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DSN 64-Meter Antenna L-Band (1668-MHz) Microwave System Performance Overview

J. Withington

Radio Frequency and Microwave Subsystems Section

In 1985, L-band (1668-MHz) receive-only feed systems were installed on the three DSN 64-meter antennas to provide tracking support for two non-NASA spacecraft. The specifications, design approach, and operational test results are presented in this article. The L-band microwave system met all of its tracking goals and is currently being upgraded to include a C-band (5000-MHz) uplink.

I. Introduction

In support of several international space exploration projects—the French/Soviet Vega mission to Venus (June 1985) and Halley's comet flybys (March 1986)—JPL was asked in late 1983 to modify the DSN to receive the L-band telemetry used by the Soviet space program. The major hardware implementation was undertaken by the JPL Radio Frequency and Microwave Subsystems Section, which was given the task of planning, designing, building, implementing, and documenting the microwave portions of fully operational (transferable) L-band receive systems.

II. System Requirements

The new L-band microwave system had to conform to and interface with the ongoing Mark IVA 64-meter antenna upgrade program and also had to be totally completed and operational within less than two years. Because of these constraints on time and resources, only the minimum microwave system necessary to support the immediate missions would be possible.

An extensive description of the Venus Balloon project and the L-band system requirements is given in [1]. Those requirements that affected the design of the microwave system are the following:

(1) The antennas must receive 1668 ± 5 MHz.

(2) Antenna gain must be at least 58 dBi, or 50 percent efficiency on a 64-meter antenna.

(3) System noise temperature (T_{op}) must be <35 K at zenith.

Furthermore, the system required the ability to receive the LCP signal used by the Vega spacecraft and the Venus Balloon probe, and sensitivity needs required the use of refrigerated amplifiers.

III. Design Approach

The required 58-dBi gain precluded the use of all DSN antennas except the three 64-meter antennas. The design sequence of the microwave subsystem went through two itera-

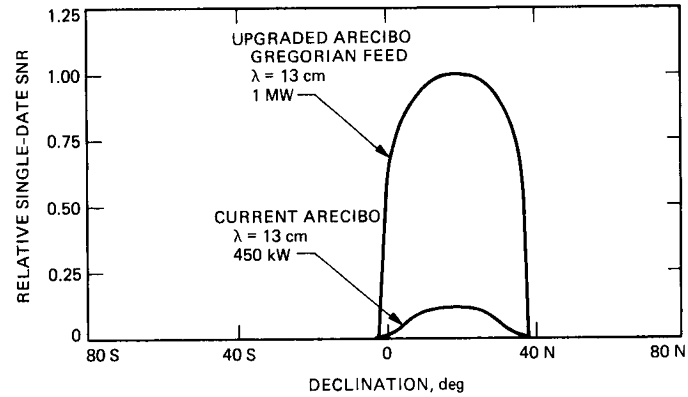

Fig. 5. Relative earth-based radar sensitivity for the Arecibo 12.6-cm radar for current and proposed Gregorian feed and transmitter improvements

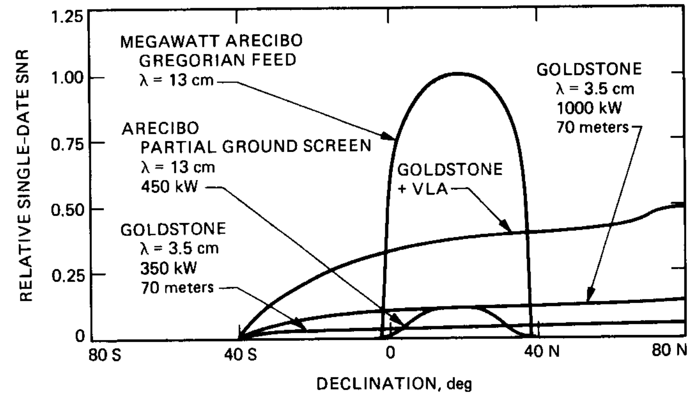

Fig. 6. Relative earth-based radar sensitivities for the Arecibo 12.6-cm radar in the 1980s and 1990s (before and after the Gregorian feed and increased transmitter power) as well as the Goldstone 3.5-cm radar in the 1990s (after the already completed aperture increase and the proposed increase in transmitter power)

