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The L-/C-Band Feed Design for the DSS 14 70-Meter Antenna (Phobos Mission)

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A dual-frequency (1.668 and 5.01 GHz) feed was designed for the DSS 14 70-m antenna to support the Soviet Phobos Mission. This antenna system was capable of supporting telemetry, two-way Doppler, and very long baseline interferometry (VLBI). VLBI and two-way Doppler information on the Phobos spacecraft was acquired with this antenna in 1989.

I. Introduction

Two Soviet spacecraft were launched in 1988 to observe Phobos and Mars. In cooperation with this Soviet project, the United States agreed to provide tracking and telecommunications from the DSS 14 70-m antenna at Goldstone. A dual-frequency (1.668 and 5.01 GHz) L-/C-band feedhorn was designed and installed on the antenna to support this project. This antenna system was capable of handling telemetry and two-way Doppler and was part of a very long baseline interferometry (VLBI) system. VLBI and two-way Doppler information on the Phobos 2 spacecraft was acquired with the antenna early in 1989. Unfortunately, both the Phobos 1 and the Phobos 2 spacecraft ceased functioning properly before the mission was completed.

To handle a simultaneous downlink frequency of 1.67 GHz and an uplink frequency of 5.01 GHz, a dual-frequency feed was designed which was composed of an L-band dual-mode horn [1] enclosing a thin, coaxially mounted, C-band surface-wave antenna [2]. A photograph of this dual-frequency feed is shown in Fig. 1.

II. Dual-Frequency Feed Design

A dual-frequency feed, composed of a horn enclosing a coaxially mounted surface-wave antenna, is described in [3]. This type of feed has the ability to efficiently illuminate a Cassegrain antenna at two frequencies simultaneously. The design of this feed is facilitated by the relatively low radio frequency (RF) interaction obtainable between the horn and the surface-wave antenna. A frequency spread of 3:1 for the Phobos mission's feed allows nearly independent adjustment of the beamwidths and phase centers. Beyond the general requirements of simultaneous L-/C-band operation and low impact on the existing 70-m system, Table 1 lists the primary RF requirements of the 70-m antenna with this dual-frequency feed. A drawing of the L-/C-band feedhorn is presented in Fig. 2.

A. Surface-Wave C-Band Feed

In the design of a C-band feed for the 70-m antenna at Goldstone, the following needs were addressed:

(1) A common L-/C-band phase center for simultaneous operation.

(2) A suitable RF radiation pattern; e.g., beamwidth (10 dB) $\sim$ 26 deg, approximate Gaussian shape, and low cross-polarized radiation.

(3) Low interference with the L-band horn's radiation pattern.

(4) Ability to accommodate 15 kW continuous RF power.

(5) Circular polarization.

A surface-wave antenna that could be mounted coaxially inside the L-band horn was selected to satisfy the above needs. This C-band feed was composed of two main parts: an artificial dielectric rod, in this case a disc-on-rod [2] that supports a surface wave, and a launching horn that excites a surface wave on the disc-on-rod. The major challenge of this design was to obtain a high surface-wave (HE_{11}-mode) launching efficiency. Higher launching efficiency allows greater isolation from the L-band horn and greater control over the C-band RF radiation pattern. Improved launching efficiency was accomplished in two ways. First, the TE_{11}-mode smooth-wall launching horn used in [2] was discarded and an HE_{11}-mode corrugated horn was used for a better match with the HE_{11}-mode surface-wave antenna. Second, the surface-impedance taper at the input of this antenna was optimized for high surface-wave launching efficiency.

Over most of the length of the disc-on-rod, the surface-impedance profile, controlled by varying the disc diameter along a constant diameter rod, was designed to balance two conflicting needs: first, to couple the surface wave tightly enough to minimize its interaction with the surrounding L-band horn and, second, to couple the surface wave as loosely as practical to minimize the resistive loss. Over the length of this disc-on-rod, after the input launching taper, the disc diameter was gradually made smaller in a series of straight sections and tapers. Finally, the surface wave was coupled loosely enough to achieve the needed effective aperture at the radiating end of the disc-on-rod. The length of the disc-on-rod was adjusted to collocate its phase center with that of the surrounding L-band horn (approximately 20 in. inside the aperture). Details of the disc-on-rod and launching horn are shown in Figs. 3 and 4.

