Microwave Time Delays for the Dual L-C-Band Feed System

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A new dual-frequency feed system at Goldstone is designed to receive the Phobos spacecraft signal at L-band (1668 ±40 MHz) and transmit to the spacecraft at C-band (5008.75 ±5.00 MHz) simultaneously. Hence, calculations of the time delay from the C-band range calibration coupler to the phase center of the L-C dual feed and back to the L-band range calibration coupler are required to correct the range measurements. Time delays of the elements in the dual-frequency feed system are obtained mostly from computer calculations and partly from experimental measurements. The method used and results obtained are described in this article.

I. Introduction

The L-C dual-frequency system involves placing a C-band feed inside the L-band feedhorn on the centerline (Fig. 1) [1]. The C-band disc-on-rod, which is physically thin and has minimal effect on the radiation from the L-band feedhorn, was designed using the phase velocity (V_p) data of the disc-on-rod antenna (cigar antenna) [2]. The C-band wave is tightly coupled to the surface of the disc-on-rod so that it is relatively independent of the L-band horn surrounding it. Therefore, the L-band and C-band time delays may be calculated independently.

II. Time Delay at L-Band

The L-band feedhorn and the C-band disc-on-rod compose a coaxial feed which is analyzed using a mode-matching method [3, 4]. In order to apply the coaxial computer program, the disc-on-rod is decomposed into a combination of discs and short rods and the L-band horn is decomposed into short circular waveguides with different radii. There are 585 coaxial sections for the L-C coaxial feed in the program. The program calculates the modes propagating from each discontinuity between coaxial sections from the feedhorn throat to the radiating aperture of the L-band horn. The coaxial program also computes the amplitude and phase of the transmission coefficient (S_{21}) for each mode at each L-band frequency. The three dominant modes are TE_{11}, TM_{11}, and TE_{12}, with power distributions of approximately 81.29 percent, 15.92 percent, and 2.79 percent respectively (Fig. 2). The time delay for each mode is obtained according to the following equation [5]:

$$t_g = \frac{d\phi}{2\pi df}$$

where ϕ is the transmission phase and f is the frequency. The time delay of the L-band is the sum of the time delays of TE_{11}, TM_{11}, and TE_{12} multiplied by the respective power distribution.

The L-band rectangular-to-circular transformer (WR430 to WC504) is designed to have the same cutoff frequency

(1372.24 MHz) in each transformer section. This results in the same group velocity (V_g) in each section.

$$V_g = c\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}$$

Here c is the speed of light in a vacuum, λ is the wavelength and λ_c is the cutoff wavelength [6]. Hence, for the purpose of calculating group velocity, the transformer may be considered as a piece of straight rectangular waveguide WR430 or circular waveguide WC504. The time delay is equal to L/V_g, where L is the length of the waveguide.

The time delays of the L-band combiner/polarizer and the filter were measured with a Hewlett-Packard 8510 network analyzer. The time delays of all the elements in the L-band system at 1668 MHz are shown in Table 1. The total time delay of the L-band system from the center of the calibration coupler adapter probe to the L-band radiating aperture is 37.935 nsec. This value is then adjusted for the distance to the phase center, which is in the center of the L-band feedhorn and 20 inches away from the L-band feed aperture. The adjusted time delay is 36.443 nsec.

III. Time Delay at C-Band

A C-band corrugated horn (launcher) launches the C-band wave onto the disc-on-rod, which is in the center of the C-band launcher and the L-band feedhorn. Although they also form a coaxial feed, the large radius of the L-band horn with respect to the C-band wavelength makes a complete analysis using the coaxial program impractical. Before entering the L-band feedhorn, the C-band wave is already trapped well onto the disc-on-rod. Since the C-band wave is coupled tightly to the disc-on-rod, it is not influenced by the large-diameter L-band horn. The ratio of free-space wavelength to wavelength on the disc-on-rod antenna as a function of normalized disc depth [1] gives a good estimate of the time delay of the disc-on-rod in free space, which is approximately equivalent to the time delay of the disc-on-rod in the L-band feedhorn. The time delay of the C-band disc-on-rod is calculated partly with the coaxial program and partly using the phase velocity of the disc-on-rod antenna given in [1].

The polarizer (quarter-wave plate) may be considered to be a combination of two coaxial waveguides with different outer radii and a 90-degree phase difference. The time delay of the quarter-wave plate was taken to be the average of time delays of these two coaxial waveguides as computed by the coaxial program.

The rectangular-to-coaxial waveguide junction may be decomposed into the rectangular waveguide and the coaxial waveguide. The time delay of the rectangular-to-coaxial waveguide junction is the sum of the time delay of the rectangular part and the time delay of the coaxial part which was obtained from the coaxial program.

The time delay of each element in the C-band system at 5008.75 MHz is shown in Table 2. The total time delay of the C-band system from the center of the calibration coupler adapter probe to the L-band feed aperture is 25.610 nsec. This value is also adjusted to the phase center of the disc-on-rod which is the same as that of the L-band horn. The adjusted time delay is 23.918 nsec.

