The Advanced Receiver II Telemetry Test Results at Goldstone

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This article describes the telemetry performance of the Advanced Receiver II (ARX-II) in tracking and demodulating signals from various deep space missions. The tests were performed at Goldstone, and the spacecraft tracked were Pioneer 10, Pioneer 11, Voyager 2, Magellan, and the International Cometary Explorer (ICE). These missions present a broad range of operating conditions to test the ARX-II in terms of signal-to-noise ratio (SNR) and the symbol rate of the received signal.

I. Introduction

The Advanced Receiver II (ARX-II) is an all-digital receiver capable of performing various tasks [1]. Its Doppler extractor has been tested at Goldstone [2], and its telemetry performance was measured in Compatibility Test Area 21 (CTA21) [3].

In late November 1990, the received signal from Pioneer 11 exhibited unpredictable behavior. The ARX-II was sent to Goldstone to try to acquire and lock onto the received signal and demodulate the symbols. There was strong evidence that the onboard oscillator of the spacecraft was malfunctioning and that a one-way link would not be possible. Data are presented for both the one-way mode, in which the ARX-II was not able to maintain lock and did not demodulate the symbols, and the three-way mode, in which the symbols were detected. While at Goldstone, other spacecraft were tracked, including Voyager 2, Pioneer 10, Magellan, and International Cometary Explorer (ICE). The ARX-II logged data from all these signals, and some segments are presented in this article. In Section II, the ARX-II configuration in SPC-10 and the various spacecraft signals are discussed. The measured parameters are presented and discussed in Section III, followed by the conclusion in Section IV.

II. ARX-II Configuration and Spacecraft Parameters

The ARX-II was placed in SPC-10 and connected to the Very Long Baseline Interferometry (VLBI) downconverter (D/C), as shown in Fig. 1. The output of the VLBI D/C provided an intermediate frequency (IF) signal in the neighborhood of 300 MHz. The signal was further downconverted by the ARX-II, digitized, and processed to obtain carrier lock and symbol detection. In a parallel effort, the received signal was also processed by the Block IV (Blk-IV) receiver/Baseband Assembly (BBA) combination or by the Block III (Blk-III) receiver/Subcarrier Demodulation Assembly/Symbol Synchronization Assembly

(SDA/SSA) combination. Depending on the spacecraft, either the Blk-IV/BBA or the Blk-III/SDA/SSA combination was used by the station operators. Due to the urgency of the assignment, no arrangements were made to obtain data from the station receivers, and as a result, no performance comparison of the various demodulators is attempted in this article. A complete set of tests was performed in CTA21 for performance comparison; [3] contains the results.

As mentioned earlier, several spacecraft were tracked with various signal-to-noise ratios (SNRs) and symbol rates. Table 1 summarizes the key signal parameters from each spacecraft, such as received carrier power-to-noise ratio (P_c/N_0), subcarrier frequency (F_{sub}), symbol rate ($R_{sym} = 1/T_s$ where T_s denotes the symbol period), and symbol signal-to-noise-ratio (SSNR). The parameters shown are the predicts and are typically close to their measured values. Pioneer 10 represents the weakest received signal, with $P_c/N_0 = 12$ dB-Hz, a symbol rate of 32 symbols per second (sps), and SSNR = 1.0 dB. On the other hand, Magellan transmits the signal with the highest data rate, at 537.6 ksps, and with SSNR = 1.5 dB. Actually, both channels of Magellan were tracked with the lowest data rate at 80 sps and a 17.0-dB SSNR. Voyager 2 and ICE signals represent intermediate symbol rates at 1200 sps and 256 sps, respectively.

III. Measured Performance

In all the figures to follow, the parameter sets shown are the ones that the ARX-II used for tracking the received signal from the spacecraft: the loop type indicating the order of the carrier digital phase-lock-loop filter, the bandwidth of the loop B, the update period of the loop T_u, the estimation period of the logged data points T_e, and the Doppler period T_d. In the figures, the steady-state phase error ϕ_{ss}, the symbol SNR, and the frequency deviation for each case are shown.

Pioneer 11 data are presented first, for both one-way and three-way links. In the one-way mode, an attempt was made to lock onto the received carrier on DOY 293. The numerically controlled oscillator (NCO) of the ARX-II was swept at the predicted Doppler rate F_d of 0.2 Hz/sec. The estimated P_c/N_0 and the corresponding steady-state phase error ϕ_{ss} are shown in Figs. 2(a) and 2(b), respectively. Loss of carrier lock was frequently encountered, which was also experienced by the monitor and control at SCP-10. When in lock, the P_c/N_0 was estimated to be about 16 dB-Hz with a 10-deg steady-state phase error. The period of dropping lock was roughly about once every 10 sec. Open-loop data were also obtained using the ARX-II. In this case, the frequency was swept at 0.2 Hz/sec, and a fast Fourier transform (FFT), size = 512, rate = 200 Hz, was performed using 10-min data segments. For an ideal tone with a fixed frequency, one expects to observe a peak at the frequency offset. In Fig. 2(c), the peak is depicted versus time. The mean of the frequency offset was about 18 Hz, with about 40-Hz root-mean-squared (RMS) frequency excursions. Figure 2(d) depicts a histogram of the offset frequency, which is a crude estimate of the probability density function of the offset frequency. From these tests, it was concluded that the signal is experiencing frequency changes on the spacecraft transponder, with a frequency deviation of about 40 Hz.