The 15 kW of continuous C-band power transmitted on the surface-wave antenna presented three problems. First, the removal of the disc-on-rod's resistive heat loss of approximately 600 W was accomplished with an internal water flow (0.6 gallons per minute) through the entire length of the rod. Second, the disc-on-rod was primarily supported (in a high-power field) by aramid string tension members at regular intervals along its length. This dielectric string was small in diameter (0.025 in.) and nearly transparent to the L-/C-band propagation. Third, in order to protect the L-band low-noise amplifier from the transmitted C-band power, isolation was provided by tight coupling of the surface wave near the base of the L-band horn and the addition of a bandpass filter in the L-band waveguide.

Two additional components were designed as part of the C-band feed: first, a coaxial waveguide, TE_{11}-mode, quarterwave-plate polarizer, and second, a rectangular-waveguide-to-coaxial-waveguide transition in which an inductive post was mounted to impedance-match the C-band feed to the transmitter.

B. L-Band Feed

The L-band feed was made up of a dual-mode "Potter" horn [4], a four-arm waveguide network to bypass the C-band input, a suppressor for unwanted modes in the circular waveguide, and a circular-to-rectangular-waveguide transition. The L-band feedhorn was a sheet metal dual-mode antenna with a TE_{11}/TM_{11}-mode converter step (see Fig. 2). The L-band received signal was extracted by a symmetric, four-arm network just forward of the C-band launcher, and the signal was recombined just behind the C-band input. This L-band network not only made room for the C-band input, but also served as a circular polarizer by the fact that one opposing pair of arms was one quarter of a guide wavelength longer than the other pair.

The L-band horn was impedance-matched over a 5 percent bandwidth primarily by adjusting the axial position of the C-band launch horn relative to that of the L-band horn and placing inductive posts in the four waveguides of the bypass network near its junction with the L-band horn.

The L-band mode suppressor consisted of diagonally opposed probes inserted into a circular waveguide orthogonal to the desired TE_{11} mode's E-field and phased to couple higher order propagating modes (TM_{01} and TE_{21}) to a resistive load. Without this suppressor, higher order mode resonances occurred within the feed at L-band.

III. Results

The dual-frequency feed was put through a series of RF tests[1] including pattern, voltage standing wave ratio (VSWR), L-/C-band isolation, high power, and noise temperature. Typical amplitude and phase RF radiation patterns for this L-/C-band feed are shown in Figs. 5 and 6. The VSWR was less than 1.14:1 at L-band and less than 1.08:1 at C-band. The isolation provided by this feed geometry between the C-band input and the L-band output was greater than 38 dB. The high-power tests included a 15 kW run for 4 hr continuously with no anomalies. The L-band feed noise temperature was 8.15 K.

The dual-frequency feed was mounted on the DSS 14 70-m antenna and system tests were performed. Details of the 70-m system test with this L-/C-band feed in place are given in [5]. Table 2 summarizes the test results. The system was in compliance with the requirements listed in Table 1 except that the L-band system temperature was 35.3 K instead of the required 35 K or less.

[1] For a detailed account of these tests, see M. Gatti, *C-/L-Band Feed Test Summary*, JPL Interoffice Memorandum 3334-88-052 (internal document), Radio Frequency and Microwave Subsystems Section, October 18, 1988.

References

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[2] S. A. Brunstein and R. F. Thomas, "Characteristics of a Cigar Antenna," *JPL Quarterly Technical Review*, vol. 1, no. 2, Jet Propulsion Laboratory, Pasadena, California, pp. 87–95, July 1971.

[3] S. Narasimhan and M. S. Sheshadri, "Propagation and Radiation Characteristics of Dielectric Loaded Corrugated Dual-Frequency Circular Waveguide Horn Feeds," *IEEE Trans. Antenna Propagat.*, vol. AP-27, no. 6, pp. 858–860, November 1979.

[4] P. D. Potter, "A New Horn Antenna with Suppressed Sidelobes and Equal Beamwidths," *Microwave J.*, vol. VI, no. 6, pp. 71–78, June 1963.

[5] S. Gatti, A. J. Freiley, and D. Girdner, "RF Performance Measurement of the DSS-14 70-Meter Antenna at C-Band/L-Band," *TDA Progress Report 42-96*, vol. October–December 1988, Jet Propulsion Laboratory, Pasadena, California, pp. 117–125, February 15, 1989.

