X-Band Phased Array Antenna (XPAA) Summary

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The Earth Observing-1 (EO-1) mission provides for the on-orbit demonstration of a high data rate, low-mass X-band Phased Array Antenna (XPAA) for returning to ground the imaging data stored in the EO-1 solid-state recorder. The nominal mission life for EO-1 was one year. Figure 1 shows an exploded view of the EO-1 spacecraft and illustrates the location of the XPAA. The XPAA, designed and built by Boeing's Phantom Works, combines the functions of antenna, 2-axis gimbal, gimbal controller, and solid-state power amplifier (SSPA) in a single, low-cost package. Phased array technology offers significant benefits over mechanically pointed parabolic antennas, including the elimination of deployable structures, moving parts, and the torque disturbances that moving antennas impart to the spacecraft. The latter feature results in the conservation of spacecraft power and enables the ability to take precision optical measurements while simultaneously transmitting high-rate data. The division of the SSPA function into 64 individual element amplifiers enhances the reliability and fault tolerance of the X-band downlink system.

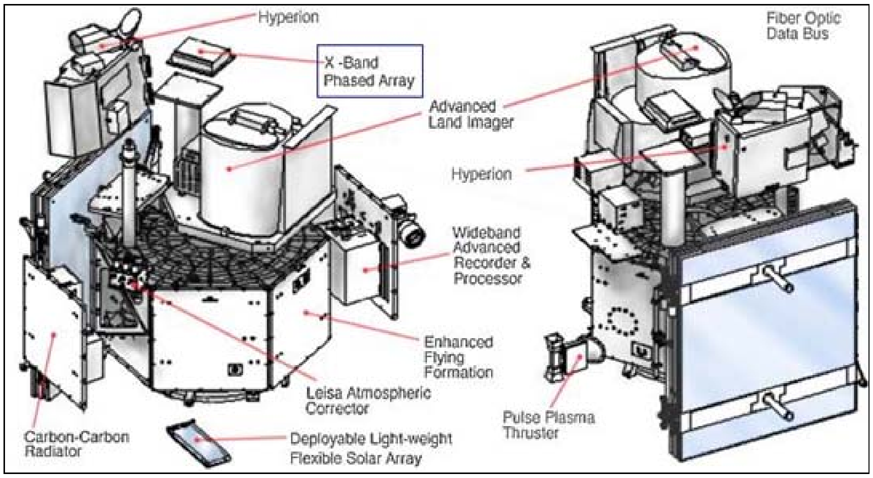

Figure 1. Exploded view of EO-1 spacecraft indicating the location of the XPAA at the end of a boom on the nadir-facing panel.

The antenna operates at a frequency of 8225 MHz, transmits data at 105 Mbps with a minimum effective isotropic radiated power (EIRP) of 22 dBW, has an integral controller and power conditioner, communicates with the spacecraft over a MIL-STD-1773 fiber-optic data bus, and is fully space qualified. The antenna aperture consists of an 8 x 8 array of modules, each comprising a dielectrically loaded, circular waveguide, two orthogonal antenna feeds, a phase shifter, and a dual power amplifier. The 64 modules are mounted in a printed wiring board, which distributes radio frequency (RF) excitation, logic control signals, and power to each module. The array and remote service node (RSN) are located in a single 12 x 13 x 2.9-inch enclosure with a total mass of 5.5 kg. Figure 2 presents a photograph of the XPAA prior to spacecraft integration.

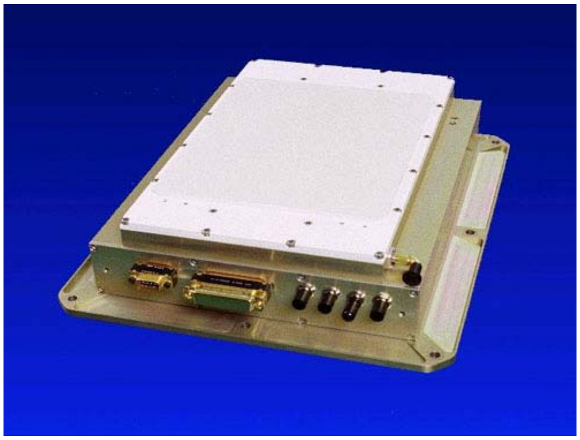

Figure 2. Photograph of the XPAA prior to spacecraft integration.

A system configuration diagram is presented in Figure 3.

