground station at a rate of 105 Mbps.

Describe the interface with the spacecraft or the Advanced Land Imager (ALI):

The spacecraft interface for commanding is via a GSFC provided ESN imbedded in the contractor supplied 1773 interface. Low level X-band excitation (< 250 milliwatts) from the transmitter is required to drive the XPAA, via coaxial cable. An 11" by 13" area is required on the nadir panel for mounting the array (3" depth).

Describe the impacts on the spacecraft or the ALI:

Communication link rates compared to the S-band downlink are be increased by 10-15 dB, depending on final configurations chosen. Data rates are increased to 105 Mbps while providing link margins that are robust and representative of operational missions. Contact time requirements can be correspondingly reduced. Antenna beam pointing in real time (approximately 1 second updates) is required via the 1773 ESN interface. Overall weight and power requirements are increased (see below).

***Describe your proposed approach to the integration and test of the* technology:**

Tested engineering models of a single transmit element and a 16 element subarray have been delivered in sequence to LeRC for evaluation and verification of their RF characteristics prior to contract award. Integration and test of the flight model after delivery will be accomplished in a manner similar to past communications systems. Antenna pattern performance will not be evaluated once the antenna is integrated with the spacecraft, but output power, spectrum, and data characteristics will be evaluated with a test hood, which fits over the antenna and couples the radiated power to test instrumentation. Since the exciter/modulator is supplied by the flight team, many I&T functions can be executed (particularly during the "flat-sat" phase) without the actual antenna.

Describe your proposed approach to operations in general and to validation in particular for the candidate technology:

The XPAA based X-band transmitter will provide downlinks of science data to Spitzbergen at rates of 105 Mbps using QPSK modulation. This rate and format is proposed to minimize or eliminate modifications to existing ground station equipment for this mission. During a single 8 minute pass per day (480 seconds), up to 50 Gigabits of data can be transferred at 105 Mbps. Should the X-band system fail on orbit, S-band transmission of data at 4 Mbps Fairbanks is proposed. Preliminary estimates indicate that for a 15
Gigabit minimum daily downlink requirement, Fairbanks alone will be able to receive the data.

Validation of the phased array antenna subsystem will be accomplished by analysis of the science data from EO-1 at the ground station. For each pass within the accepted slant range to the ground station, the XPAA will be commanded to transmit the data stream. As the XPAA is operating, telemetry data on XPAA currents, voltages, and temperatures will be forwarded to the C&DH via the 1773 interface for subsequent return to the ground and analysis. Bit and burst error rates can be evaluated by comparing Reed Solomon corrected and uncorrected science data frames. No special data streams are required for this analysis. In addition, received signal to noise levels will be evaluated during a number of passes to determine the peak-of-beam scan performance of the array. If necessary, additional performance validation tests could be performed on dedicated passes; e.g. command the antenna beam to scan or nutate during the pass and thus create an amplitude modulation on the data stream. From these data, additional antenna pattern and sidelobe information can be derived.

Describe the specific impacts on spacecraft resources:

Mass:	+5kg XPAA +4kg Exciter
Power:	+45W peak while radiating for XPAA
Volume:	+ 429 in3 (11" x 13" x 3") XPAA, including controller
Thermal:	+45 W transferred from XPAA to s/c mounting
Propellant:	N/A
C&DH:	Accommodation of 105 Mbps data rate
Communications:	Addition of X-band exciter for 105 Mbps data rate link
ACS/pointing:	Pointing commands (~1/sec.) required from S/C via 1773 interface
Flight S/W:	Pointing algorithms
Environmental:	Baseplate maintained between 0 and 40 degrees C.

Describe any facilities issues or special GSE or FSE:

Item	Provider
Essential Services Node	GSFC/Code 735
X-band exciter	Swales/Litton
Test Hood / Coupler	Boeing
BER Test Set*	Swales/Litton
Lab Test Downconverter / Demod*	Swales/Litton

*These items are required for any communications system which would be flown.

AVAILABILITY:

Identify the earliest date when an ETU or comparable demonstration hardware (and/or software) would be deliverable to the project:

Tested engineering models of a single transmit element and a 16 element subarray have been delivered in sequence to LeRC in November and December 1996, and again in March 1997, respectively, for valuation and verification of their RF characteristics.

Identify the earliest date when flight hardware (and/or software) would be deliverable to the project:

Current planning date for the flight unit (hardware and software) is 18 months after contract award, or October 1998.

RECOMMENDED DISPOSITION

Justify the incorporation of this technology on the NMP/EO-1 flight. Weigh the benefits described in the introduction against the accommodation impacts associated with budget, schedule, and overall risk. Is the NMP/EO-1 flight a suitable, cost-effective testbed for this candidate technology? How well does this candidate technology contribute to the most robust technology mission that we can afford?

The phased array technology was unanimously ranked as highest priority by the Communications IPDT for validation on the first EO mission (EO-1). This ranking was based on the significant power, mass, and costs benefits that would be derived over existing mechanical systems. Furthermore, demonstration of this technology would place NASA in a leading technology role, with potential spin-off to commercial and other government applications.

EO-1 is representative of the high data rate missions of the future that would directly benefit from the phased array-based transmitter. Thus the opportunity provided by EO-1 for validation is extremely timely, is very characteristic of small spacecraft, and is very cost effective for NASA.

The proposed flight approach of the X-band phased array for the primary science data downlink will greatly help the adoption of this technology within NASA, while the use of the S-band transponder, which is basic equipment on EO-1, as a transmitter back-up, minimizes risk of the mission. Additionally, Boeing's current level of phased array development and general commitment to leadership in this technology, is a strong risk mitigation factor.

The X-band phased-array transmitter complements the EO-1 instrument well and affords a high data rate capability that could only be achieved by a higher cost, higher complexity, mechanical system. While some uncertainties remain in terms of integration costs, the proposed acquisition strategy mitigates the associated cost and schedule risks.

As a result, it was recommended that this technology be incorporated for flight on New Millennium EO-1.