Table 1. RF requirements

Parameter	C-band	L-band
Bandwidth, MHz	5010 ±10	1668 ± 40
Gain, dBi	—	≥ 57
Effective isotropic radiated power, dBm	≥ +138	—
Noise temperature, K	—	< 35
Polarization	Right circular	Left circular
Ellipticity, dB	< 2	< 2
Power, kW	≥ 15	—

Table 2. Measured RF performance

Parameter	C-band	L-band
Bandwidth, MHz	5010 ±10	1668 ± 40
Gain, dBi	—	59.5
Effective isotropic radiated power, dBm	+138.3	—
Noise temperature, K	—	35.3
Polarization	Right circular	Left circular
Ellipticity, dB	< 2	< 2
Power, kW	≥ 15	—

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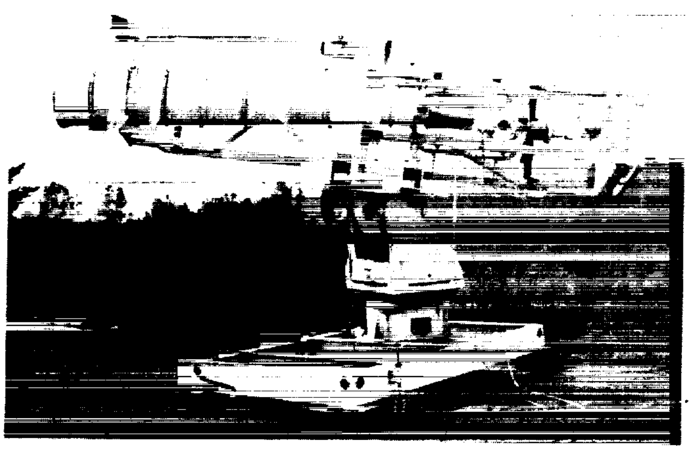

Fig. 1. L-/C-band feed.

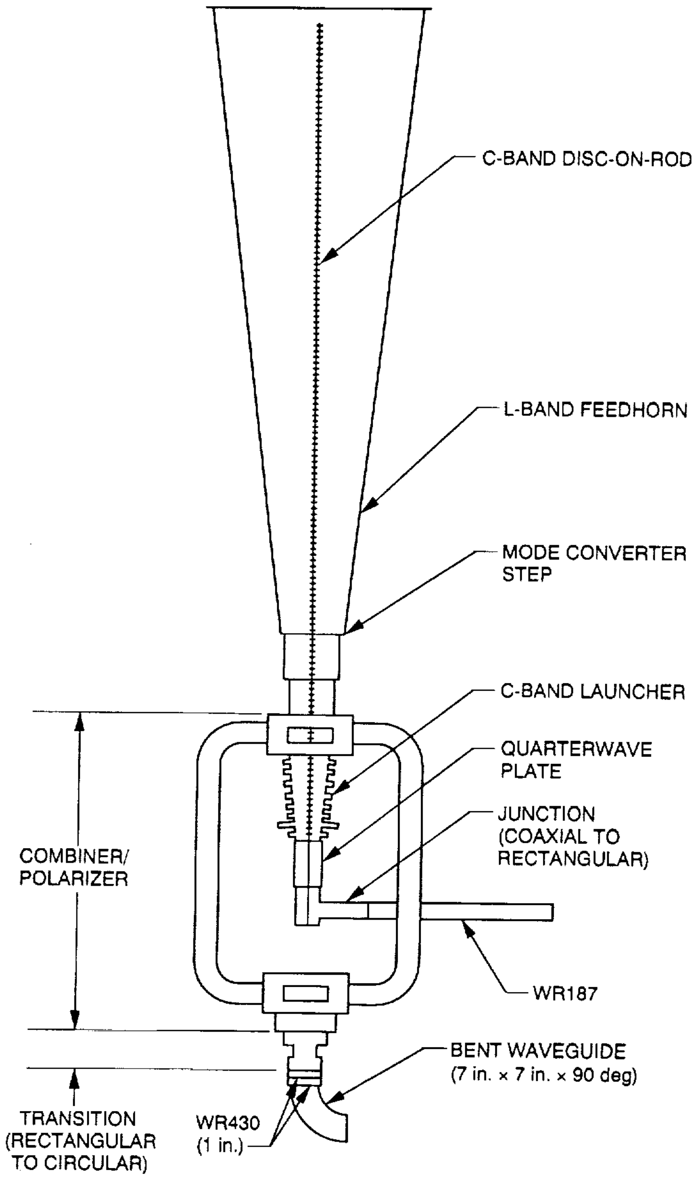

Fig. 2. L-/C-band dual-frequency feed system.