tions. In the first analysis, it was envisioned that the "host country" feedcone position on the 64-meter (tricone-fed) antenna would be used. This would have involved the construction of three new feedcones outfitted with 22.4-dBi-gain L-band feedhorns. However, since this installation was to be permanent, a third operations feedcone on the 64-meter antenna was not acceptable to various science groups who use the third (host country) feedcone for radio science, radar, and other calibrations. Cost and implementation-time constraints also made this approach infeasible.

An alternative method, and the one that was implemented, was to suspend a feedhorn in the area between the XRO and the host country feedcone (Fig. 1). The idea was to cantilever a feedhorn on a bracket bolted to the top of the XRO feedcone. Since weight was then a critical concern, a sheet metal smooth-wall dual-mode horn 134 inches long, with a 38-inch aperture, was designed to be a light, low-loss, but narrowband (approximately ±40-MHz) solution with the illumination efficiency necessary to meet system requirements.

The outrigger horn suspension design presented one problem: the aperture of the feedhorn was too large to allow the phase center of the feedhorn to be placed on the focal ring of the asymmetrically fed 64-meter antenna. As a result, the phase center of the L-band feed lies some 24 inches radially outward from the focus ring (3.4 wavelengths), which produces a small scan loss in beam peak gain and beam pointing squint. Figure 2 shows the basic horn/antenna geometry used on the three 64-meter antennas. Initial analysis as reported in [2] predicted 60 percent efficiency, giving 58.8 dBi of gain. A simple scan angle equation using the antenna Cassegrainian magnification factor predicted a scan angle of 0.26 degree. A 58.8-dBi-gain antenna has a 0.2-degree half-power beamwidth.

A narrowband (1690 ± 50 MHz) quarter-wave plate polarizer was used to meet the circular polarization requirement. Spare DSN WR 430 waveguide components and a WR 430 switch completed the microwave feed system. No feedhorn pointing adjustments were provided because there was confidence that the fabrication techniques of machining the correct feedhorn orientations directly into the mounting brackets would provide the required accuracy. Since machining surfaces on the feedcones customarily provide alignment for their prospective feedhorns, it was felt that accurate mounting of the L-band feedhorn brackets on the feedcone surfaces would provide the necessary pointing alignment.

Two completely redundant, cryogenically cooled (physically cooled to 14 K) L-band FET LNAs provide the necessary preamplification. The FET amplifiers were designed with 38 dB of gain and a usable bandwidth of about 200 MHz. A bandpass filter in front of the amplifiers is used to limit the bandwidth response of the FET amplifier to about 100 MHz (1668 ± 50 MHz). This was done to prevent out-of-band noise (at 2100 MHz) from the S-band transmitters of co-situated antennas in Spain and Australia and to prevent known RFI threats from saturating the preamplifiers. (A signal level approaching –40 dBm may be enough to saturate these FETs.)

The complete cooled FET system, with horn, polarizer, and waveguide, was assembled and tested to determine the microwave temperature contribution to the overall system T_{op}. The temperature contribution was determined to be approximately 10 K for the hardware and 14 K for the L-band FET LNA. Adding the temperature contributions and including 5 K for cosmic noise plus spillover and 1-K follow-on, the predicted system T_{op} was 30 K at zenith.

An L-band to S-band upconverter is used to convert the output of the L-band FETs to S-band. This allowed use of all station S-band receiver equipment necessary to meet the Vega telemetry processing requirements. In effect, the stations are transparent to the fact that L-band, not S-band, is being received. The upconverter further limits the bandwidth of the L-band system to 10 MHz, fixing the total bandwidth of the overall L-band receive system at 1668 ± 5 MHz.

A complete component-by-component description of the L-band microwave system can be found in the two L-band operation and maintenance manuals [3], [4]. Figure 3 is a block diagram of the complete system.

