70 METER DEEP SPACE NETWORK
ANTENNA UPGRADE DESIGN

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INTRODUCTION

The Jet Propulsion Laboratory (JPL) located in Pasadena, California, USA (a part of California Institute of Technology) is responsible for the technical direction, engineering and operation of the National Aeronautics and Space Administration (NASA) Deep Space Network (DSN).

The DSN consists of a number of installations including large ground microwave reflectors devoted to tracking highly elliptic (Earth) orbiters as well as deep space probes. One major subnetwork of the DSN total consists of three 64 meter diameter Cassegrain antennas, located in Australia, Spain and the United States. This 64M subnet primarily services deep space probes and as such has frequent high technical performance demands placed upon it. Such demands typically arise from various efforts to maximize flight mission data return; in many cases such planning and execution efforts are mounted a posteriori. An example of such efforts is the current Voyager spacecraft and ground system reprogramming for opportunities at Uranus and Neptune. Since such valuable opportunities for additional scientific return should be met with a balanced flight/ground system, the DSN is in a frequent state of technical improvement. In this paper we outline the plan and technical design to increase the 64M diameter to 70M as well as other microwave performance upgrades. An X-Band (8.4GHz) gain increase of +1.9dB (1.55 factor) is expected. This significant network performance upgrade is scheduled, during the flight of Voyager, between the Uranus (1986) and Neptune (1989) encounters.

For purposes of a clear understanding of the microwave feeding arrangements on these instruments, it is useful to briefly consider the evolution of such feeds. The early instrument, circa 1965-1970, was limited to single band (S-Band) use. A unique invention termed tricone enabled a large, outdoor bandswitch in "open" waveguide. This arrangement consists of three "feedcones" -housings within which are maintained the feeds, receive preamplifiers, transmit filters (if any) and other equipments characteristic of "front end". The feedcone centerlines are displaced about 1100mm from the main reflector centerline. A unique subreflector is used. Termed asymmetric, this subreflector is initially made oversized, then it is rotated longitudinally about its back focus, which is coincident with the paraboloid focus in the normal manner. Rotation continues until the subreflector vertex is pointed to one of the tricone feedhorns. Then the oversized subreflector is trimmed to occupy only that cone describing the outline of the paraboloid projected back to its focus. Finally, on the centerline axis of the paraboloid, two bearings are affixed to the subreflector so that axial rotation results in the Cassegrain focus describing a perfect circle through the feedhorn phase centers. By then stopping such subreflector axial rotation at three predetermined points corresponding to feedhorn phase centers, perfect microwave/mechanical axis pointing exists. That is, this system does not suffer from scanned off axis beams. There is a perfect aperture phasing in this tricone system, save small crosspolarization effects yielding insignificant

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squints to circular polarized beams (<0.1 beamwidth). The tricone invention/development was completed in time for implementation upon all three 64M DSN instruments, circa 1972.

Still, even with the tricone bandswitch, only one microwave feed was functional at a given time. Operationally this meant that, although S- and X-Band seperate feeds now occupied two of the three available tricone feedcone positions, only S- or X-Band could function at a given time. In 1972 both the 1976 Viking Mars Project and the 1974 Mariner-Venus-Mercury Project were planning for simultaneous S- and X-Band capabilities. That is, low noise receive functions were needed at both bands with high CW power uplink at the S-Band (2.1GHz). The solution was an additional pair of (sub)-subreflectors, termed reflex-dichroic. In this system, a dichroic plate functions to mirror the X-Band Cassegrain focus to a point in space between the S- and X-Band separate feedcones. Thus the dichroic plate must be a good refector at S-Band, for low noise receive and high CW power transmit purposes. Simultaneously, the dichroic plate must provide a passband for the X-Band low noise receive function. Finally, the connection between the S-Band mirrored focus in space between the feed systems and the S-Band horn phase center is accomplished with an ellipsoidal reflector section which has the property that any ray passing through one foci is directed through the other foci. Therefore, simultaneous S- and X-Band operation can be provided by the tricone, using the reflex-dichroic feed. Additionally, reception at L-, Ku- and Ka-bands for radio astronomy/engineering evaluation purposes and transmission at S- and X-Bands (both up to 400 KW, CW) for planetary radar is provided by the third feedcone.

CURRENT STATUS AND PLANS

Presently all DSN 64M instruments are of conventional paraboloid-hyperboloid (albeit asymmetric subreflector) design. Thus aperture efficiency is limited to the mid-60 percentiles at long wavelength. At X-Band the combination of conventional (quadric) surfaces, surface tolerance, blockage and feed system factors limit efficiency to a bit above 50 percent. Even at that, it has required a special dual hybrid mode feedhorn at X-Band, for improved amplitude illumination. Without this horn, aperture efficiency would fall below the 50th percentile.

To provide the required performance upgrade the following improvements are planned:

- Extension of the main reflector surface to 70M diameter.
- Certain large scale stiffenings of the backing structure.
- Improved contour accuracy reflecting panels.
- Automated two-axis subreflector focussing.
- Shaped dual reflector contour design for uniform illumination.
- Improved quadripod feed support.
- An optional main reflector peripheral noise shield.

A discussion of each element of the plan follows:

° 70 METER EXTENSION

The 64M main reflector radial ribs will be removed from radius approximately 15M, to be replaced with entirely new ribs to a final radius of 35M. The primary reason for this rather complete replacement is driven by preassembly/field erection requirements, thereby minimizing time out of service. The physical area increase of the resulting instrument will provide +0.8dB (1.20 factor) performance increase, essentially frequency independent.

