MEASUREMENT OF THE EARTH-OBSERVER-1 SATELLITE X-BAND PHASED ARRAY

Kenneth Perko[(1)], Louis Dod[(2)], and John Demas[(3)]
(1) Goddard Space Flight Center, Greenbelt, Maryland, (2) Swales Aerospace, Beltsville, Maryland, (3) Near-Field Systems, Carson, California

ABSTRACT

The recent launch and successful orbiting of the EO-1 Satellite has provided an opportunity to validate the performance of a newly developed X-Band transmit-only phased array aboard the satellite. This paper will compare results of planar near-field testing before and after spacecraft installation as well as on-orbit pattern characterization. The transmit-only array is used as a high data rate antenna for relaying scientific data from the satellite to earth stations. The antenna contains distributed solid-state amplifiers behind each antenna element that cannot be monitored except for radiation pattern measurements. A unique portable planar near-field scanner allows both radiation pattern measurements and also diagnostics of array aperture distribution before and after environmental testing over the ground-integration and pre-launch testing of the satellite. The antenna beam scanning software was confirmed from actual pattern measurements of the scanned beam positions during the spacecraft assembly testing. The scanned radiation patterns on-orbit were compared to the near-field patterns made before launch to confirm the antenna performance. The near-field measurement scanner has provided a versatile testing method for satellite high gain data-link antennas.
Keywords: Antenna Measurements, Phased Arrays, Near Field Scanners, Planar Near Field, Data Acquisition.

1.0 Introduction

This paper describes the successful RF testing of a high-data rate transmit-only antenna for the Earth Observer-1 Satellite launched from Vandenberg AFB in November 2000. The phased array antenna operates at an X-Band frequency and provides a high data-rate downlink from the satellite to earth ground stations. The requirement for increased science data rates from small satellites has caused the development of high-gain phased arrays that are electronically scanned without mechanical motion. The National Aeronautics and Space Administration, (NASA), has developed antennas spacecraft phased array antennas at X-, Ku-, and Ka-band frequencies for this requirement. This X-Band antenna is the first phased array to be flown from this development program. Boeing Phantom Works developed the antenna under NASA contract. The antenna was delivered to NASA after acceptance testing at Boeing Phantom Works. The antenna was then integrated into the Earth Observer Spacecraft-1 (EO-1) at Swales Aerospace. The antenna consists of 64 antenna elements, each with its own power amplifier integrated into the array package. Power dividers and phase shifters are included in the antenna feed network. A digitally modulated low-level X-band signal is input to the array. A radome covers the planar array face as shown in figure 1.

This paper will describe the antenna testing of this array. The antenna is a phased array that scans a high gain beam using phase shifters. This antenna does not require mechanical motion that must be compensated by the satellite stabilization system. Planar near field measurements were made on the phased array before installation on the spacecraft. The phased array was installed on the spacecraft and near-field testing was repeated during the spacecraft integration. The portable near-field scanner system allowed testing of the antenna on the spacecraft in large test chambers as well as at the box-level in the assembly area.

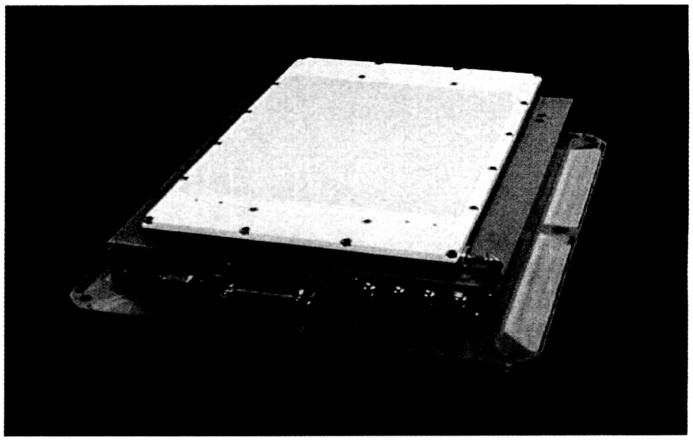

Figure 1. X-Band Phased Array Antenna

The planar near-field scanner permitted rapid non-intrusive tests of the array and provided a diagnostic tool for the assessment of the performance of the 64 solid-state amplifiers behind the 64 circularly polarized antennas in the array. There are no monitoring points for RF sampling of the transmitted signal from the array. However, the near-field measured amplitude and phase data from the full array can be back-transformed to obtain the aperture distribution of the array. The aperture distribution contains the illumination from each of the 64 antennas forming the array and the element locations and amplitudes are clearly visible in the plots from the transform as shown in figure 2. Repeated measurements during the test and integration of the spacecraft antenna provided valuable diagnostics on the illumination of the array. Figure 3 shows the antenna near-field testing on the spacecraft.

