Telecommunications Antennas for the Juno Mission to Jupiter

Joseph D. Vacchione
Ronald C. Kruid
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
818-354-7253
818-393-5235
Joseph.D.Vacchione@jpl.nasa.gov
Ronald.C.Kruid@jpl.nasa.gov

Aluizio Prata, Jr.
Department of Electrical
Engineering-Electrophysics
University of Southern California
Los Angeles, CA 90089
213-740-4704
prata@vsoe.usc.edu

Luis R. Amaro
Anthony P. Mittskus
Jet Propulsion Laboratory
4800 Oak Grove Dr.
Pasadena, CA 91109
818-354-5956
818-354-5524
Luis.R.Amaro@jpl.nasa.gov
AnthonyP.Mittskus@jpl.nasa.gov

Abstract—**The Juno Mission to Jupiter requires a full sphere of coverage throughout its cruise to and mission at Jupiter. This coverage is accommodated through the use of five (5) antennas; forward facing low gain, medium gain, and high gain antennas, and an aft facing low gain antenna along with an aft mounted low gain antenna with a torus shaped antenna pattern. Three of the antennas (the forward low and medium gain antennas) are classical designs that have been employed on several prior NASA missions. Two of the antennas employ new technology developed to meet the Juno mission requirements. The new technology developed for the low gain with torus shaped radiation pattern represents a significant evolution of the bicone antenna. The high gain antenna employs a specialized surface shaping designed to broaden the antenna's main beam at Ka-band to ease the requirements on the spacecraft's attitude control system.**

TABLE OF CONTENTS

1. INTRODUCTION

The Juno mission to Jupiter carries a suite of nine (9) science instruments over the course of a six year journey to the gas giant. The onboard instruments will investigate Jupiter's origins, its interior structure, its deep atmosphere and its magnetosphere. The spacecraft is spin stabilized and carries three large solar arrays to provide power, making it the first mission to the outer planets using solar rather than a radioisotope thermoelectric generator (RTG) for power. When the spacecraft arrives at Jupiter in 2016, it will complete 32 highly elliptical orbits over the course of its one year science mission.

Throughout the cruise to Jupiter and during the scientific observation phase, the spacecraft telecommunications system will make use of five (5) separate antennas ranging in gain from approximately 6 dBic up to approximately 44 dBic (note there are several other antennas aboard the Juno spacecraft used for science instruments). While principally used for telecommunications applications to the Deep space Network (DSN) at X-band, the antennas also serve in radio science gravity experiments at both X-band and Ka-band.

The mission required a full sphere of antenna coverage in order to provide command and telemetry throughout the various mission phases. The Earth gravity assist flight path sends the spacecraft out beyond Mars orbit immediately after launch and then back toward the Earth where it uses Earth's gravity to achieve the required velocity to reach Jupiter. During this phase of the mission, all five antennas are used. Two antennas, identical aft facing and forward facing low gain antennas (LGA) are used for initial near Earth communications. When near Earth, the spinning spacecraft is sun pointed resulting in a nearly 90º angle between the spacecraft rotation axis and the Earth; an antenna with a torus shaped low gain antenna pattern, the so called Toroidal Low Gain Antenna (TLGA), is used to maintain the communications link. As the distance to Earth increases and the Earth-spacecraft angle is reduced, medium and high gain antennas are employed. After the Earth gravity assist, the spacecraft continues its cruise to Jupiter during which time, after the range increases beyond "near-Earth" distances, the spacecraft relies mostly on the earth pointed high gain antenna. Course correcting spacecraft engine burns require that the spacecraft turn 90º to the Earth where the TLGA is used providing communications that are limited to very low data rate signals to confirm successful completion of the operation. Once at Jupiter, the high gain antenna acts as the principal command, telemetry, and data transfer conduit. It also serves in the radio science experiments. A chart showing the antennas used as a function of mission time line and spacecraft distance from the Sun, Earth and Jupiter is provided in Figure 1.

Each of the five antennas plays important roles in the mission. Two of the antennas, the high gain antenna and the toroidal low gain antenna required development of new technology to facilitate the operational requirements. In addition to the launch dynamic environment and deep space

978-1-4577-0557-1/12/$26.00 ©2012 IEEE

thermal requirements, the Juno antennas needed to be designed to withstand a very high radiation environment for the near-Jupiter portions of the elliptical orbits around the planet. In the remainder of this paper, the technology employed for each of the antennas will be described. In Section 2, the classical low and medium gain antennas will be described. In Section 3 the development of the newly adopted bicone antenna will be discussed. Finally, in Section 4, the novel shaping technique employed for the high gain antenna will be discussed.

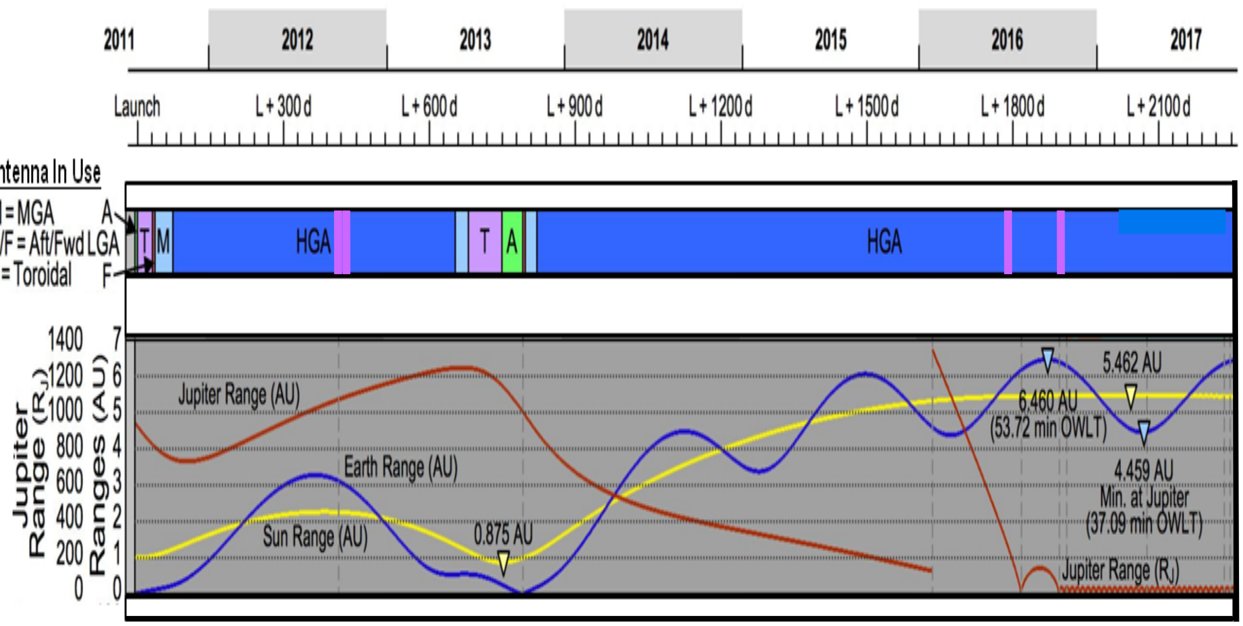


Figure 1 Mission time line, spacecraft distances, & antenna in use. Note L + 300d means launch + 300 days

2. Low & Medium Gain Antennas

There are two identical choked horn LGAs employed on the Juno spacecraft, one forward facing (FLGA) and mounted near the aperture of the high gain antenna and one mounted on the aft deck (ALGA) of the spacecraft (see Figure 3). The antennas provide fairly broad hemispherical circularly polarized coverage over the NASA Deep Space Network (DSN) X-band transmit (~7.1 GHz) and receive (~8.4 GHz) bands with gains > 8.7 dBic & > 7.7 dBic near boresight for the receive and transmit bands, respectively. The edge of coverage gains are ~-5.7 dBic at +/- 78 deg from boresight. As can be seen in Figure 1, the two low gain antennas are used relatively briefly near Earth when the spacecraft orientations may be far afield from nominal spacecraft-forward-toward-Earth orientation. These choked horns (Figure 2) were used on the NASA Mars Reconnaissance Orbiter (MRO) and represent one variant of a family antennas used on many of the NASA deep space missions. This simple antenna consists of an open ended circular waveguide with choke rings to minimize back-hemisphere radiation and provide circular pattern shape with good circular polarization characteristics. The circular waveguide is fed by a Chen & Tsandoulas style [1] hybrid septum polarizer to generate the required right-hand circular polarization. Only one of the two ports of the hybrid polarizer is routed to the spacecraft radio while the other is used during ground testing. There is a pair of tuning irises in the circular waveguide to provide good match - better than 25 dB return loss over both transmit and receive bands. These robust antennas are easily able to withstand the -160 C to +170 C thermal environment and the 25 Watt transmit power with no multipactor breakdown.