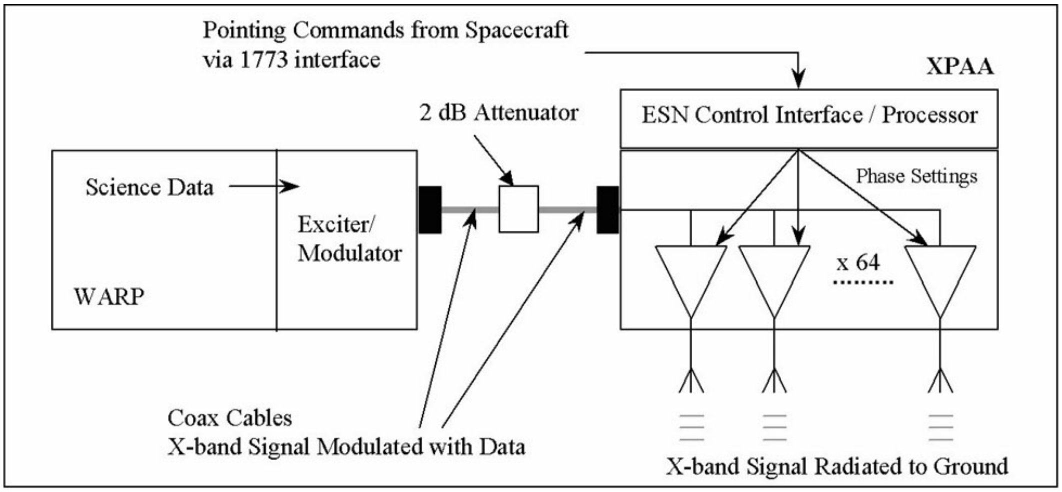

Figure 3. EO-1 X-band system configuration diagram.

The validation plan for the XPAA called for collecting data to meet the following objectives:

- Validate the communications link error performance.
- Validate the antenna pattern scan performance of the phased array.
- Validate the performance and reliability of the antenna's electronics and software in the space environment.

The following discussion summarizes the results obtained from the validation activity.

The phased array radiation patterns were measured, before and after delivery by Boeing to Goddard Space Flight Center (GSFC), by the planar near field technique. The tests confirmed the radiation pattern beamwidth and sidelobe levels, and verified commanded scan positions.

The EO-1 XPAA validation of bit error performance found no evidence of bit errors inherent to the XPAA. Burst error statistics were consistent with the differential coding performed on the spacecraft. Data collected with various background noise levels indicated that phase shifts associated with steering the beams on the phased array do not interfere with the phase shift keying of data bits on the link. The Reed-Solomon and differential coding was adequate to correct errors within the power of the Reed-Solomon code.

EO-1 downlinks to 11.3-meter dishes in Poker Flats, Alaska; Svalbard, Norway; and Hobart, Australia, have over 10 dB of margin and are virtually error-free over 10-minute passes. The upper limit to the bit error rate (BER) is consequently 1.6×10^{-11}. The actual estimated BERs span the range from 10^{-7} to 7×10^{-3}, which is close to the limit of the Reed-Solomon code's ability to correct random errors.

The minimum required EIRP of 22 dBW was achieved at the maximum scan angle of 60° from normal.

For antenna pattern measurement, the XPAA was set to point its beam to boresight (elevation angle θ=0, azimuth angle ϕ=0) during a near-overhead pass to the GSFC (Bldg. 28) 3-meter antenna ground station. Figure 4 shows the resulting measured pattern that was produced, in black squares. The red diamond data that is overlayed is the equivalent curved cut obtained from near field scans prior to launch.

The on-orbit performance of the XPAA was validated, first and foremost, by the conduct of successful science downlinks. These were routinely achieved within the first two months of the mission. The XPAA's antenna pattern and performance, while scanning, were also measured from the ground and compared with pre-launch data.