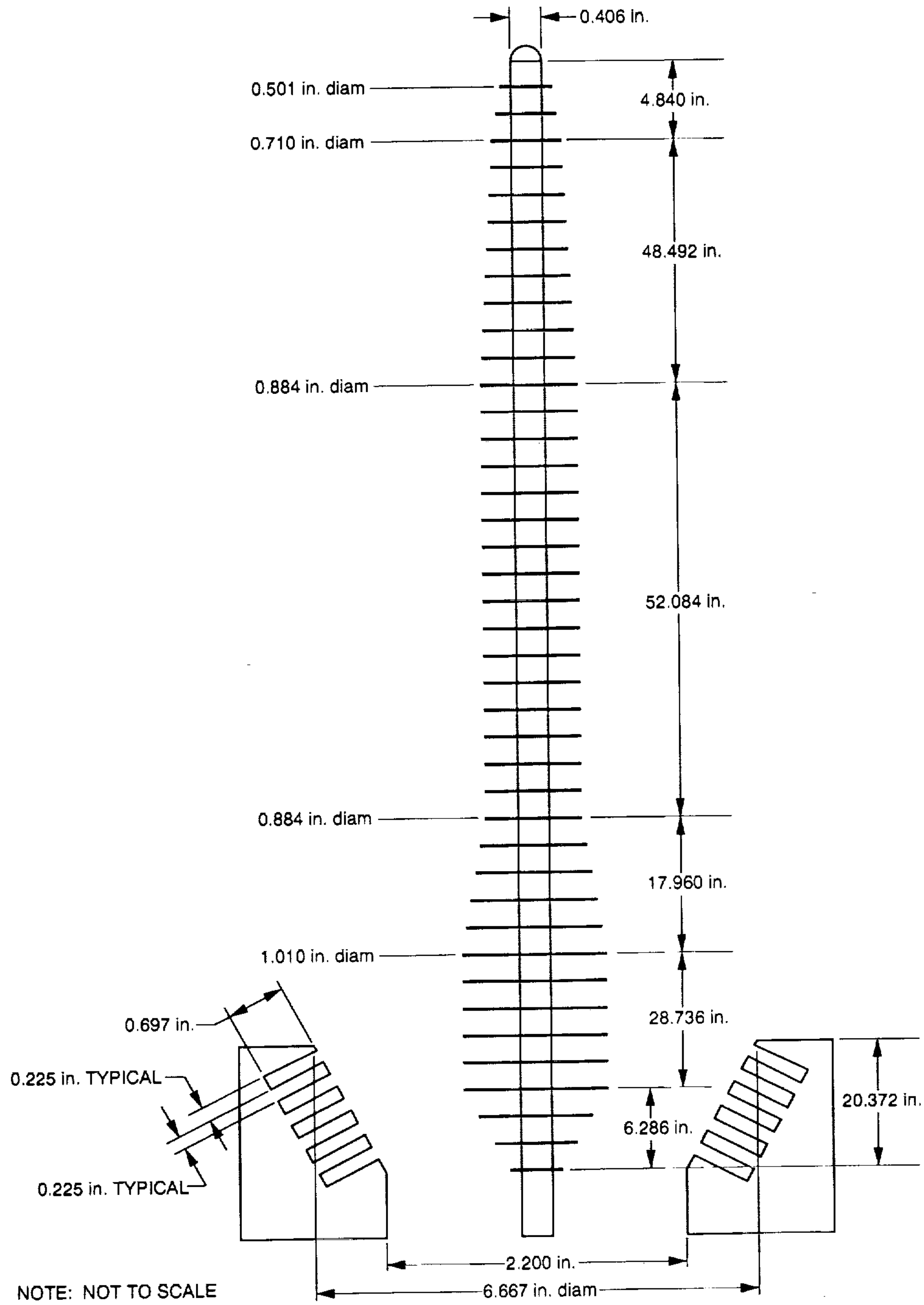

Fig. 3. C-band disc-on-rod and launching horn.

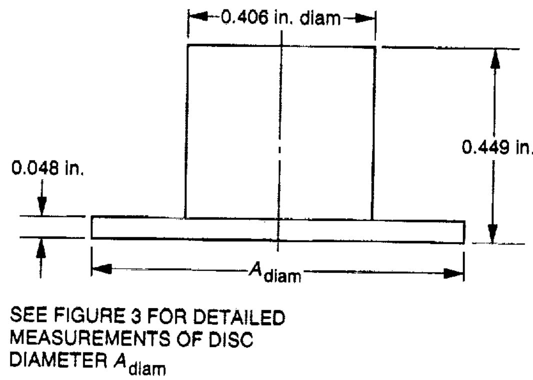

Fig. 4. Element detail of disc-on-rod.