The other horn-style antenna on board the Juno spacecraft is a medium gain conical horn (MGA – see Figure 2). This simple horn antenna has also been used on several NASA missions including the Mars Exploration Rover cruise stage. Like the low gain antennas, it is used near Earth but it is also used in case of an emergency at far-out ranges if necessary. It provides >18.8 dBic and >18.1 dBic near boresight for the DSN receive and transmit bands, respectively. Its moderately broad beamwidth provides ~13.5 dBic gain over a +/-12 degree cone for modest spacecraft off point scenarios. Like the FLGA and ALGA, the MGA is fed by the hybrid septum polarizer and employs dual circular waveguide irises to achieve a better than 22 dB return loss over the two operational bands. In the case of the MGA, both ports of the polarizer are used to allowing both right and left circular polarization. This is done to provide an alternate telecommunications system network path in the event of a hardware failure.

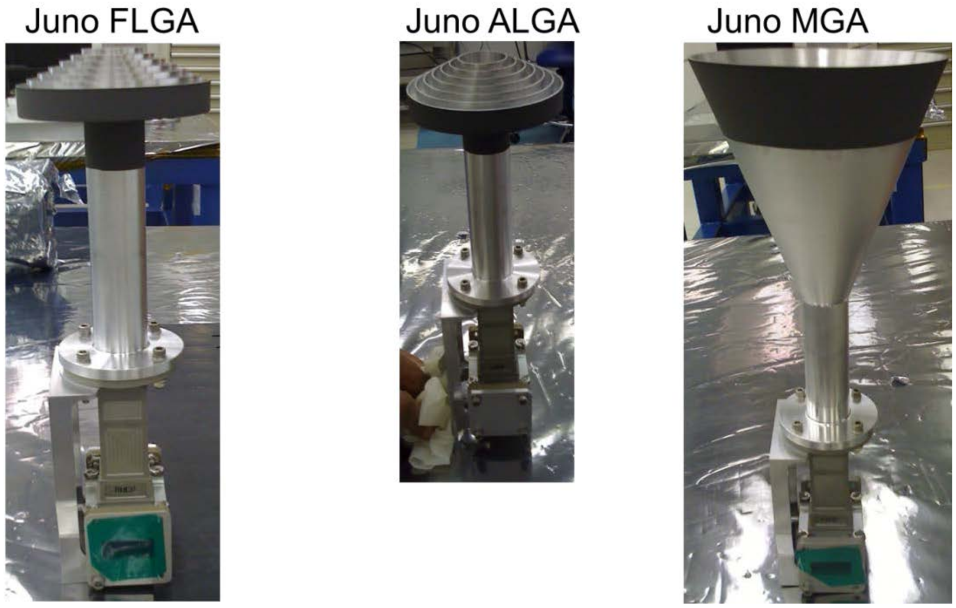


Figure 2 Juno Fore low gain, Aft Low gain (the Fore & Aft LGAs are identical except for mounting bracket details), and Medium Gain antennas.

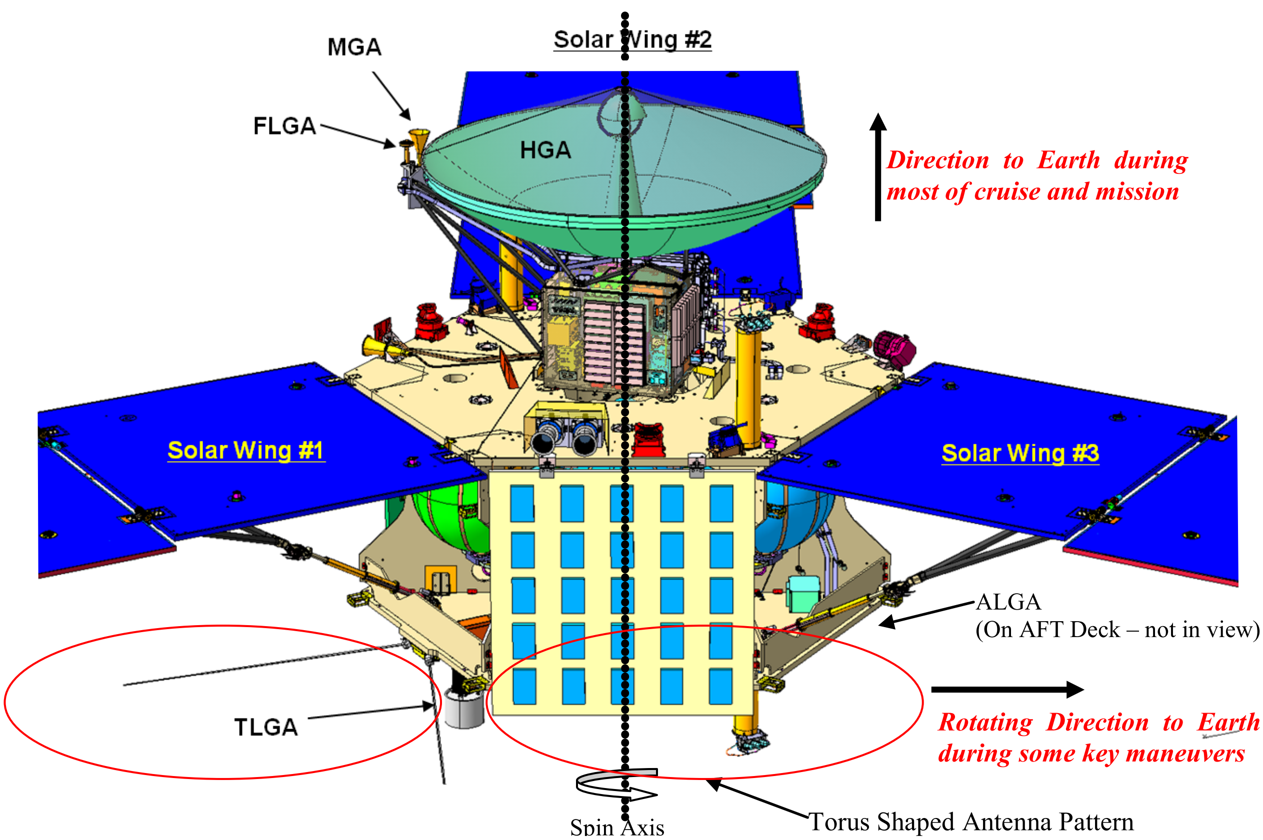


Figure 3 Locations of telecommunication antennas on the Juno Spacecraft

3. TOROIDAL LOW GAIN ANTENNA

Whereas throughout the majority of the mission cruise and science operations the forward side of the spacecraft points toward Earth within a +/-0.25 deg cone, there are times when the spacecraft attitude is well outside that cone. In fact, during several key spacecraft main engine firing events for course corrections and Jupiter orbit insertion, the craft turns approximately 90 deg from Earth point. Since the spacecraft is spin stabilized rotating at a few revolutions per minute, a conical shaped antenna beam will not allow for a telecommunication's signal lock as the broad side of the craft turns past when in the 90 deg attitude; A torus shaped antenna radiation pattern is instead required. The natural antenna that produces a toroidal antenna pattern is the dipole, but the limited ~2.2 dB peak gain would be insufficient at the large distances between Earth and Jupiter. Other variations on the dipole could include a stacked dipole array, but at the 7 – 8.5 GHz frequency range, the small wire geometry may lead to narrow bandwidth, excessive losses, difficulty in fabrication, and possible problems with multipactor break down. Another approach could involve a cylindrical array of printed antenna elements, but once again, there will be problems with bandwidth, high losses, and a tendency toward producing a highly scalloped antenna pattern. One dipole geometry that showed promise was the biconical antenna.

The standard linear bicone antenna is a variant of the classical dipole with the two linear wire elements replaced with linear cones (Figure 4). This arrangement expands the bandwidth of the dipole out to as much as 3 octaves or more. It is also a more robust geometry enabling ease of fabrication and higher breakdown thresholds over the X-band operational frequencies. It is also possible to expand the gain of the standard dipole by increasing the effective aperture of the bicone antenna through increases of the cone diameters and height. This approach, however, can only lead to marginal gain increases when using the standard linear cone. As one increases the cone size, phase variations across the aperture between the cones increases. Increasing aperture area leads to larger phase variation. In order to maximize the directivity from any aperture antenna, however, the phase (and amplitude) should be kept as uniform as possible. Thus, for a given radius, the bicone gain reaches a maximum value versus height. This can be seen in Figure 5 which shows directivity of a family of curves of increasing bicone radius as a function of bicone aperture height. The directivity increase drops off relative to the ideal directivity for a given aperture size due to mounting phase errors relative to uniform aperture phase. In order to achieve the desired directivity (~6 dBi & 8 dBi @ 7.1 GHz and 8.4 GHz, respectively) the diameter and height of the antenna would be 640 mm and 161 mm, respectively, which would be excessive. In order to overcome this physical limitation, a new style bicone was developed. It was found [2] that using a parabolic shaped aperture (Figure 6) provides half the aperture phase error compared to the standard linear profile. Thus an antenna of half the diameter can provide the desired directivity.