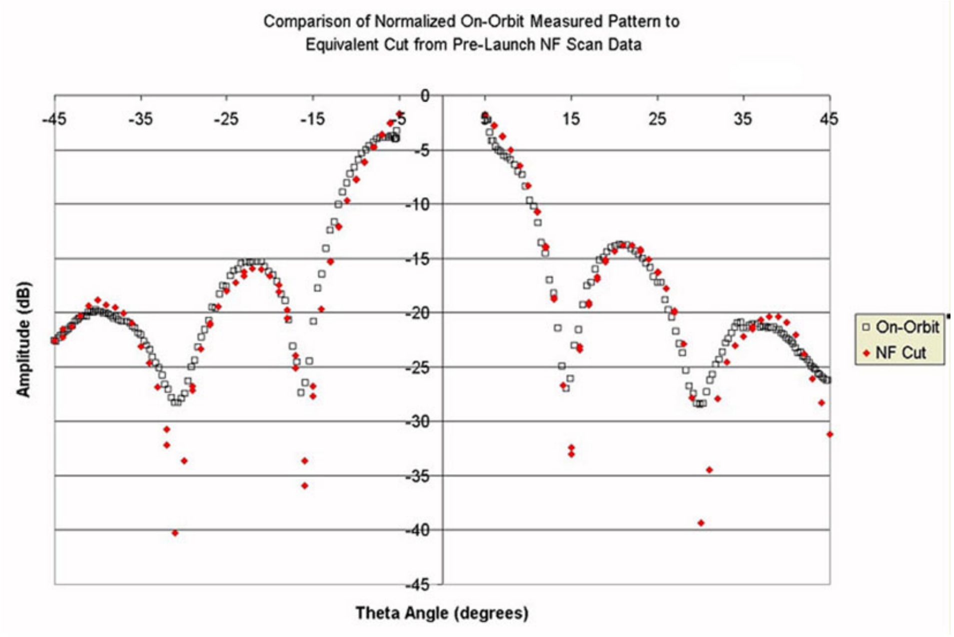

Figure 4. Antenna pattern from EO-1 after launch, adjusted for range and path losses, compared to equivalent cut derived from pre-launch near field measurement data.

For scan-performance measurement, the XPAA was operated normally; its beam pointed every half-second toward the ground station by commands from EO-1's attitude control system. As EO-1 passed over the ground station, received power varied as the EIRP from the XPAA changed due to range and scan angle effects. The 11-meter antenna at Wallops Flight Facility was used to collect this data. Figure 5 depicts the results from one such test of the XPAA. Curves showing the elevation of EO-1 as seen from the ground during the pass, and the EIRP expected from XPAA, and published characteristics for the Wallops ground station were used in calculating the predicted signal-to-noise ratio. The calculated signal-to-noise ratios show surprisingly good agreement with the measured values.

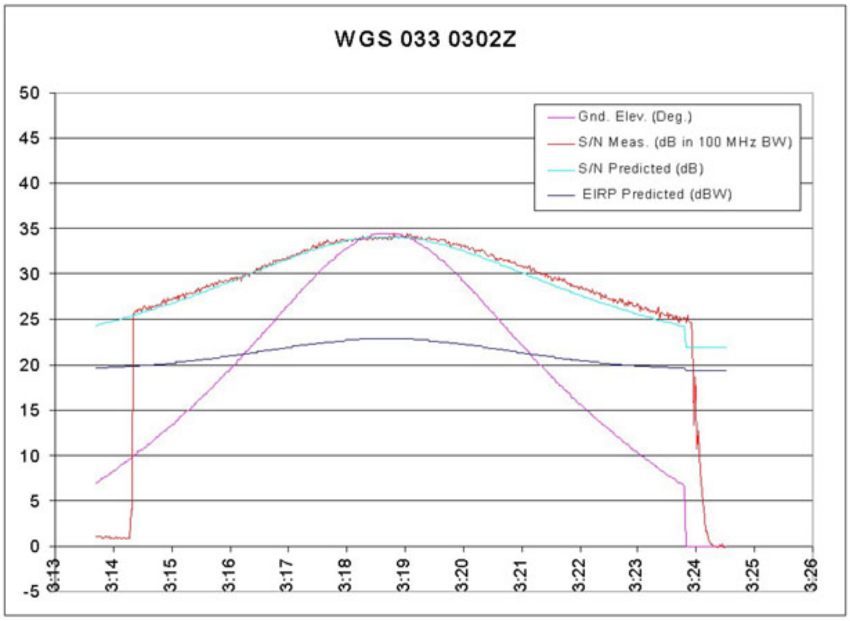

Figure 5. Predicted and actual signal-to-noise ratios at the Wallops ground station during an EO-1 pass. The predicted level includes adjustments for slant range and EIRP variation of the XPAA due to scan angle.

Throughout the first year of on-orbit operation, the XPAA has been operated at a rate more than five times the original requirement, without difficulty. All tests show a consistent performance throughout the life cycle of the antenna. Final measurements of the array on-orbit using a ground station have provided data that is consistent with the pre-launch results, confirming the successful end-to-end RF performance of the XPAA. By all measures made so far, the XPAA is performing flawlessly. It was designed to meet a requirement of one downlink per day, delivering 40 Gigabits per day to the ground. The EO-1 project is currently receiving more than 160 Gigabits of data per day during 4-5 downlinks via the X-band system.