In Fig. 3, the estimated P_c/N_0 (in dB-Hz) is shown in the three-way mode for Pioneer 11. In this case, the ARX-II was able to maintain lock and demodulate the symbols. The corresponding symbol SNR, steady-state phase error, and received frequency estimates are shown in Fig. 4. The receiver was employing a type-III loop with a 1-Hz bandwidth. Also shown in Fig. 3 are the estimates of the carrier power-to-spectral level for the other spacecraft, namely Voyager 2, Pioneer 10, ICE, and both data channels of Magellan. Pioneer 10 has the lowest received P_c/N_0 at 11 dB-Hz, and Magellan has the highest at about 43 dB-Hz (low data rate channel).

The Magellan data are presented in Figs. 5 and 6, with the low data channel in Fig. 5 and the high data channel in Fig. 6. In both cases, a type-III loop was used, resulting in zero steady-state phase errors, with a carrier loop bandwidth around 25 Hz.

Signals with medium data rates were tracked, namely those of Voyager 2 and ICE. The data are presented in Figs. 7 and 8, respectively. The estimated symbol SNR from ICE was about 1 dB, and from Voyager 2 it was about 2.5 dB. Pioneer 10 was also tracked with roughly a 0-dB symbol SNR. It has the lowest symbol rate at 32 sps, and the estimated parameters are shown in Fig. 9. A type-II loop was used resulting in a nonzero steady-state phase error.

IV. Conclusion

The ARX-II successfully tracked the signals and demodulated the symbols from Pioneer 10, Pioneer 11, Voyager 2, ICE, and Magellan. The overall carrier-to-noise spectral level and symbol SNR estimates in each case were consistent with the predicted values.

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References

[1] S. Hinedi, "A Functional Description of the Advanced Receiver," *TDA Progress Report 42-100*, vol. October–December 1989, Jet Propulsion Laboratory, Pasadena, California, pp. 131–149, February 15, 1990.

[2] S. Hinedi, R. Bevan, H. Del Castillo, P. Kinman, D. Chong, and R. Labelle, "Digital Doppler Extraction Demonstration With the Advanced Receiver," *TDA Progress Report 42-100*, vol. October–December 1989, Jet Propulsion Laboratory, Pasadena, California, pp. 160–173, February 15, 1990.

[3] S. Hinedi, R. Bevan, and M. Marina, "The Advanced Receiver II Telemetry Test Results in CTA-21," *TDA Progress Report 42-104*, vol. October–December 1990, Jet Propulsion Laboratory, Pasadena, California, pp. 140–156, January 15, 1991.

Table 1. ARX-II and spacecraft parameters

Spacecraft	DSS	P_c/N_0, dB-Hz	F_{sub}, kHz	R_{sym}, sps	SSNR, dB
ICE	14	20	1.024	256	1.0
Voyager 2	15	26	369	1200	2.5
Magellan					
Low rate	15	33	960	537,600	1.5
High rate	15	43	22.5	80	17.0
Pioneer 10	14	12	32.768	32	1.0
Pioneer 11	14	17	32.768	128	2.0

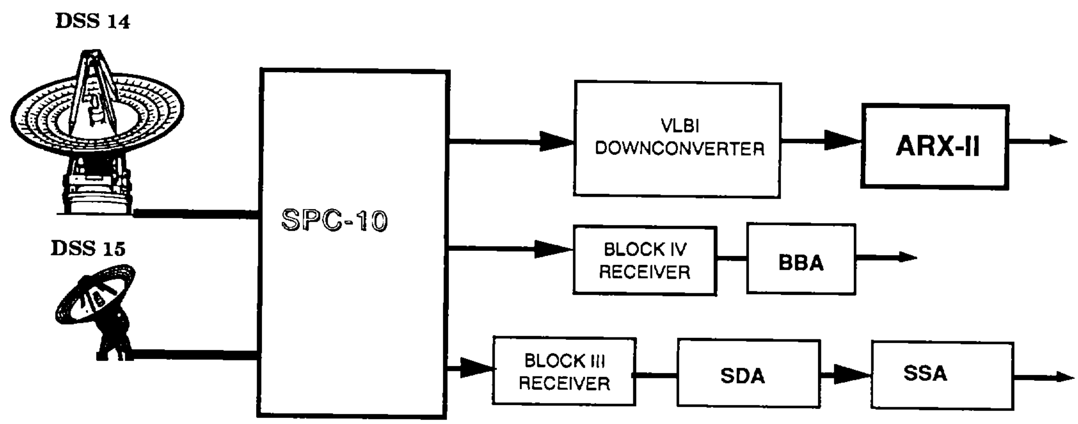

Fig. 1. SPC-10 test configuration with ARX-II.