° STRUCTURAL STIFFENINGS

The original 64M structural design accomplished in the very early 1960's was computer modeled and optimized based on a quarter section analysis. This necessary limitation reflects machine capacity capabilities of that time. More recently it has been possible to model a half section. Because of the twin elevation wheels necessary in a design employing separately founded master equatorial pointing reference/control platform (rising to the intersection of azimuth and elevation axes), the symmetric half section computer model is superior to the quarter model. Accordingly, some structural bracing within the inner 15M radius zone (so-called box girder) has been identified as beneficial in further limiting gravitational distortions as a function of elevation angle. At X-Band, and at 10 and 80 degrees elevation angle, approximately +0.3dB (1.07 factor) improvement will be realized.

° IMPROVED REFLECTING PANELS

Present 64M reflecting panels measure to be approximately 0.9mm rms, leading to an X-Band loss factor of nearly 0.5dB (0.89 factor). It appears feasible to achieve considerably better manufacturing and installation accuracies; perhaps 0.25mm or better for the manufacturing portion. Although we plan to employ conventional civil engineering (theodolite) techniques to initialize an X-Band quality surface, it is anticipated that the microwave "holographic" technique will be profitably applied, using strong available sources in geosynchronous Earth orbit, to fine tune reflecting panel settings as has been recently demonstrated at several other installations. The combination of improved panel manufacturing and setting accuracies is expected to increase X-Band gain by +0.5dB (1.12 factor).

° AUTOMATED TWO AXIS FOCUSSING

For many years, DSN X-Band 64M operations have been conducted, by first manually activating the axial (Z) focus, as elevation angle is changed, and later by automating this function. Conceptually this maintains the subreflector rear focus in necessary juxtaposition with the more limber and moving main reflector focus, as a function of elevation angle. A careful structural analysis involving main reflector best fit paraboloid focus together with quadripod feed support and subreflector unit deflections, has identified the value of lateral (Y-or gravity vector) focussing as well as axial. However, lateral focussing produces a beam shift of the final ensemble radiation pattern, necessitating pointing feedback correction. A new microprocessor based table lookup/compare/ feedback machine has been developed for this purpose. The performance benefits at X-Band will be similar in nature and magnitude and additive to those achieved by the structural stiffening activity mentioned above.

° SHAPED DUAL REFLECTOR DESIGN

Techniques have been available since the mid 1960's to synthesize, by ray optics, uniform aperture illumination of a two reflector antenna. Many systems of this kind have been realized, some performing very well with an overall area efficiency in the neighborhood of 75 percent. These techniques refer to symmetric two reflector systems, and the asymmetric fed JPL tricone development complicated the design steps and delayed deployment of such shaping techniques within the DSN until this time. To provide a design for the current tricone geometry, first, a symmetric dual reflector system is synthesized, retaining only the symmetric main reflector portion. Then the necessary asymmetric subreflector is phase synthesized to match the selected feed offset. An interesting factor arises in the case of X-Band feeding. As described above, the present quadric 64M systems employ a high efficiency dual hybrid mode horn, in an attempt to realize higher aperture illumination efficiency at that critical frequency band. Such horns are not used in other frequency bands due to size and bandwidth considerations. However, with the shaped dual reflector technique to be used, we must design those contours to a standardized horn amplitude function. Therefore, it will be necessary to replace the dual hybrid horn with a conventional single mode horn having that standardized radiation pattern available at all other frequency bands. The expected result from the dual shaped reflector design is an overall +0.6dB (1.15 factor) improvement, essentially frequency independent.

° IMPROVED QUADRIPOD FEED SUPPORT

In order to accommodate a different (shaped) subreflector, significant changes are necessary in the apex region of the existing quadripod structure. Again, based on the important constrained out of service time it becomes economic to have a completed all new structure available for rapid installation. This further enables preassembly and test of the automated two axis focussing subsystem. Advantage is taken of this opportunity to provide a reduced shadow (blocking) design. An anticipated improvement of 0.3dB (1.07 factor) has been calculated for this change. However, such a performance estimate is highly simplified and not considered particularly reliable. Accordingly, this possible factor is not used in final accountings of overall improvement.

° OPTIONAL MAIN REFLECTOR NOISE SHIELD

A basic principle adopted in this overall project is to provide an optimum gain to system noise temperature (G/T) at the X-Band. Accordingly, the synthesis is fine-tuned, at least in the sense of main reflector edge illumination/spillover balance, at X-Band. Despite the large wavelength size of the subreflector diameter (approximately 230λ and 60λ) at X- and S-Bands respectively, the X-Band optimization results in somewhat high S-Band spillover (about 0.8 percent or 2 Kelvins) above the optimum for that band. In many usual designs, 2 Kelvins is not a vital factor. However, the DSN achieves S-Band total noise levels of approximately 20 Kelvins; a 2 Kelvin increase is a loss of 0.4dB (0.91 factor). Accordingly, it may be necessary to fit a relatively low accuracy, relatively porous peripheral noise shield of perhaps 1M radius, beyond the quality X-Band surface extending to 70M diameter. This decision has not yet been made due to questions arising regarding cost/benefit tradeoffs.

SUMMARY

The three primary elements of the above plan (area increase, reflecting panel precision increase, and shaped dual reflector surfaces) are counted to obtain an expected +1.9dB (1.55 factor) gain increase at X-Band. Other elements of the plan primarily serve to reduce gain change with elevation angle, that is to "flatten" the gain as a function of elevation angle plot. And, in one case (improved blockage quadripod) the estimated improvement is not yet considered reliable. Nevertheless, a 1.55 factor increase in receive capability on an already sophisticated well-performing set of instruments is indeed a large and ambitious undertaking.