IV. Performance Measurements

The last of the L-band equipment was being installed on the 64-meter antennas at the time of the two Vega spacecraft launches. The remaining five-month period to the Venus encounter was used to track the Vega spacecraft, with very limited time to calibrate the L-band system. The minimal time available for antenna testing was used only to verify that the L-band microwave system met its design specification. This involved measuring the scan offset, system efficiency, and T_{op}. The 64-meter antenna 100 percent efficiency ratio of 1.166 K/jansky, along with the flux values of calibration sources (listed at 1665 MHz in the *Astronomical Almanac* [5]), was used to determine the antenna efficiency.

The measured values for gain, T_{op}, and scan offset on the three 64-meter antennas are shown in Table 1. As can be seen from the table, all efficiency values seem to be low by approximately 12 percent, and the T_{op} appears to be high by the same amount.

The possibility that more than 0.1 dB of loss was being caused by scan loss, beam broadening, or other antenna anomalies was excluded when the measured scan offset and measured half-power beamwidth were considered. The predicted scan offset of about 0.26 degree was subsequently measured to be 0.26 degree, and the predicted half-power beamwidth of 0.20 degree was measured to be 0.19 degree. All measurements were felt to be within 5 percent.

Tracking azimuth and elevation offsets made necessary by the specific orientation of the L-band feedhorn were the following:

El = -0.120 degree
Az = 0.232/cos (El) degree

In subsequent tracking exercises, these values proved accurate enough to point on source to within 2 arc minutes over the 20- to 80-degree elevation range. This demonstrated the ability to blind point to less than 0.2 half-power beamwidth at L-band.

V. Analysis

Because of the 12 percent efficiency value differences obtained (see Table 1), a Physical Optics (PO) analysis was made of the L-band feed configuration on the 64-meter antenna. This analysis showed a spillover higher than that originally predicted. The PO analysis values at zenith, given in kelvins, are as follows:

Antenna temperature	8.5 (cosmic plus sky plus spillover)
Feed components	10.0
FET LNA	14.0
Station follow-on	1.0
Total	33.5

This total is compatible with measured data.

Similarly, the 0.6-dB loss difference between the measured and originally predicted values was resolved by PO analysis. The analysis predicted a scan offset angle of 0.26 degree, a half-power beamwidth of 0.19 ± 0.01 degree with a slightly elliptically shaped beam (0.01-degree difference), and an on-scan axis gain of 59.46 dBi, or 70.6 percent efficiency (including a 0.03-dB scan loss and higher spillover) over a feedhorn placed on the focal ring of the 64-meter antenna. The 0.03-dB scan loss compares favorably with the approximate (0.05-dB) prediction published earlier [2]. The following additional antenna losses, expressed in decibels, must be subtracted from the PO result:

Surface RMS (97%)	0.13 dB
Spar and subreflector blockage (88%)	0.56
Feed dissipation losses (98%)	0.09
Feed mode losses (96%)	0.18
Total additional loss	0.96 dB

Adding all losses, the PO-based prediction is that the scan axis gain peak should be 58.5 dBi for an efficiency of 57 percent. This is compatible with the measured data. At least at DSS 14, another reason for the loss differential may be that these measurements were made before the full extent of FET saturation by RFI was understood. Some gain nonlinearity caused by saturation may account for the lower efficiencies reported here and by K. M. Liewer [6].

VI. Summary

This article includes all the measured data recorded during the L-band calibration sequence. Further work is needed to upgrade the L-band system to include a C-band uplink and to increase the bandwidth of the L-band to S-band upconverter. From what is currently understood of the RFI environment that exists at the Goldstone site, it is concluded that the radio science involved will not be degraded by RFI included in the wider bandwidths. It should be noted, however, that RFI spectrums of considerable power have been observed as close as 12 MHz from the Venus Balloon signal center frequency of 1668 MHz.

VII. Conclusion

The L-band microwave system met its design requirements, was successfully implemented in the short time allotted, and met all of its tracking goals.

Acknowledgments

The author would like to thank the scientists, engineers, and technicians who worked with and around him to make the microwave portion of this project a success. D. Jones provided information on blind pointing and efficiency testing at DSS 14. P. Parsons provided half-power beamwidth and offset measurements at DSS 14. A special thanks is extended to Art Freiley for doing the measurement at DSS 63 that enabled this article to be completed.