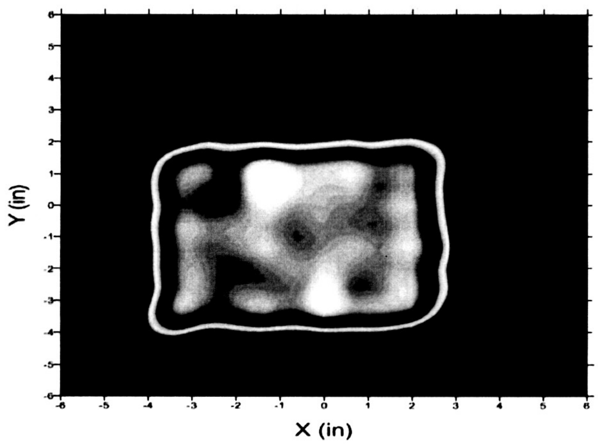

Figure 2. Phased Array Aperture Distribution from Near-Field Back-Transform.

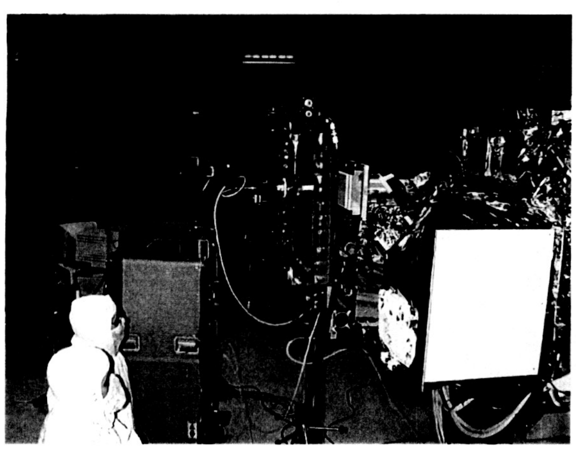

Figure 3. Near-Field Scanner measurement of the Phased Array on the EO-1 spacecraft.

2. Preflight Testing

The first pre-flight testing involved the radiation pattern and EIRP measurements of the phased array immediately after delivery from Boeing. These tests were made on the antenna alone before installation on the spacecraft. The second phase of the testing involved repeated measurement of the antenna after installation on the spacecraft. The original antenna data sets were compared to the antenna measurements while installed on the spacecraft using near-field measurements of radiation patterns and gain. Back transforms from the near-field data were used for diagnostics before and after spacecraft environmental testing. Finally, on-orbit patterns were measured using the NASA Goddard 3 meter ground station. These measurement series have confirmed the end-to-end performance of the array as it is scanned.

The post-shipping initial radiation pattern measurements of the antenna array were conducted at Swales Aerospace. The Near-Field Systems portable 2x2 scanner was installed over the antenna and horizontal scans of the antenna were performed. The amplitude contour plot data from the initial near-field measurement is shown in figure 4.

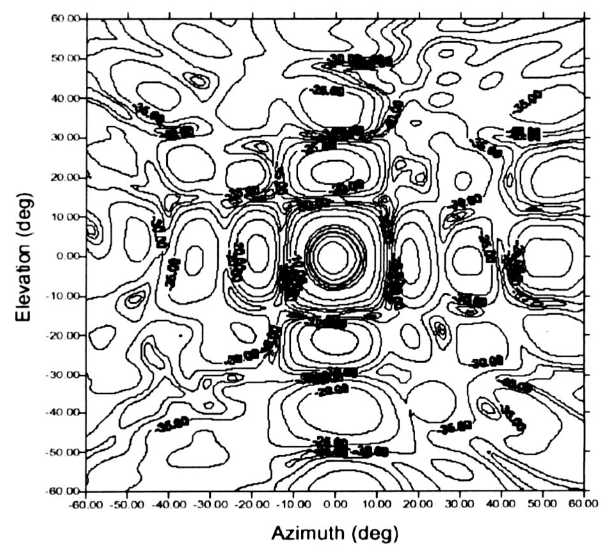

Figure 4. Phased Array Initial Measurement, Far-Field Contour Plot From Measured Near-Field Data.

The near-field measurements at Swales were compared to the radiation pattern data supplied by Boeing. There was good agreement on the pattern data and the antenna was prepared for spacecraft integration. The aperture distribution was obtained by the back transform of the near-field data as shown in figure 2.