A further development was needed to meet all of the Juno project goals for this antenna. The radiation pattern from the parabolic aperture was found to have high side lobes. This presented a problem with spacecraft scattering and led to an inefficient distribution of radiated field, placing nulls in at elevation angles where it was desired to use the antenna. To minimize sidelobes, a common approach involves the use of corrugations for horn antennas. Although the addition of corrugations lowered the directivity by a small amount, the resulting antenna had low sidelobes and adequate directivity (Figure 7).

In order to minimize transmission line losses and avoid multipactor breakdown, a rectangular waveguide to coaxial waveguide transition was developed [2]. The final antenna design is illustrated in Figure 8 and Figure 9. The transition was matched to the corrugated horn and achieved better than 20 dB return loss over the entire band from 7 GHz – 9 GHz.

The final design task for this antenna was to convert the nominal linear-vertical radiated polarization to circular polarization so as to optimize the link with the circularly polarized DSN antennas. To this end, the four-layer meander-line polarizer of [3] was adopted to the cylindrical aperture of the corrugated parabolic bicone antenna.

The design of the integrated bicone / polarizer antenna had to take into account several factors including;

(1) ***Charge environment:*** the very high radiation environment encountered during the close-approach portions of the elliptical orbit around Jupiter leads to significant surface charging of susceptible materials. The antenna needed to minimize use of dielectrics in order to avoid this charging. For the 4-layer polarizer, an Astroquartz™ substrate was chosen for its low RF losses and its robust material properties. No sandwich materials were used in between the layers to maintain layer alignments; mechanical foot tabs were instead employed between the bottom of the substrates and the bottom of the cones for support and also to provide D.C. ground for the meaner-lines. As a further mitigation against radiation charging an outer germanium Kapton® blanket with lightly carbon loaded Kapton® was employed. The blanket added about ~0.25 dB of loss but minimizes the fluence of high energy electrons that would otherwise be penetrating to and charging the substrate layers. The carbon loading enables sufficient D.C bleed currents to prevent charge buildup on the outer blanket;

(2) ***Thermal environment:*** The design needed to provide vertical latitude to allow for the thermal mismatch between the aluminum parabolic cones and the Astroquartz™ polarizer substrates. This was done by allowing the top of the substrates to float relative to the top of the cones;

(3) ***Launch Environment:*** In order to avoid potential rocking motion between the upper and lower bicone's (this could potentially lead to damage to the thin center conductor which connects the cones), the outer polarizer layer was more substantially affixed at the upper and lower interfaces with the cones providing support during launch. Thermal mismatch was once again accommodated by slotting fastener holes used on the upper cone interface. An exploded view showing all of the antenna's design features is provided in Figure 9.

The final flight unit antenna was qualified for flight through a series of tests including thermal cycling (-175 C to +70 C), random vibration testing, pyro shock testing, high power vacuum testing, and radiation pattern / gain measurements. The antenna passed all the environmental testing. It was found to have good RF performance and met the antenna requirements. Figure 10 shows the measured radiation patterns and axial ratio as a function elevation angle. Note that the desired low elevation sidelobes have been achieved and the overall pattern envelope closely follows the predicted response. The antenna pattern had a ~1 dB slow variation as a function of angle around the antenna. The polarization also shows similar variation. This performance is thought to be caused by possible asymmetries in the as-assembled relative positions of the four-layer polarizer. Even with the non-ideal azimuthal performance, the antenna handily met its RF performance requirements.

When placed on the aft deck of the spacecraft, analysis shows that there is some significant antenna radiation pattern interaction with the surrounding structure, but the performance is still within required limits for required link margins. This has been borne out to date through actual in-flight performance.

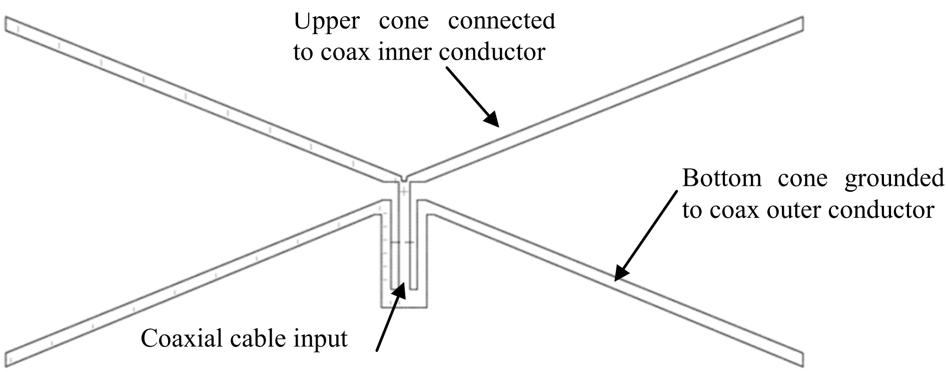


Figure 4 Standard Linear Bicone Antenna

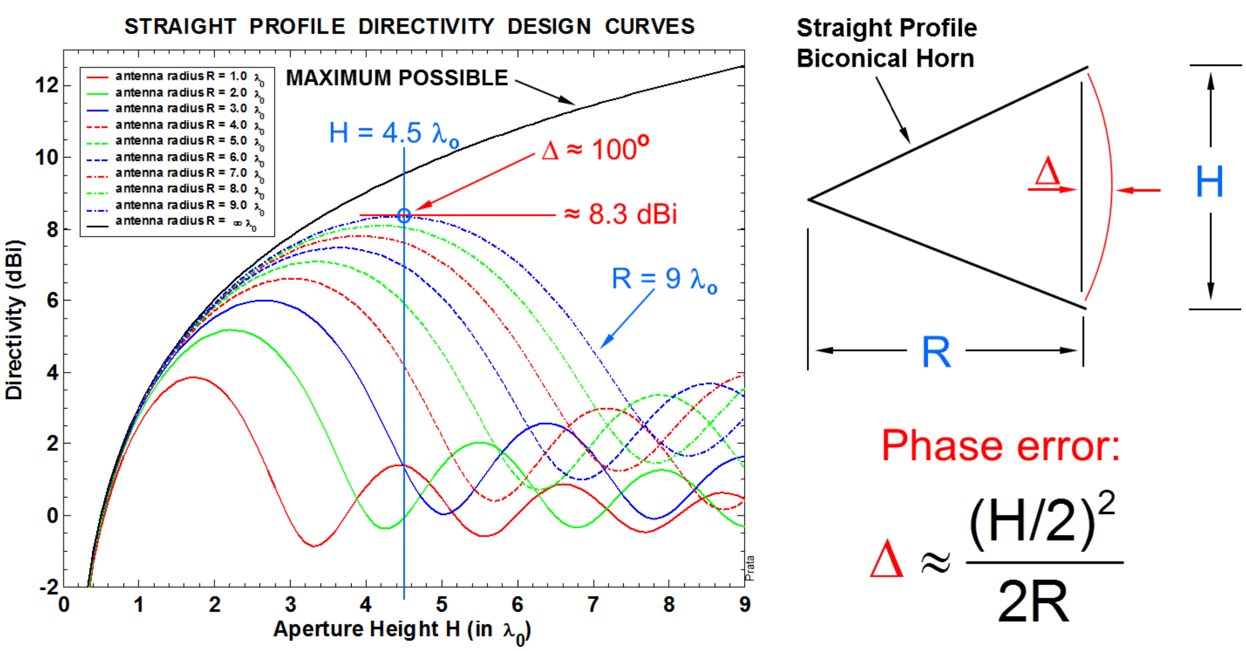


Figure 5 Directivity as function of bicone height and radius; directivity increases asymptotically reach a ceiling for increasing aperture size.