Acknowledgments

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References

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Table 1. Time delay of each element in the L-band system from the phase center to the center of the calibration coupler adapter at 1668 MHz

Element	t_g, nsec
L-band horn	10.54767
Combiner/polarizer	13.127
Transformer (WR-WC)	1.24856
WR430 (1 in.) × 2	0.14908 × 2
Bent waveguide (7 in. × 7 in. × 90 deg) × 3	1.63918 × 3
Filter (25 in.)	4.6348
Coupler (8.5 in.)	1.26715
Adapter (2.6 in. to center)	0.40251
Total time delay	36.443

Table 2. Time delay of each element in the C-band system from the phase center to the center of the calibration coupler adapter at 5008.75 MHz

Element	t_g, nsec
C-band horn and disc-on-rod	14.27128
Polarizer (quarter-wave plate)	0.80277
Junction (WR-coax)	0.51666
WR187 (44 in.)	4.79729
Bent waveguide (4 in. × 4 in. × 60 deg)	0.68505
WR187 (18.5 in.)	2.01704
Coupler (5 in.)	0.54515
Adapter (2.6 in. to center)	0.28348
Total time delay	23.918

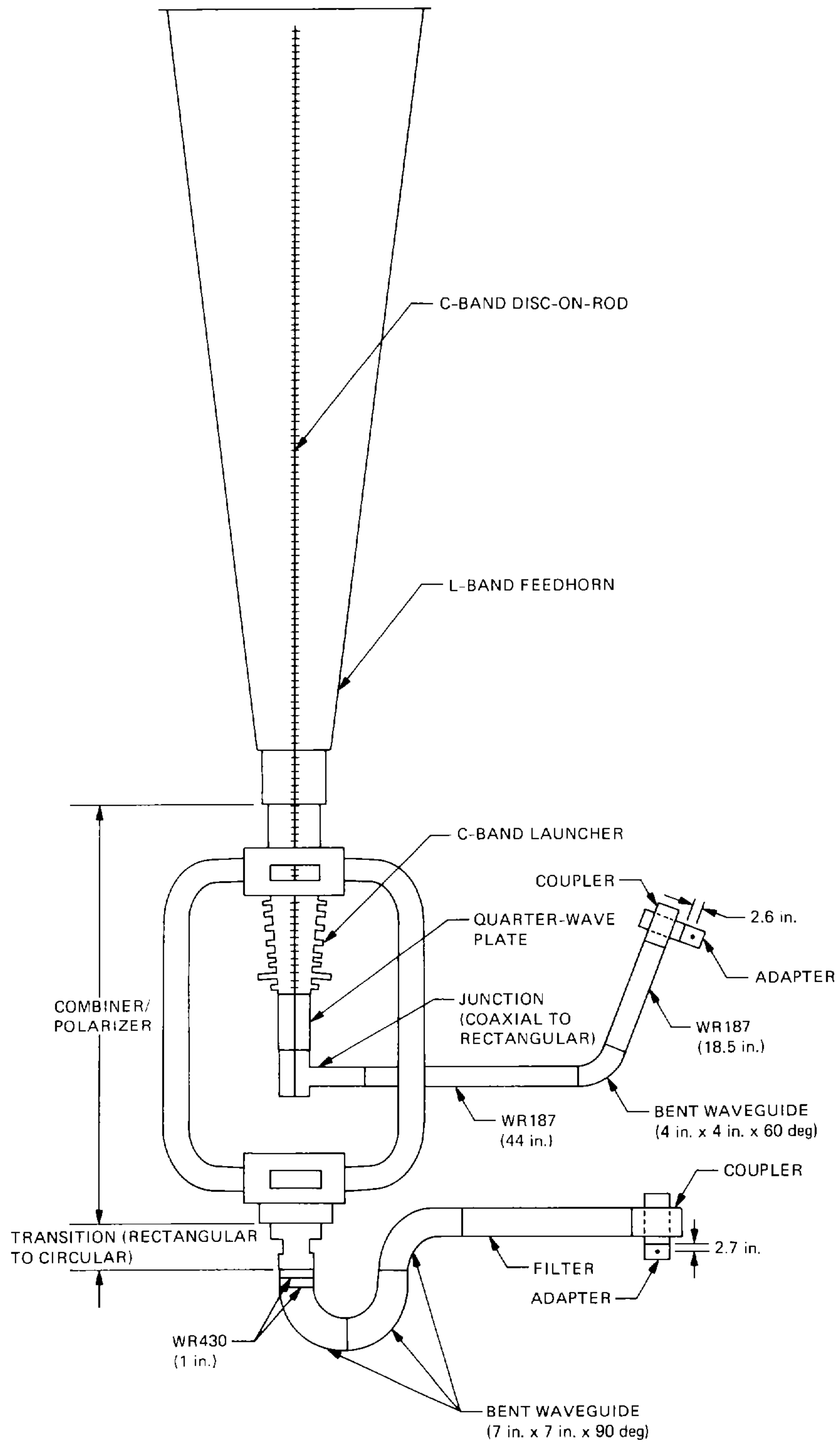

Fig. 1. L-C dual frequency feed system.

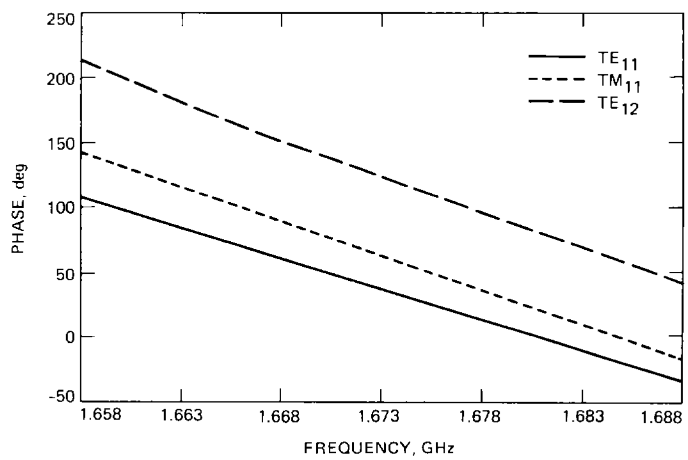

Fig. 2. Phase of the transmission coefficient versus frequency for the L-band feedhorn with a taper.