The phased array with its embedded active amplifiers was measured for output power versus input power to determine the compression level of the active amplifiers behind each antenna element. The comparison of the data measured at Goddard and the data taken at Boeing show excellent agreement as shown in figure 5.

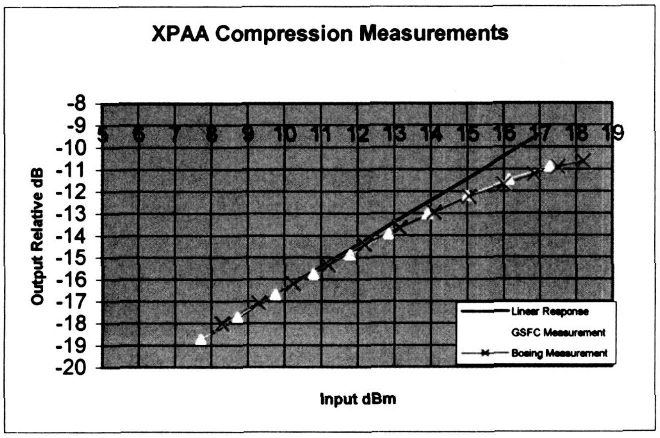

Figure 5. Compression Curves Measured by Boeing and Goddard.

Near-field measurements of the phased array were taken for various scanned beam positions. The coordinate system for the scanned antenna patterns is shown in figure 6. This measurement series allowed the testing of the flight software for the digital phase shifter setting and confirmation of the true pointing location versus prediction.

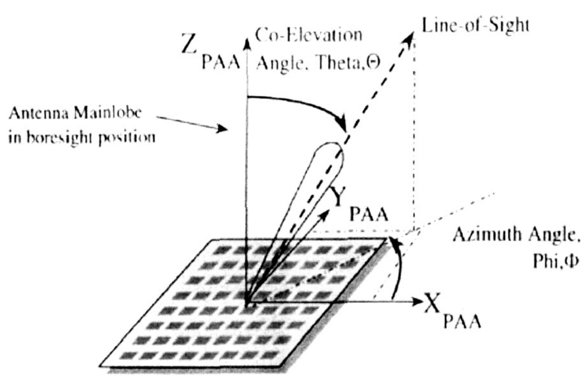

Figure 6. Coordinate System for far-Field Antenna Patterns.

The three dimensional far-field radiation patterns for four commanded scan positions are shown in figure 7. These patterns show the scanned main lobe and sidelobes for the uniform distribution array.

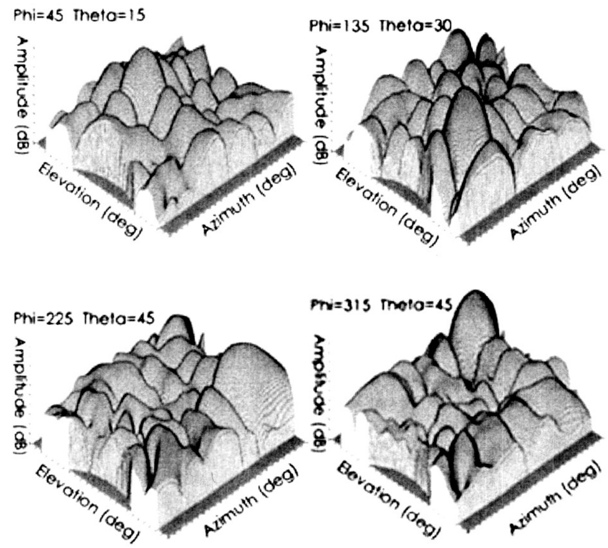

Figure 7. Three-dimensional Scan Patterns for Four Pointing Angles.

The scanned pattern data holograms provided diagnostics for future measurements of the antenna as the spacecraft underwent environmental testing such as thermal–vacuum testing and vibration testing. Figure 8 shows amplitude across the aperture as the antenna is commanded to scan position, (theta = 45, phi =315 degrees).

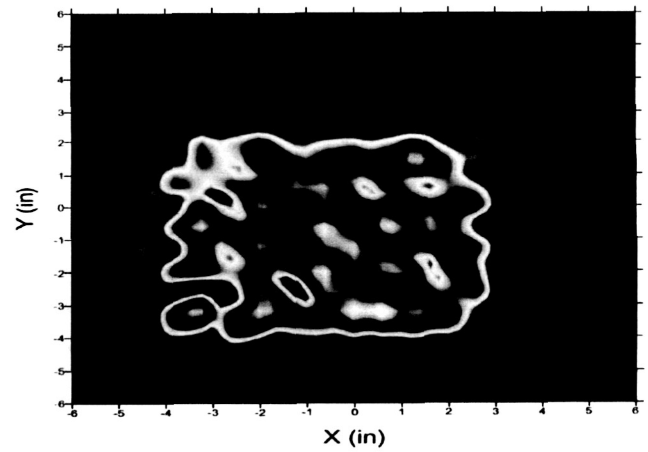

Figure 8. Aperture Amplitude for Theta = 45, Phi = 315 Degree Scan.