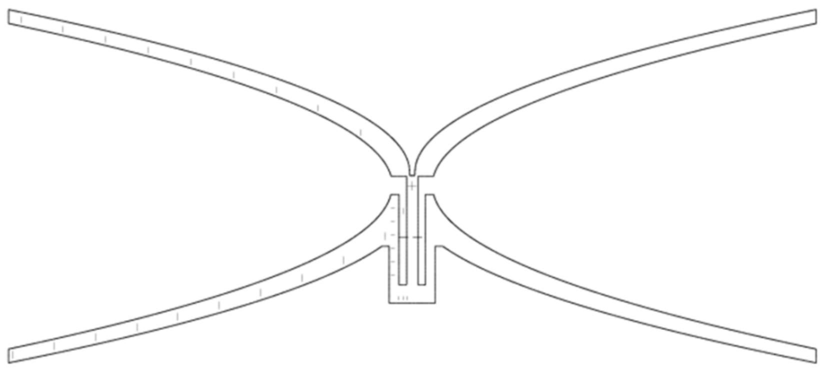


Figure 6 Parabolic Aperture "bicone" antenna

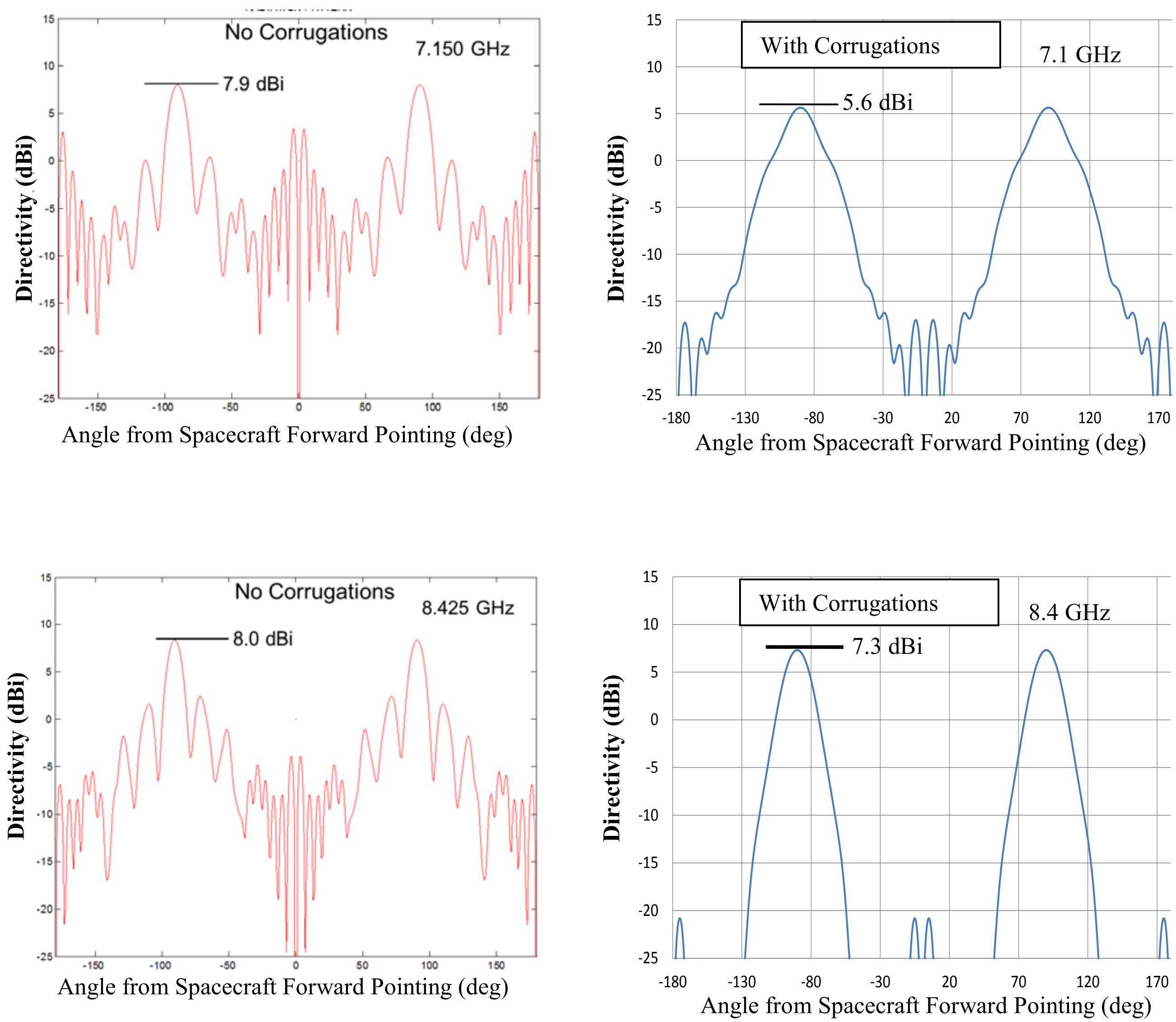


Figure 7 Computed Radiation Pattern for Toroidal Low Gain Antenna (TLGA) – comparison between parabolic bicone with and without corrugations.

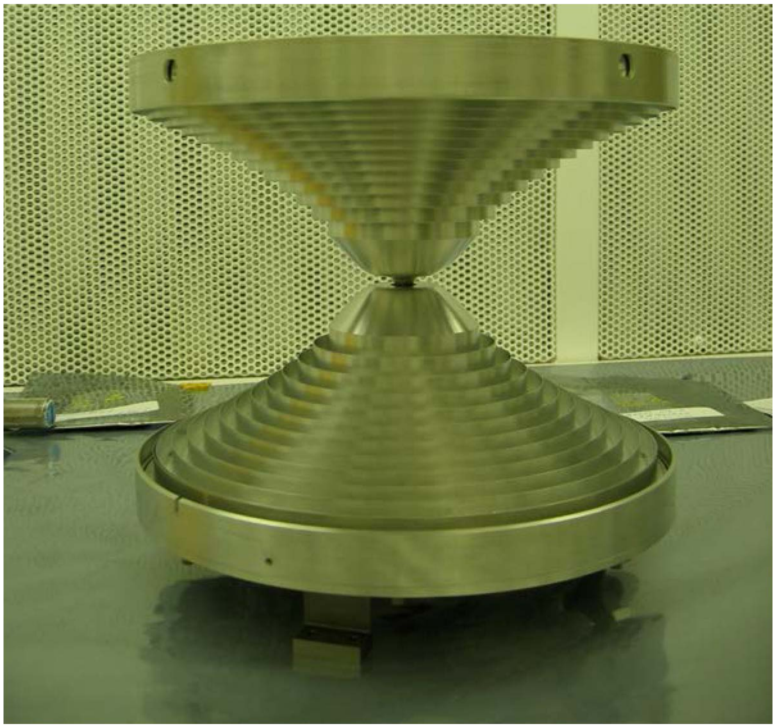


Figure 8 Corrugated, parabolic biconical antenna

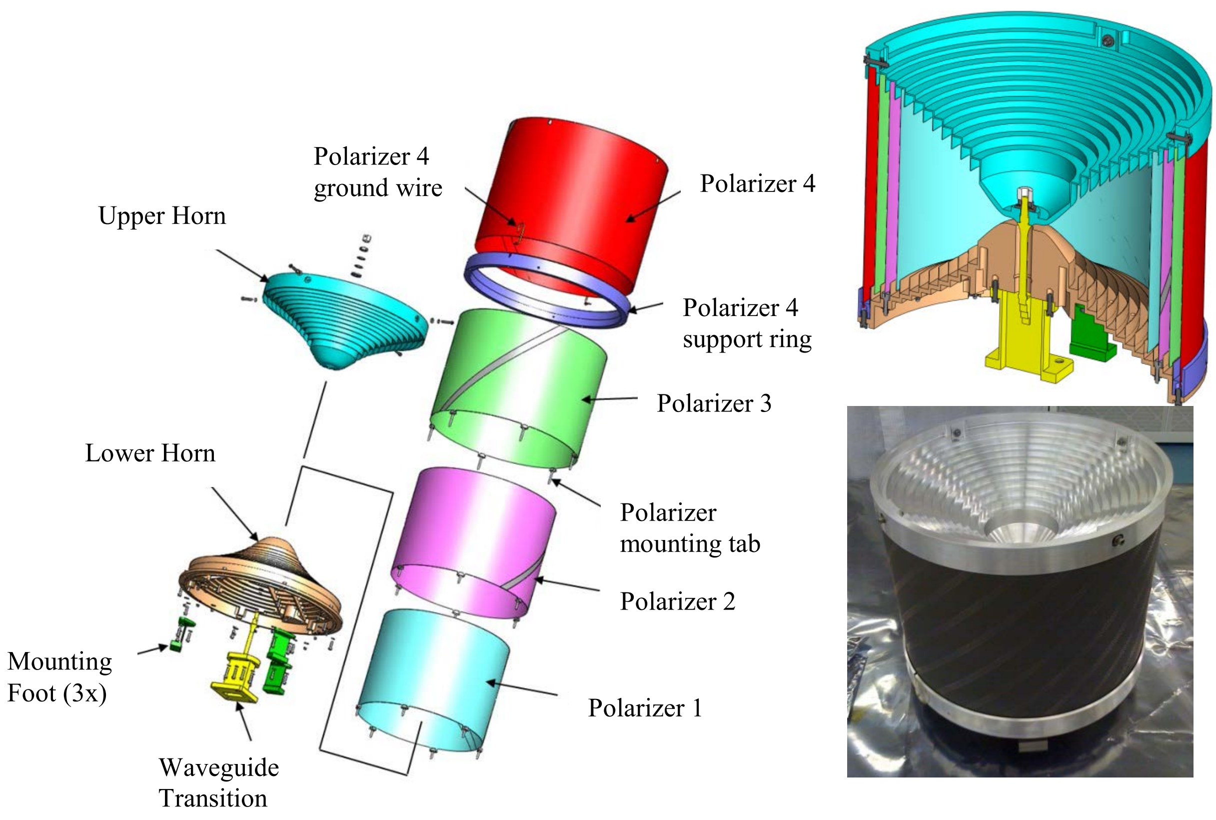


Figure 9 Toroidal Low Gain Antenna Assembly; exploded view (left), cross section view (upper right), and Juno Flight unit without outer blanket (lower right)

