Multipath Effects on the Time Delays of Microwave Cassegrainian Antennas

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Preliminary results of a theoretical study of multipath errors on antenna time delays are discussed. A computer program has been developed to simulate multipath scattering between cone surfaces and the subreflector.

I. Introduction

During the early years of development of Cassegrainian antennas for space applications, the emphasis was on high-gain and low-noise performance. More recently, it has become equally important for deep space tracking antennas to have a high degree of phase and group delay stability as a function of antenna pointing angles and environmental changes.

Requirements for measurements of group delay through the antenna originated from navigation requirements for updated information on the absolute range (distance) of a spacecraft from earth-based tracking stations. More accurate measurement requirements later evolved from radio science projects which needed antenna time delay information for such experiments as electron content measurement in the interplanetary media and for verification of Einstein's general theory of relativity which involved using time delayed spacecraft signals passing through the solar corona. More recently, knowledge of antenna group delay and delay stability has become very important to such projects as ARIES for Earth crust movement studies, Very Long Baseline Interferometry (VLBI) for determining station locations, and VLBI clock synchronization work.

When a large antenna is used to track a signal coming from a spacecraft or VLBI radio source, gravity loading causes deformations of the antenna structure as a function of antenna pointing angle. The antenna time delay change due to gravity loading could cause significant errors in station location determination if the effect of this error-source is not analyzed and accounted for. A primary cause of time delay changes of Cassegrainian antennas (due to gravity loading) is defocusing of the subreflector. This paper discusses two forms of subreflector defocus-related time delay changes. These are time delay changes in the absence and in the presence of multipath signals.

II. Effects of Subreflector Defocusing

A. Primary Signal Delay

Figure 1 shows the geometry of a Cassegrainian antenna with an S- and X-band reflex feed system. The cones are aluminum housings which contain feed assemblies as well as transmitter and receiver equipment. A single ray is shown to depict a typical primary ray path, but it is understood that the farfield signal is a plane wave and similar rays impinge upon the entire dish surface and subsequently arrive at the receive horn via the Cassegrainian antenna optical paths.

In the past when more accurate values of time delays were not required, it was reasonable to assume that the RF path length change resulting from subreflector defocusing was just twice the distance that the subreflector was defocused. A more careful study (Ref. 1) of the typical 64 m Cassegrainian antenna showed that the path length change is closer to 1.76 times the defocused distance, as shown in Fig. 2. For this result, the feed horn pattern was accounted for and amplitude and phase relationships precisely calculated after finding the specular reflection points on the subreflector in the defocused positions. This more rigorous treatment is necessary because these data will be useful for modeling and correcting one of the VLBI measurement errors caused by antenna time delay changes.

B. Multipath Error

An error that is difficult to model and analyze accurately is the multipath error. It is currently one of the largest uncertainties in VLBI measurements. This error is caused by a small portion of the primary rays undergoing multiple reflections between the cone surfaces and the subreflector. Near-field experiments using time domain instruments have pinpointed the cone roof and cone support platform as the dominant multipath generating surfaces. The composite multipath signal combines in and out of phase with the primary signal when the subreflector defocuses. This results in a cyclical error pattern not only in amplitude and phase but also in the group delay characteristics of the antenna (e.g., see Fig. 2). The existence of these multipath signals was also verified by a farfield experiment (Ref. 2) that involved measurements of the round trip group delay changes while ranging to the Viking spacecraft in its interplanetary flight to Mars.

III. Computer Program

In order to correlate experimental results to theory, a theoretical analysis was performed and a computer program developed for the multipath geometry, shown in Fig. 3. Although the multipath sources cannot be modeled exactly, the computer-aided analysis is very useful for verifying sensitivity of the multipath errors to antenna geometry and frequency and also for establishing bounds of the error magnitudes. In this computer program, cone reflecting surfaces are simulated by a circular plate whose diameter and location along the axis of dish symmetry are selectable.

In determining the initial paraboloid illumination, the three "first-order" rays considered are: (Fig. 3a)

(1) feed → hyperboloid → P: R_1

(2) feed → hyperboloid edge #1 → P: E_{11}

(3) feed → hyperboloid edge #2 → P: E_{21}

In determining the dominant components of higher-order scattering, the following multiply-reflected rays have been included: (Fig. 3b).

(4) feed → hyperboloid → plate → hyperboloid → P: R_3

(5) feed → hyperboloid → plate → hyperboloid edge #1 → P: E_{13}

(6) feed → hyperboloid → plate → hyperboloid edge #2 → P: E_{23}

(7) feed → hyperboloid → plate upper edge → P: E_{P3}

Where necessary, the blocking effects by the plate have been accounted for. All transition region effects have been accounted for using the method of Kouyoumjian and Pathak (Ref. 3) although, under far-field assumptions, the Uniform Asymptotic Theory treatment (Ref. 4) produces nearly the same numerical values. An iterative solution of the geometrical-optics problem permits arbitrary positioning of the feed, hyperboloid, and plate (Ref. 1).

IV. Results

A typical result from the computer program is shown in Fig. 4. The result is for a geometry consisting of a circular plate 569 cm in diameter placed 519 cm behind the S-band feed horn of a 64-m Cassegrainian antenna. The far field phase was first computed in the presence of multipath and then in the absence of multipath and then differenced. These calculations were done at two VLBI microwave frequencies f_2 and f_1. From these data the time delay change due to multipath can be calculated at any subreflector defocus position from the VLBI bandwidth synthesis equation $\Delta\tau = -[\Delta\phi_2 - \Delta\phi_1]/[360(f_2 - f_1)]$ where $\Delta\phi_2$ and $\Delta\phi_1$ are the data in Fig. 4. Comparisons between experimental data from S- and X-band multipath tests and results of the computer program described in this paper will be presented in a future report.