The phase distribution for the same scan distribution is shown in figure 9. This phase contour may be compared with the boresite beam position where the phase is uniform across the aperture as shown in figure 10.

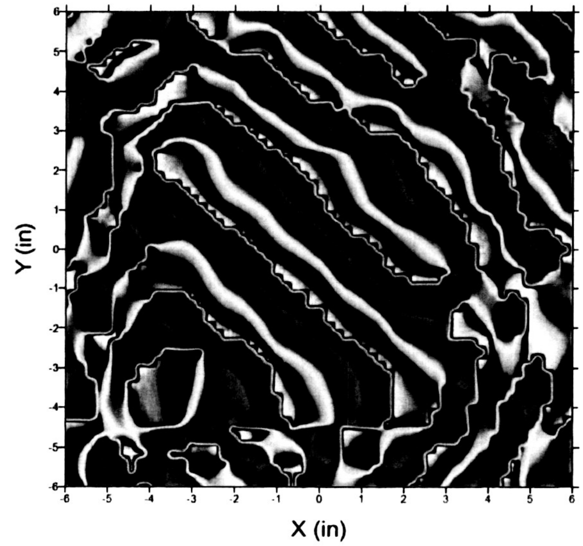

Figure 9. Aperture Phase distribution for Scan position, Theta= 45, Phi = 315 Degrees.

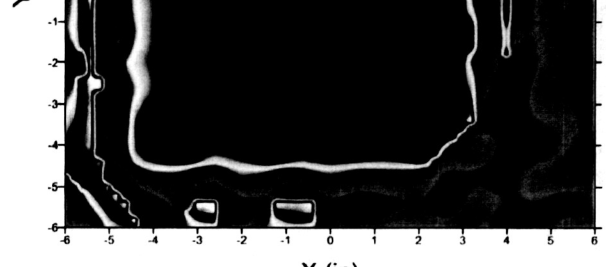

Figure 10. Aperture Phase Plot for Boresite Beam, Theta= 0, Phi = 0.

3.0 Antenna Testing on EO-1 Spacecraft

The downlink signal from the spacecraft phased array is monitored during ground testing of the spacecraft. A "hat coupler" is placed over the aperture of the X-Band Phased Array. The hat coupler is lined with absorber material and contains a small probe antenna. The coupler provides a lossy transfer of RF downlink signal for spacecraft data monitoring purposes. The coupler is useful for housekeeping data monitoring but it does not permit the measurement of the antenna as the beam scanning software is activated. The portable 2x2 near-field scanner allows the non-intrusive monitoring of the antenna scan performance during spacecraft system testing as shown in figure 3. The spacecraft is mounted on a positioner in a large clean room. The NSI portable scanner is then located near the spacecraft and positioned in front of the X-Band Phased Array aperture. The Agilent 8510C network analyzer is placed in the clean room near the scanner. Antenna near-field tests can then be performed as the spacecraft is tested and then scanner can then be quickly removed from the proximity of the spacecraft. Since the phased array has no method for RF monitoring of all of the distributed amplifiers behind each phased array antenna element, the health of the phased array package can be monitored as needed. Confirmation of the spacecraft software for the antenna pointing can also be checked before launch. The near-field measurement method using the lightweight portable planar scanner should be useful for transmit-only arrays planned for future satellites. Spacecraft antenna testing of large antennas on communications satellites involves the development of large near-field scanner systems in high-bay anechoic test chambers. These facilities are designed for testing the large communications satellite and are expensive but necessary for that class of payloads. The small satellite payload such as EO-1 with an electronically steered phased array can be tested at minimum cost and schedule using the portable scanner. The ability to use the holograms to determine the status of the antenna during the manufacture through spacecraft integration is unique to this method.

4.0 On-Orbit Antenna Testing

Initially, there were problems receiving the X-band downlink signal after launch of the EO-1 Spacecraft. These problems were traced to the ground stations and were corrected. As part of the downlink problem investigation, the radiation patterns of the X-Band antenna while on-orbit were measured using two NASA ground stations. The tests involved pointing the X-band main lobe at boresite by commanding the satellite's phased array from ground. The received power from the boresite staring antenna was then measured for selected satellite passes that passed near-nadir for the ground stations location. The power received at the ground station was corrected for path loss changes as the satellite moved over the station. The orbital path is projected on the measured pattern contour in figure 11. It can be seen that the boresite pattern is correct and that the antenna performance is confirmed. The resulting radiation pattern measured from on-orbit was then compared with the radiation pattern from the near-field tests of the array taken during spacecraft integration. The comparison of the two patterns in a rectangular plot is shown in figure 12.

