Ground Tracking System Phase Fluctuation Spectra

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Spectral analysis of solar wind plasma fluctuation requires knowledge of the average ground tracking system phase fluctuation spectrum. This article presents typical ground tracking system phase fluctuation spectra as deduced from two-way S-band doppler noise measured at large Sun-Earth-Probe angles.

I. Introduction

An extremely important tool in solar wind investigations is the spectral analysis of either single-frequency (S) or dual-frequency (S-X) doppler phase fluctuations. As a part of this analysis, one needs to know something about the spectral characteristics of phase fluctuations induced in the ground tracking system, so that this effect may be separated out or at least known to be insignificant when compared to the particular solar-wind-induced phase fluctuations being analyzed. In Reference 1, test results are documented of measured two-way S-Band doppler (phase) noise for the Pioneer 10, Pioneer 11, Helios 1, and Helios 2 spacecraft when they were at large Sun-Earth-Probe (SEP) angles, so that the solar wind contribution (to the doppler noise) was minimized. The doppler noise was computed for sample intervals between 1 and 60 seconds, with the number of doppler samples fixed at 15 in all cases, hence resulting in an observational time scale proportional to sample interval. Reference 2 presents a method whereby sample interval dependent doppler noise is easily converted to the equivalent fluctuation spectrum; it will thus be the purpose of this article to translate the average doppler phase fluctuation (noise) data from Reference 1 into equivalent phase fluctuation spectra.

II. Measured Ground Tracking System Average Phase Fluctuation Spectra

In Reference 2 it was found that the relationship between doppler noise produced by the Network Operations Control Center (NOCC) tracking validation software doppler noise algorithm[1] and RMS phase (ϕ) was:

$$\phi(\tau) \cong \frac{5}{3}\tau \cdot \text{noise}(\tau)$$

$$\tau = \text{doppler sample interval, s}$$

Reference 2 further assumed that the relationship between doppler sample interval and phase fluctuation frequency (ν) was:

$$\nu \approx (30\,\tau)^{-1}$$

[1] A "running" standard deviation computed from a least squares linear curve fit to 15 samples of actual minus predicted (average) doppler frequency.

so that the noise equivalent phase fluctuation spectrum ($P_g(\nu)$) was

$$-P_g(\nu) \equiv \frac{d}{d\nu}\{[\phi(\nu)]^2\}$$

Using this technique, the doppler noise data from Reference 1 translates to the following (ground tracking system) spectra:

Pioneer 10 : $P_g(\nu) = 1.11 \times 10^{-1}\, \nu^{-1.2}$ rad^2/Hz

Pioneer 11 : $P_g(\nu) = 1.98 \times 10^{-1}\, \nu^{-1.2}$ rad^2/Hz

Helios 1 : $P_g(\nu) = 5.00 \times 10^{-2}\, \nu^{-1.4}$ rad^2/Hz

Helios 2 : $P_g(\nu) = (1.25 \times 10^{-2}\, \nu^{-1.4} + 4.70 \times 10^{-7}\, \nu^{-3})$ rad^2/Hz

Table 1 lists the decade spaced spectral density values for each spacecraft for the phase fluctuation frequency range:

$$10\ \text{Hz} \geqslant \nu \geqslant 10^{-5}\ \text{Hz}$$

while Figure 1 presents the results in graphical form.

Although the ground tracking system is believed to be the major contributor (in combination with the particular round-trip-light-time for each spacecraft) to these fluctuation spectra, there are also spacecraft and Solar Wind components. As an example, the Helios 2 spectra for the frequency region:

$$\nu \leqslant 10^{-3}\ \text{Hz}$$

would appear to be almost solely due to solar wind plasma fluctuation, and not the ground tracking system. The most important contributor to the tracking system stability is the Deep Space Station (DSS) frequency standard, which in these cases was a rubidium standard. For the DSS which have (or will have) a hydrogen maser frequency standard, the corresponding ground tracking system phase fluctuation spectra can be expected to be substantially decreased.

References

1. Berman, A. L., "A Comprehensive Two-Way Doppler Noise Model for Near-Real-Time Validation of Doppler Data," in *The Deep Space Network Progress Report* 42-37, Jet Propulsion Laboratory, Pasadena, California, February 15, 1977.