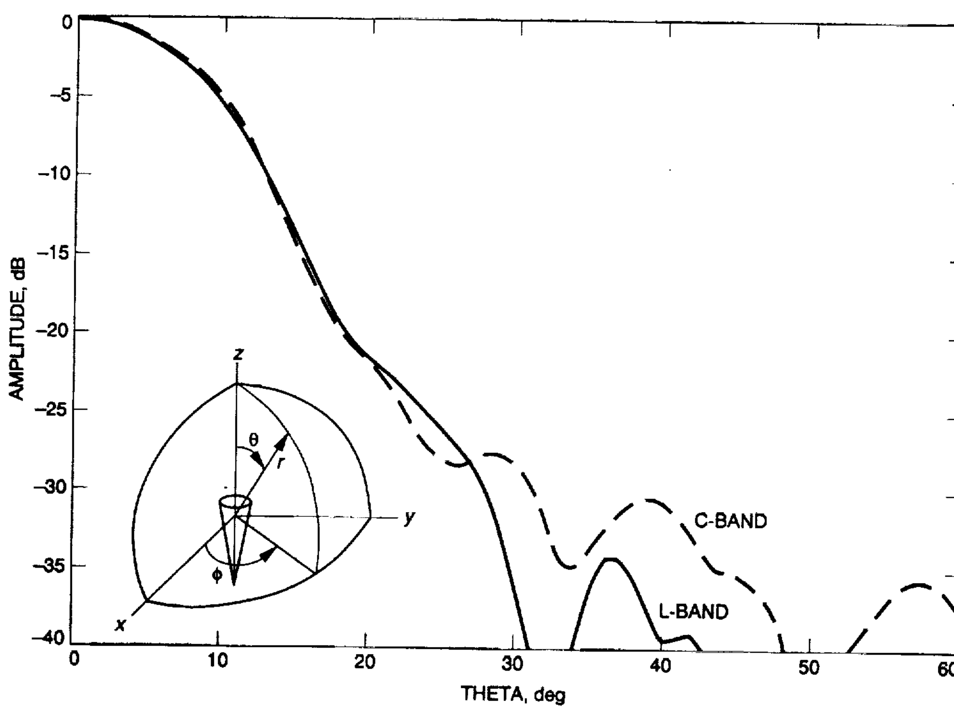

Fig. 5. Amplitude of L-/C-band feed pattern.

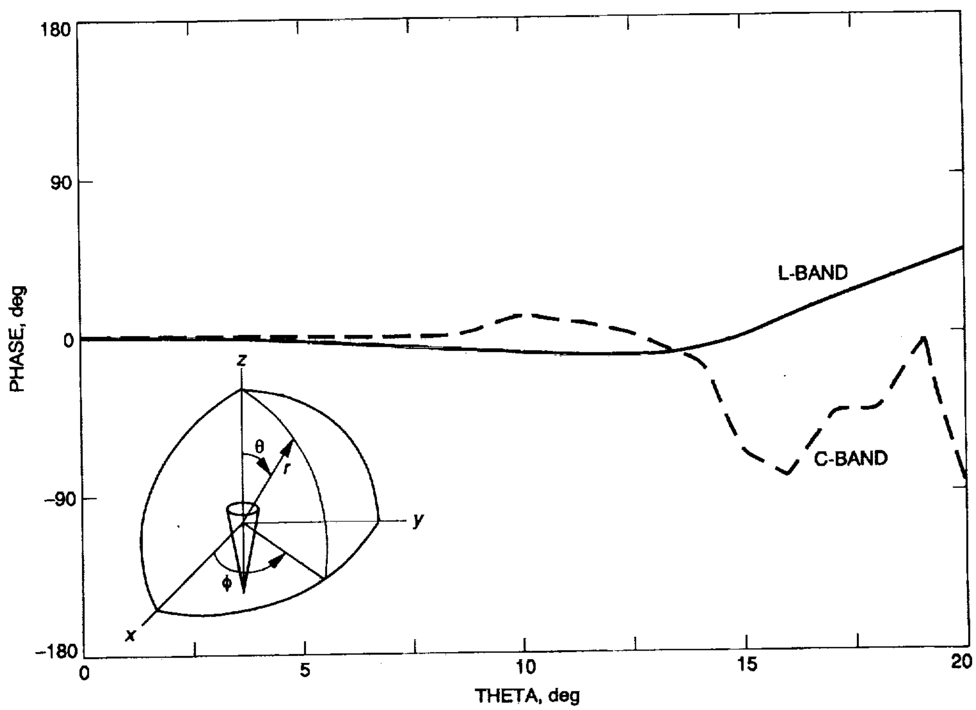

Fig. 6. Phase of L-/C-band feed pattern.