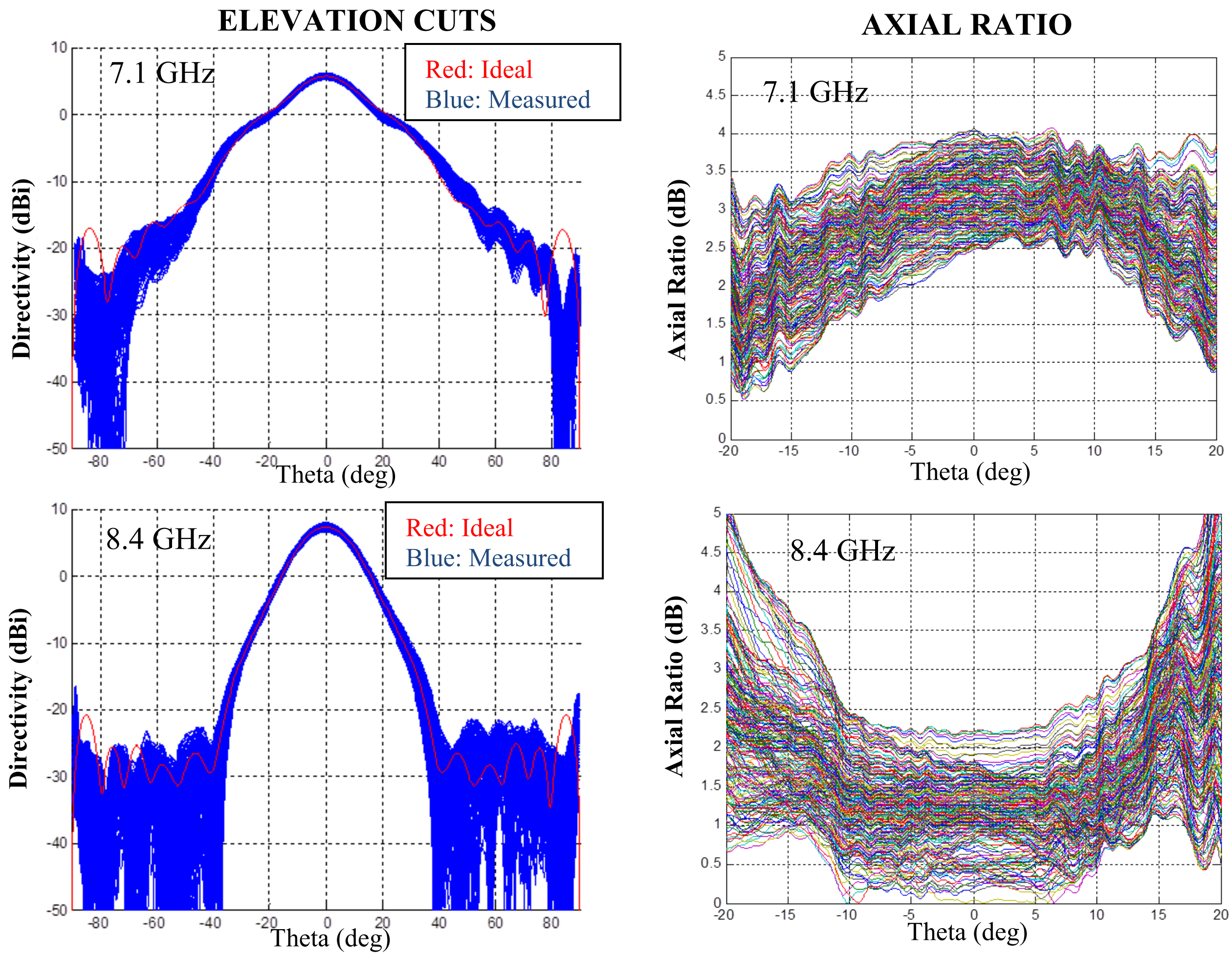


Figure 10 Measured Antenna Radiation Patterns and Axial Ratio of the Juno TLGA. A family of curves, each an elevation (theta) cut for a given azimuth angle (phi), show the performance variation around the antenna. Axial ratio goal was < 2 dB for elevation angles from -12 deg < theta < 12 deg.

4. High Gain Antenna

The High Gain Antenna (HGA) is the principal means of communications with Earth throughout most of the cruise and science mission. Given the extreme distance between Jupiter and Earth, along with a limited amount of spacecraft transmitter power (25 Watts), it is necessary to maximize antenna gain in order to achieve the required data throughput. Counter balancing this desire for gain are limitations imposed by the spacecraft and launch vehicle. The Atlas V launch vehicle and spacecraft packaging in this launch vehicle's shroud limited the diameter of the antenna aperture to about 2.5 meters. In addition, this spin stabilized spacecraft employs a very large three-armed solar array to facilitate sufficient power generation at large Jovian distance from the sun. This arrangement places a significant burden on the spacecraft attitude control limiting its ability to point the antenna's main beam to anything tighter than about +/-0.25 deg. The main operational frequency bands for telecommunications used by this mission span the DSN X-band uplink and down link (7.1 GHZ & 8.4 GHz) frequencies. With the design space allowing for a 2.5 meter aperture pointed within +/-0.25 deg, the required 43 dBi gain at the DSN receive frequency and 41.5 dBi at the DSN transmit frequency was readily achievable.

This HGA was also tasked with an additional mission of providing a Ka-band link between the spacecraft and select DSN sites as part of a gravity science experiment. The DSN Ka-band transmit and receive frequencies (~34.4 GHz and 32.1 GHz) when using a nominal 2.5 meter diameter aperture antenna would lead to a radiated beamwidth about one quarter of the X-band beamwidth. With the +/- 0.25 deg attitude control limitation, the Ka-band beam would on average be pointed such that the rapidly decreasing gain portion of the main beam skirt would be pointing at Earth leading to insufficient gain to close the link. The challenge was therefore to devise an antenna with X-band performance maximized while adjusting the Ka-band beamwidth to approximately match the X-band radiation pattern.

With the above requirements and constraints, a dual reflector Gregorian style optics was proposed (Figure 11). This optics, which consists of a parabolic main reflector and an elliptical subreflector, has the advantage of making use of a low gain feed whose geometry could be kept compact and low mass. A prototype of a dual X-Ka-band feed had already been developed during an earlier research effort for the MRO program and made a good starting point for the final Juno dual-band feed design.

The main reflector and subreflector were initially shaped using geometric optics adding subtle perturbations to the canonical geometries to adjust the main reflector radiated aperture amplitude and phase fields to be as uniform as possible while dropping the amplitude field at the outer edge of the reflector to avoid spill over losses. This arrangement leads to maximum gain at both X and Ka-band. A rather elegant approach [4] was devised to modify the Ka-band radiation pattern so its main beam had similar gain and beamwidth as the X-band beam, while not appreciably impacting the X-band performance. The idea was to conceptually split the main reflector into two concentric regions. The inner circular region's diameter was adjusted to set the gain (and associated beamwidth) to be near that of the X-band performance. The reflector surface of outer annular region is adjusted so that the radiated field is 180 deg out of phase with the inner region aperture field to approximately subtract the effects of the outer annular region from the total radiated field (Figure 12). The result was a reflector surface in which the outer annular ring region was stepped forward by about 4 mm (the step was implemented using a smooth "cosine" transition over a distance of ~50 mm to facilitate ease of manufacture). The resulting radiated far field had the desired properties with a beamwidth approximately the same as that of X-band and a flattened beam top (Figure 12). In addition, the 4 mm step was small enough that the X-band performance had very virtually no performance degradation. The as-built antenna assembly is shown in Figure 13 positioned for near-field testing. Although the step is subtle, one can easily see the transition.

The reflectors were fabricated and assembled by ATK Space Systems (San Diego) using their very stiff isogrid graphite composite fabrication technique. The mechanical design facilitated the launch loads and provided the needed stability for good Ka-band performance at the low (-175 C) Jovian temperatures. In order to limit the temperature of the reflector to the required -175 C to +135 C range during the near Earth cruise (when the antenna is often pointed directly at the sun) and throughout its entire mission onward to Jupiter, a thermal radome (blanket) is employed over the aperture of the antenna. Once again, the high radiation environment near Jupiter required a material capable of bleeding the predicted charge accumulation. The same carbon loaded Germanium Kapton® material that was used on the TLGA was employed. The HGA net gain suffers an approximately 0.25 dB loss at X-band and 0.5 dB at Ka-band due to the radome.

The final flight unit antenna, was qualified for flight through a series of tests including thermal cycling (-175 C to +135 C), acoustic vibration testing, sine-burst static load testing, thermal vacuum bake-out, and radiation pattern / gain measurements. The antenna passed all the environmental testing and it was found to have good RF performance, meeting the antenna system requirements.