2. Berman, A. L., "Phase Fluctuation Spectra: New Radio Science Information to Become Available in the DSN Tracking System Mark III-77," in *The Deep Space Network Progress Report* 42-40, Jet Propulsion Laboratory, Pasadena, California, August 15, 1977.

Table 1. Average phase fluctuation spectral density versus fluctuation frequency

Fluctuation frequency, Hz	Average phase fluctuation spectra, rad^2/Hz			
	Pioneer 10	Pioneer 11	Helios 1	Helios 2
10^1	7.0×10^{-3}	1.2×10^{-2}	2.0×10^{-3}	5.0×10^{-4}
10^0	1.1×10^{-1}	2.0×10^{-1}	5.0×10^{-2}	1.3×10^{-2}
10^{-1}	1.8×10^0	3.1×10^0	1.3×10^0	3.1×10^{-1}
10^{-2}	2.8×10^1	5.0×10^1	3.2×10^1	7.9×10^0
10^{-3}	4.4×10^2	7.9×10^2	7.9×10^2	6.7×10^2
10^{-4}	7.0×10^3	1.2×10^4	2.0×10^4	4.8×10^5
10^{-5}	1.1×10^5	2.0×10^5	5.0×10^5	4.7×10^8

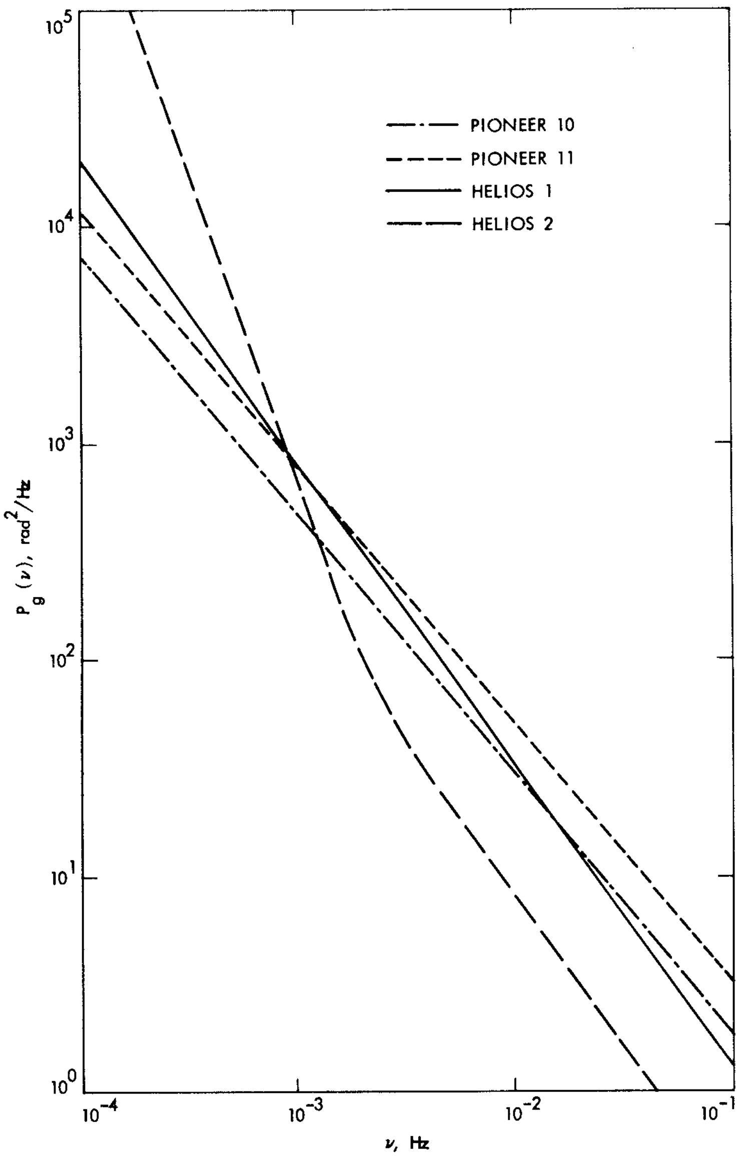

Fig. 1. Typical ground tracking system phase fluctuation spectra