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Table 1. Calculated and measured L-band microwave system efficiency and T_{op}

Source	Efficiency, % (gain) at approximately 45 degrees of elevation	T_{op}, K	Scan offset, degrees
Estimated [2]	60 (58.8 dBi)	30	0.260
Calculated (PO)	57 (58.5 dBi)	33	0.260
Measured at DSS 14	51 (58.2 dBi)	33[a]	0.260
Measured at DSS 43	52 (58.2 dBi)	36[a]	–
Measured at DSS 63[b]	55 (58.4 dBi)	34[a]	–

[a] T_{op} determined using Y-factor methods.

[b] Measured by Art Freiley, Radio Frequency and Microwave Subsystems Section.

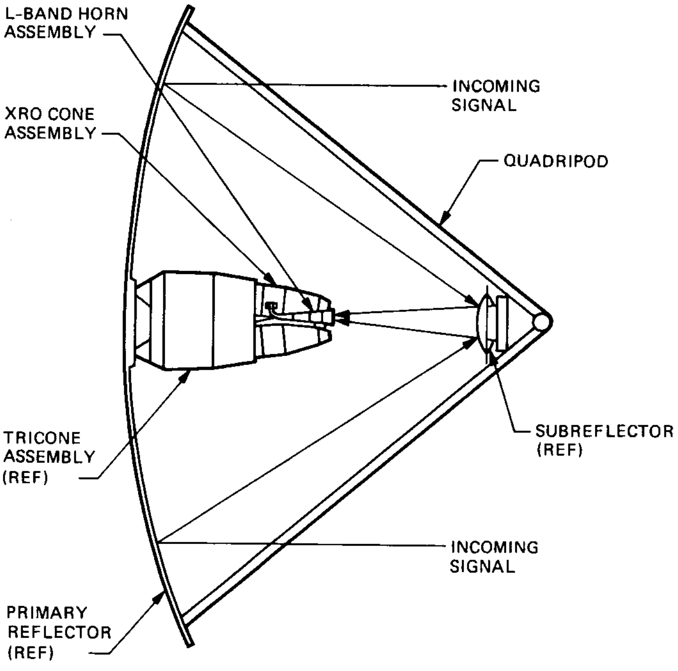

Fig. 1. L-band feedhorn antenna position

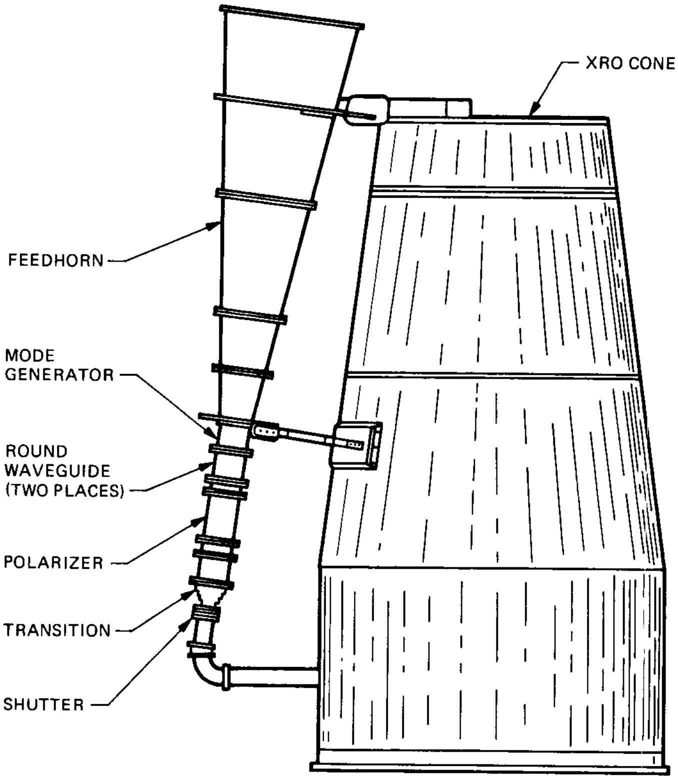

Fig. 2. L-band feedhorn geometry

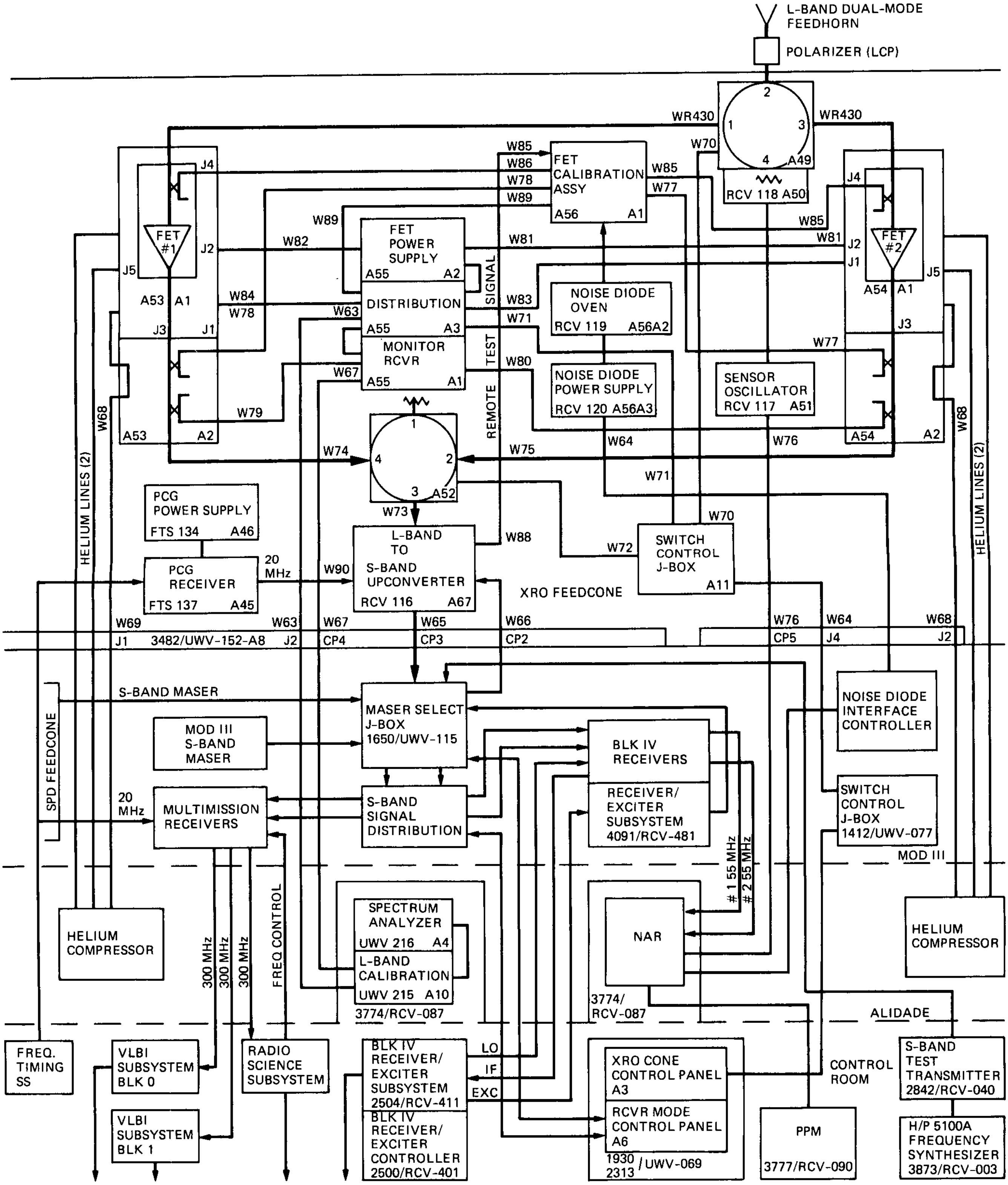

Fig. 3. Block diagram, L-band receive-only system