The X-band radiation patterns agreed very well with the predictions (Figure 14). The X-band sidelobes were somewhat higher than predicted due to interactions with the subreflector struts (interaction not captured in antenna model) but this was of little consequence. At X-band there is an approximately 20 dB return loss measured at the feed due to direct reflection from the subreflector. This return loss was high enough to interfere with the performance of the feed's polarizer. While the desired goal of better than 2 dB axial ratio for right hand circular polarization within the +/-0.25 deg edge of coverage was met for the DSN receive frequency of 8.4 GHz (achieved better than 1.72 dB), a higher than desired axial ratio (3.2 dB or less) was measured at the DSN transmit frequency (7.1 GHz). For the Juno mission the DSN receive frequency is most important and the performance was more than acceptable to close links with margin. This axial ratio problem can be avoided by including a vertex plate in the elliptical subreflector to aid in preventing direct reflection back into the feed.

At Ka-band the desired modified beamwidth was achieved. It was found, however, that the flattened wider beamwidth antenna beam had a slight squint (Figure 14). This effect was unexpected and a verified cause was not found. Simulations suggest that it may be caused by misalignment between feed, subreflector, and main reflector but no "smoking gun" was found before the antenna was required for installation onto the spacecraft. The performance degradation was small enough such that transmit and receive links can be closed with margin throughout the mission.

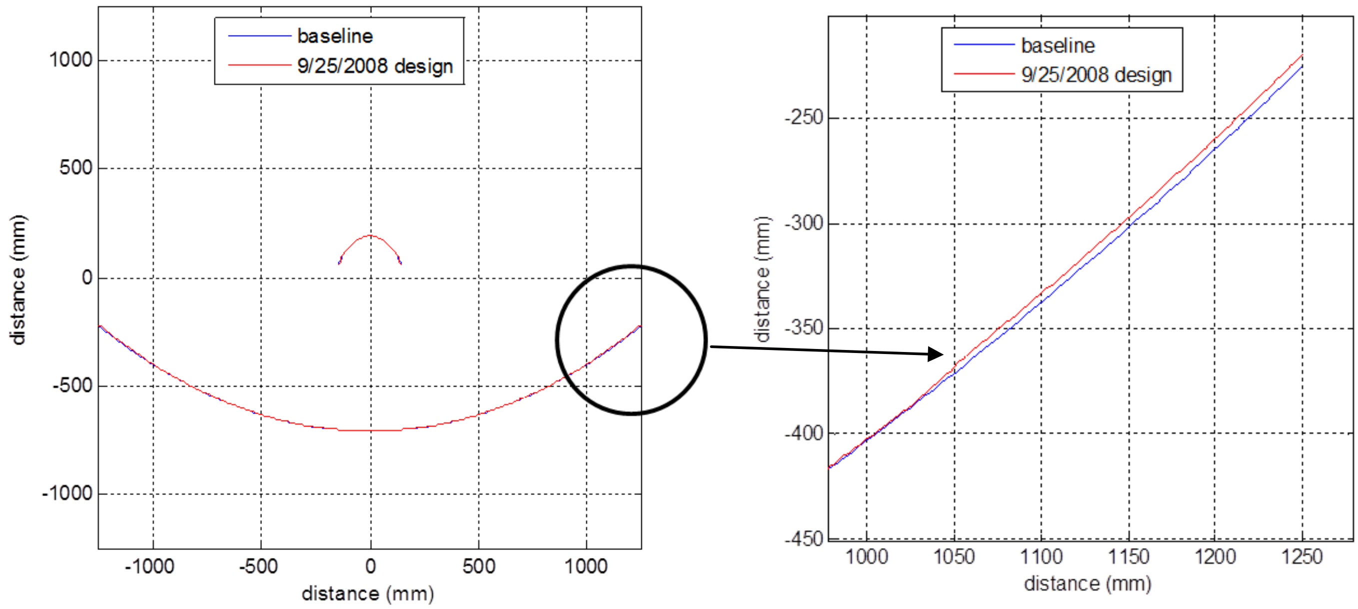


Figure 11 Classical Gregorian (parabolic main reflector and elliptical subreflector) Antenna Geometry (blue) overlay with main reflector surface step for controlling Ka-band beamwidth (blue). Right figure shows full reflector; Left figure show a zoom-in on the stepped region.

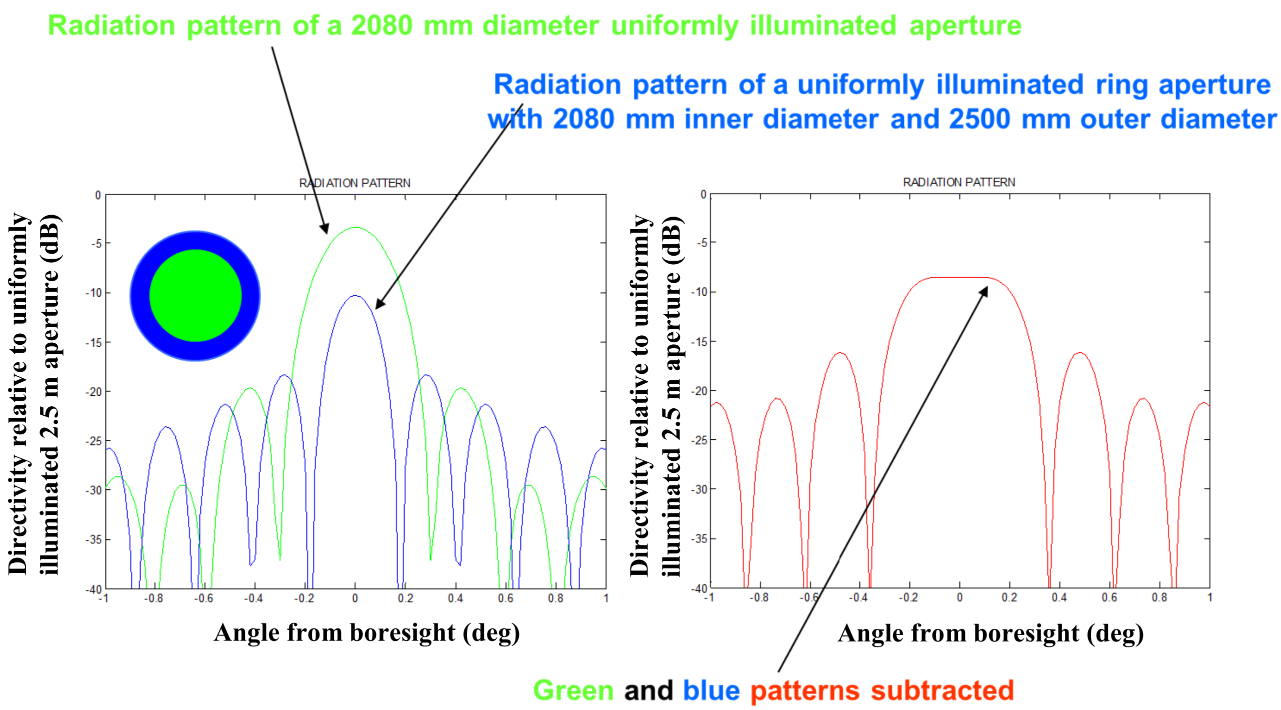


Figure 12 Ka-band Beam shaping concept; far field radiation patterns shown normalized to maximum gain that would be achieved if no beam shaping was employed.