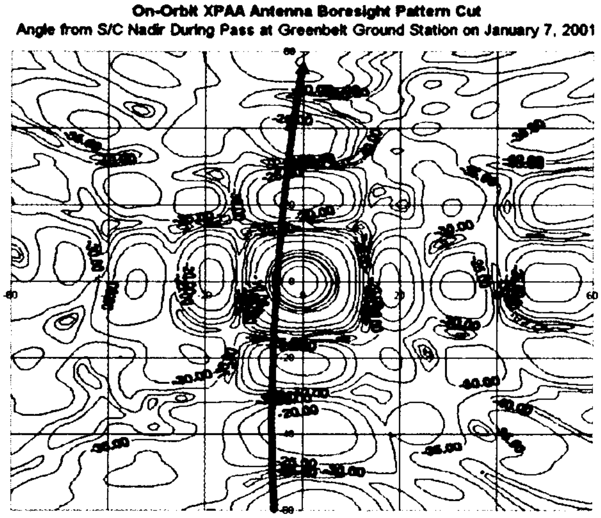

Figure 11. Measured X-Band Phased Array Pattern On-Orbit.

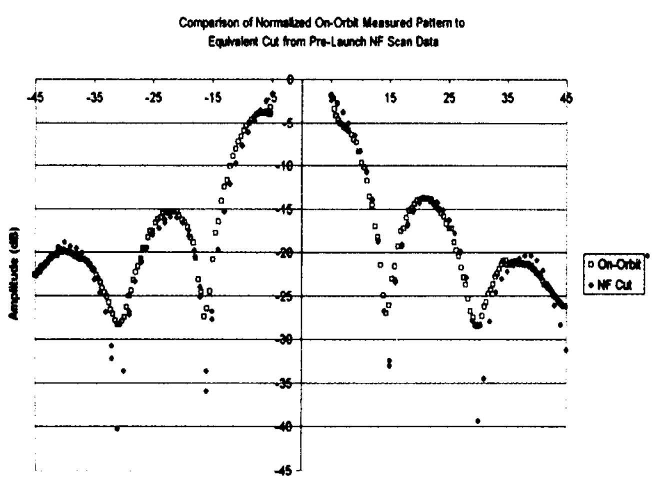

Figure 12. Comparison of On-Orbit Measured Pattern With Pre-Launch near-Field Pattern.

The comparison of the two patterns shows excellent agreement between the patterns for the main lobe and the first two sidelobes shown in the figure.

The path of the pattern cut is a curve that cuts within 5 degrees of the peak of the main beam. Figure 13 shows the resulting pattern that was produced, in black squares. The red diamond data that is overlaid is the equivalent curved cut obtained from near field scans prior to launch. The gap in the center results from the fact that the cut does not cross the peak of the beam. The deviation of the measured data near the peak of the main beam is attributed to dynamic errors in ground station antenna pointing, which are worst when the satellite is at maximum elevation.

5.0 CONCLUSIONS

Near field scanning proved to be a valuable and reliable technique for trending antenna performance throughout the mission life cycle. It was used to verify that the XPAA performed in a consistent manner throughout the spacecraft integration process. It was also used to verify the end-to-end performance of the EO-1 X-Band communications system, verifying that the antenna pointed where the attitude control system commanded.

By all measures made so far, the XPAA is performing flawlessly. It was designed to meet a requirement of one downlink per day for a year, delivering 40 Gigabits per day to the ground. The EO-1 project is currently receiving 160+ Gigabits of data per day during 4-5 downlinks via the X-Band system.

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. A NASA Ground Network station, the 11-meter antenna at GSFC/Wallops, was used to collect this data, usually in conjunction with a normal instrument data downlink. These measurements were made on clear days when rain attenuation was not a factor.

The gain of the X-Band Phased Array was measured on the spacecraft during spacecraft integration in a large clean room. The comparative gain was measured using the near-field portable scanner. The large size of the clean room and careful positioning of the spacecraft antenna in the room using a three-axis positioner allowed for reflection free measurement. A comparison with a standard gain horn in the clean room using the portable NSI near-field scanner resulted in a rapid gain measurement during the spacecraft integration testing sequence.

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