References

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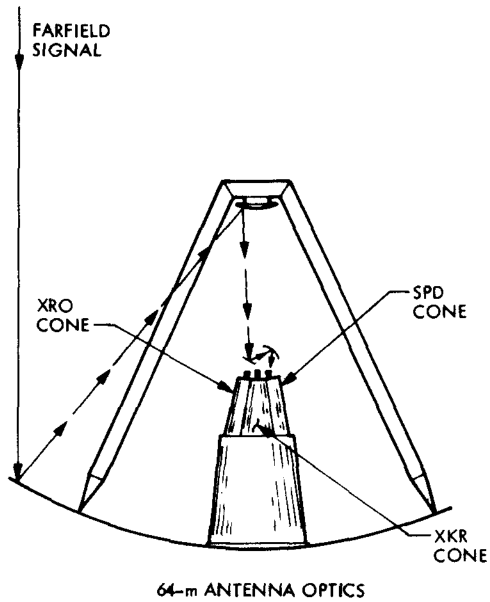

Fig. 1. 64-m-diameter Cassegrainian antenna optics of a reflex-feed system

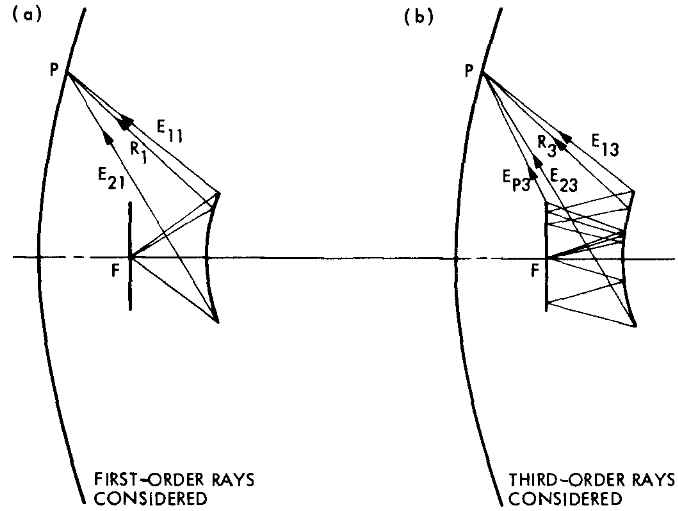

Fig. 3. Geometry for multiply-reflected rays from a circular plate on Cassegrainian antenna

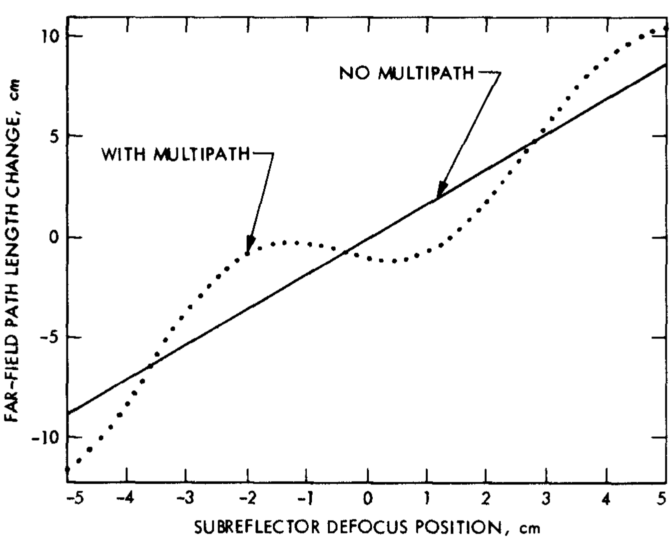

Fig. 2. Theoretical far-field delay due to subreflector defocusing on 64-m antenna at 2285 MHz center frequency and 40 MHz spanned bandwidth

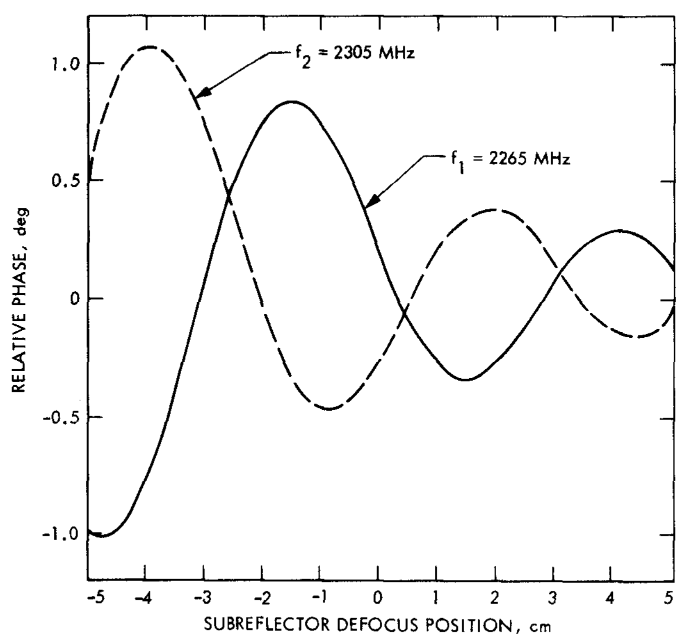

Fig. 4. Example of far-field phase ripple due to multipath and defocusing