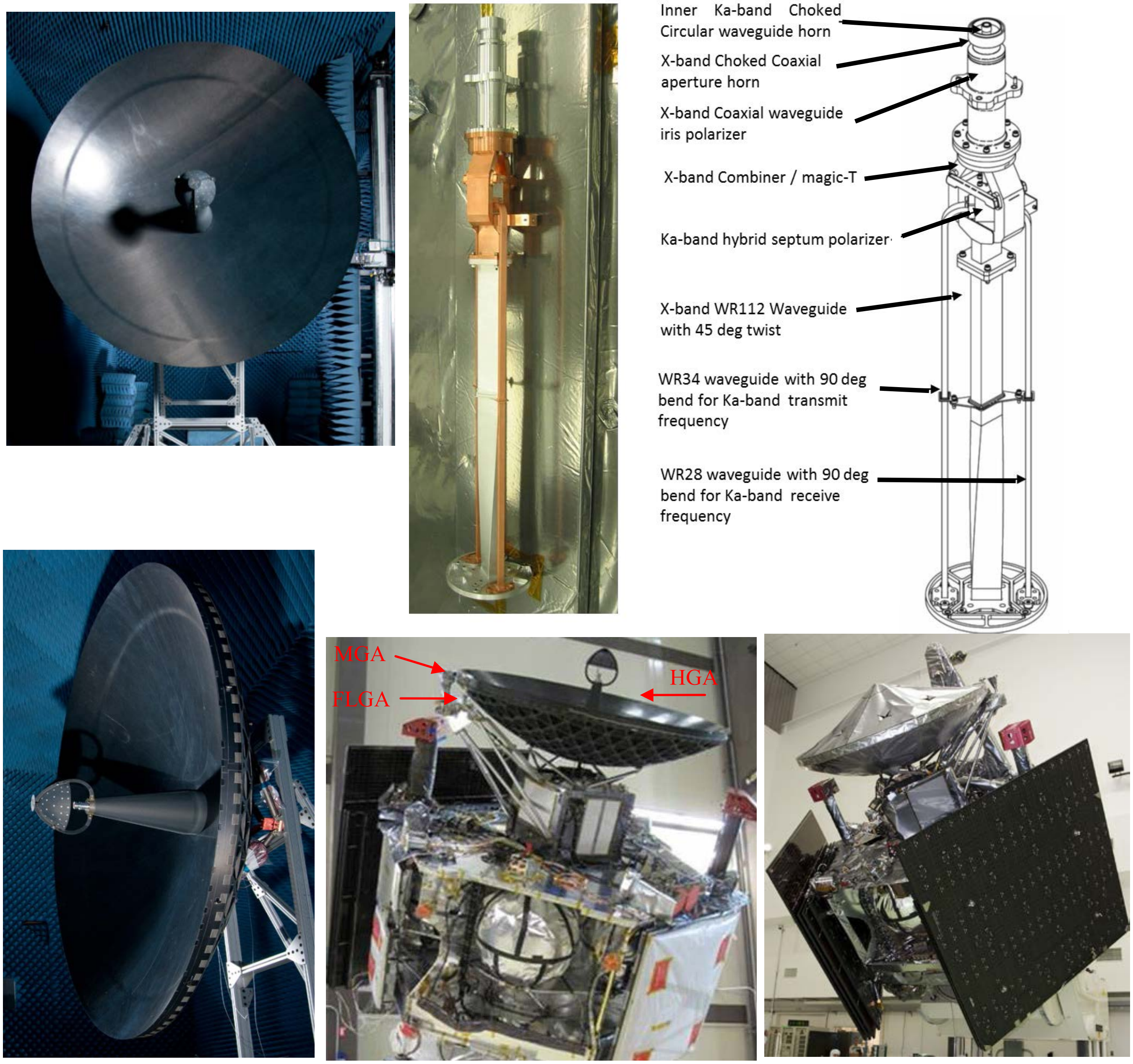


Figure 13 Juno 2.5 meter High Gain antenna; during near-field antenna pattern measurements (left) and on the Juno spacecraft with germanium Kapton® radome (lower right) and on spacecraft without (lower center) radome; HGA Feed (upper right).

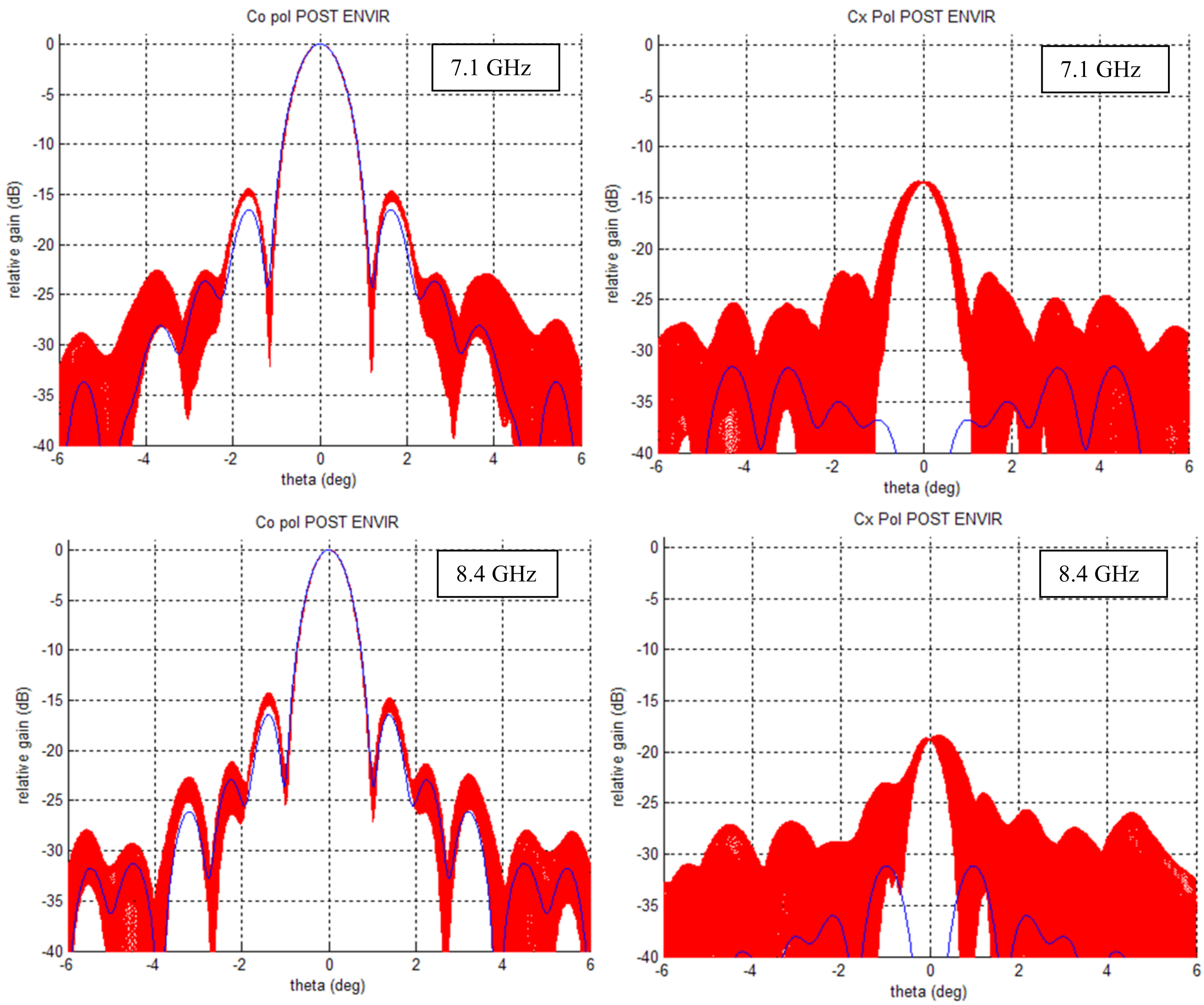


Figure 14 Radiation patterns of HGA at DSN receive frequency; In blue is shown the ideal performance; In red is shown a family of azimuth cuts (phi) versus elevation angle (theta). Notice the bottom plot shows the impact of the subreflector-to-feed mismatch on the polarization – a higher than desired cross polarization (Left hand circular) results.

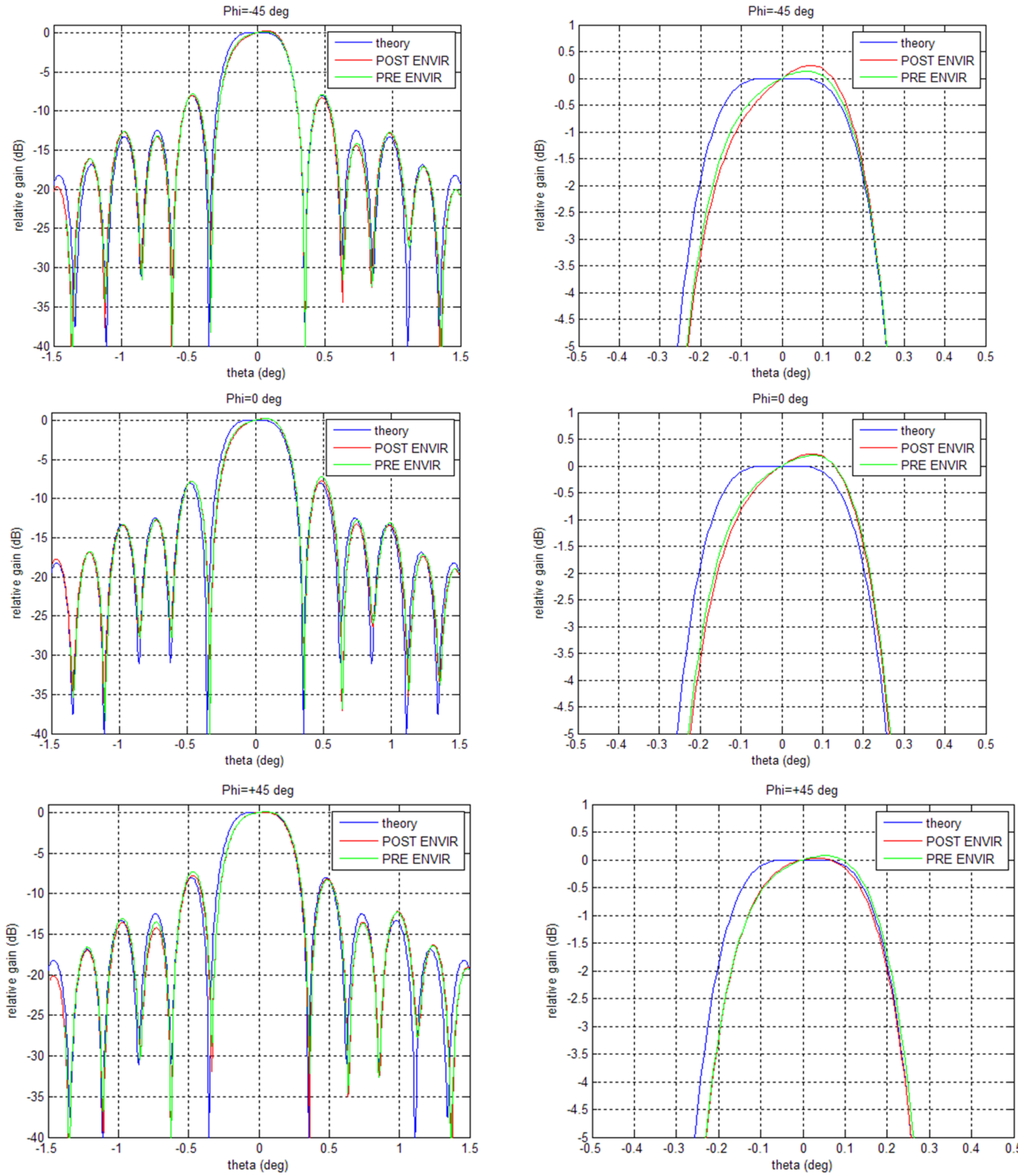


Figure 15 High Gain Antenna Ka-band (32 GHz) antenna patterns showing beam squint anomaly. Plots show overlays of elevation cuts for azimuth angles phi= -45 deg, 0 deg, & +45 deg before and after environmental test. Main beam and first few sidelobes (left); Zoom view of main beam (right).

5. SUMMARY

The Juno mission to Jupiter was successfully begun on August 5, 2011. To date all antennas (except the high gain antenna) have been tested and shown to meet all of their expected performance requirements. This mission had once again shown that there is still more room for new and interesting antenna designs. The TLGA represents a significant evolution of the standard bicone antenna and the HGA makes use of an artful design approach which was an enabling technology for the Ka-band implementation on the spacecraft. Even the more standard low and medium gain horns played their role in making these robotic deep space missions possible. It has been our experience that each new mission has presented unique challenges which have fostered the development of new antenna technologies.

ACKNOWLEDGMENTS

The work described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors wish to express their appreciation to the many JPL engineers and subcontractors who contributed their hard work in the development of the Juno telecommunications antennas.

REFERENCES

[1] Ming Hui Chen, G. N. Tsandoulas, "A wide-band square-waveguide array polarizer," IEEE Transactions on Antennas and Propagation, vol. 21, pp. 389-391, May 1973.

[2] Aluizio Prata, Luis R. Amaro et al, "Juno Toroidal Low Gain Antenna Critical Design Review," Jet Propulsion Laboratory, Pasadena, CA, Internal Design Review Package, pp. 14-26 ,June 26, 2009.

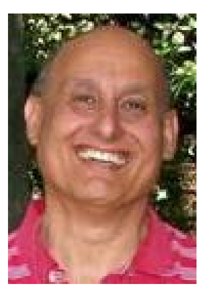
[3] Leo Young, L A. Robinson, & C. A. Hacking, "Meander-line Polarizer," IEEE Transactions on Antennas and Propagation, vol. 21, pp. 376-378, May 1973.

[4] Aluizio Prata, "Juno High Gain Antenna Optics Peer Review," Jet Propulsion Laboratory, Pasadena, CA, Internal Design Review Package, Aug 25, 2008.

BIOGRAPHIES

Joseph D. Vacchione *received a B.S. in Electrical Engineering from Northeastern University, Boston in 1985 and a M.S. & Ph.D. in Electrical Engineering from the University of Illinois at Champaign-Urbana, in 1987 & 1990, respectively. He specialized in computational electromagnetics with an emphasis on remote sensing, antenna theory, and detailed work on Frequency Selective Surfaces. He has been with JPL for more than 21 years where he has worked on the design of and led the development teams for several JPL-NASA missions including Mars Pathfinder, Mars Exploration Rover, Shuttle Radar Topography Mission, Mars Reconnaissance Orbiter, Aquarius Instrument, and Juno. His work included analysis and implementation of wire, horn, printed array, and reflector antennas.*

Aluizio Prata, Jr. was born on March 18, 1954 in Uberaba, Brazil. He received the B.S. degree from the University of Brasilia, Brasilia, Brazil, in 1976, the M.S. degree from the Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil, in 1979, the M.S.E.E. degree from the California Institute of Technology, Pasadena, in 1984, and the Ph.D. from the University of Southern California, in 1990, all in electrical engineering. From 1979 to 1983, he was with the Telebras Research and Development Center, Brazil, working on the design and construction of satellite earth station antennas. While at the California Institute of Technology he designed and implemented one of the first operational neural computers. Currently, he is an Associate Professor at the University of Southern California, working with applied electromagnetics. He is coauthor of the widely used PC interactive reflector-antenna design software RASCAL, currently with more than 1000 free copies distributed worldwide. He has been a Consultant for numerous aerospace companies, and has authored or coauthored over eighty articles, patents, and symposium papers. Dr. Prata is a member of Sigma Xi, Eta Kappa Nu, and is an eminent member of Tau Beta Pi. He was a member of the steering committee of the 1995 IEEE Antennas and Propagation Society (APS) International Symposium, was the 1996 Chair of the Los Angeles Chapter of the IEEE APS (the Chapter won the 1996 Best Worldwide Chapter Award), and was the Vice Chair of the 2000 IEEE International Conference on Phased Array Systems and Technology. He is also the USC faculty advisor for the IEEE student chapter.



Luis R Amaro received his BSEE from California State Polytechnic University, Pomona in 1984 and his MSEE from California State University, Northridge in 1998. From 1984 to 1987 he was a Member of the Technical Staff of the Metrology Dept. at Rockwell Intl. Autonetics Marine Systems Division. From 1987 to 1991 he was a Member of the Technical Staff of TRW Inc. Microwave Components Dept. He designed waveguide components such as attenuators, filters, and multiplexers for use on spacecrafts. He received a best paper award at the 1987 Measurement Science Conference for his work on power sensor calibrations. From 1986 to 1989 he served the IEEE as both Membership Chairman and Chairman of the Instrumentation and Measurement and

Industrial Electronics Societies, Los Angeles Chapter. He is a Fellow of the Institute for the Advancement of Engineering. Since 1991 he has been with the Spacecraft Antennas Group at JPL, where he is a Senior Antenna Engineer. While at JPL he has designed numerous microwave and millimeter wave components as well as antennas for multiple JPL-NASA projects including: The NASA Scatterometer (NSCAT), SeaWinds, Cassini, Deep Space One, Mars Reconnaissance Orbiter, Mars Science Laboratory Rover, Juno, and the CoNNeCT program. He has also been instrumental in the development of new technology for JPL, such as for Starlight and JIMO, involving high-efficiency reflectors, Layered Lens antennas, and Light Weight Scanning Array antennas. Mr. Amaro's interests include electromagnetic simulation and the numerical analysis of antennas and microwave components.

Ronald C. Kruid received a B.S. in Mechanical Engineering from California State University, Long Beach in 1978. He has been with JPL over 10 years where he has led mechanical engineering teams for several JPL-NASA missions including the Ocean Surface Topography Mission (OSTM), the Orbital Carbon Observatory (OCO-1), and Juno as well as leading full scale engineering development projects such as the Micro-Arc second Metrology Tested for the Space Interferometer Mission (SIM) proposal and the Surface Excavation System Tested for a Venus Lander (SAGE) proposal. Prior to JPL he spent over 20 years with Northrop Grumman and Goodrich Aerospace (formerly Corning-OCA) where he led/managed mechanical engineering teams on numerous classified programs for navigation suits, scanners and sensors, IR and visible cameras, smart munitions, laser designators, mobile test stations, etc. currently in use on ship borne, airborne and orbital platforms.

Anthony P Mittskus received a B.S. in Electrical and Computer Engineering and an M.S. in Engineering from the California Polytechnic University in Pomona in 1981 and 1982 respectively. He holds a Professional Engineering Registration in the state of California. He is currently employed by NASA's Jet Propulsion Laboratory in Pasadena where we has developed Communication and Radar equipment for the Magellan Spacecraft to Venus, the Mars Global Surveyor, Mars Exploration Rovers, Mars Reconnaissance Orbiter, and Mars Science Laboratory missions to Mars, Cloudsat and Aquarius missions to Earth, and most recently was the telecommunications Element Manager for the Juno mission to Jupiter. He previously worked several ground and space-based classified systems while employed at the Hughes Aircraft Company in Fullerton, Ca.