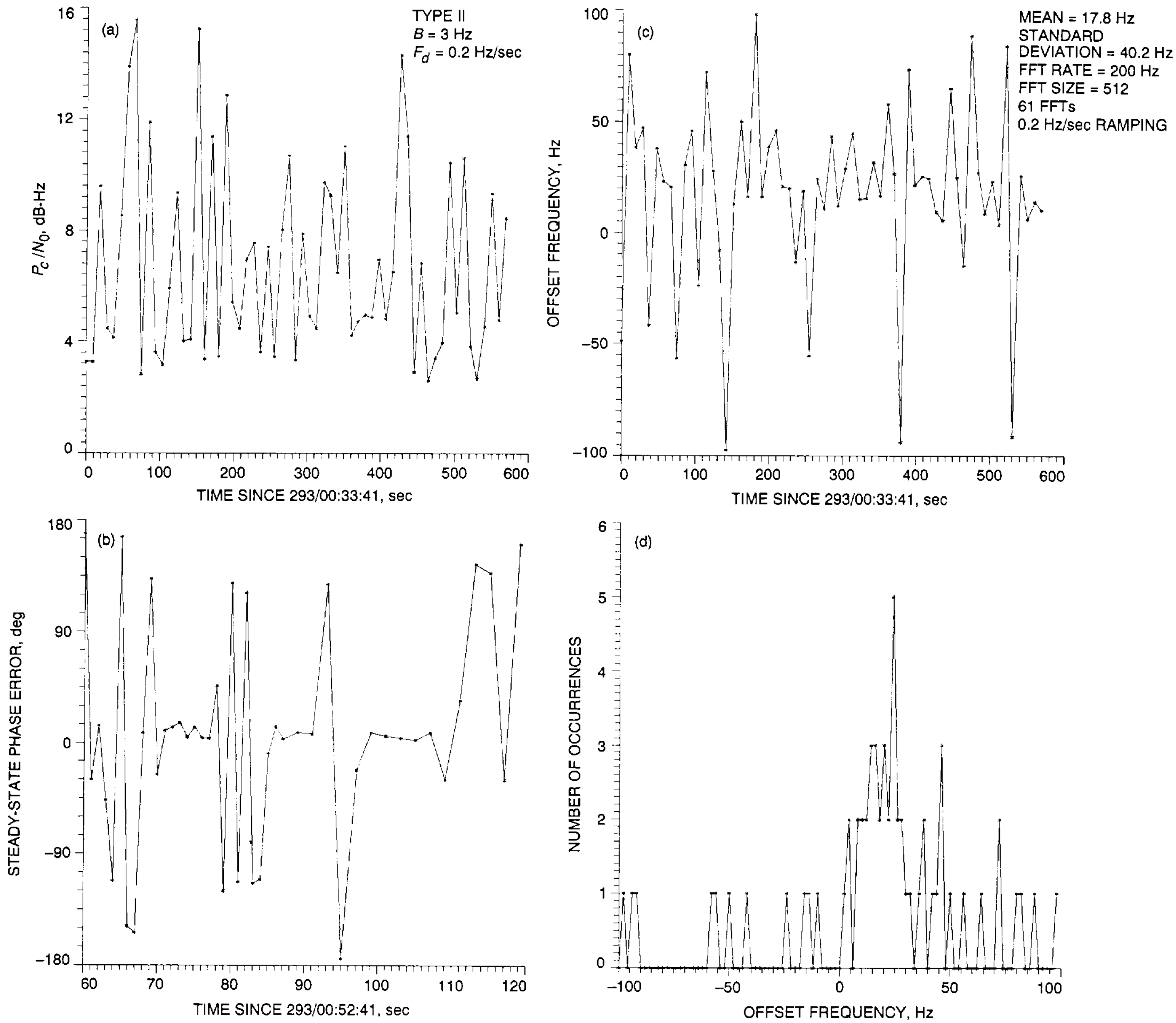

Fig. 2. Pioneer 11 one-way test results on DOY 293: (a) P_c/N_0; (b) ϕ_{ss}; (c) ΔF_c; and (d) histogram of ΔF_c.

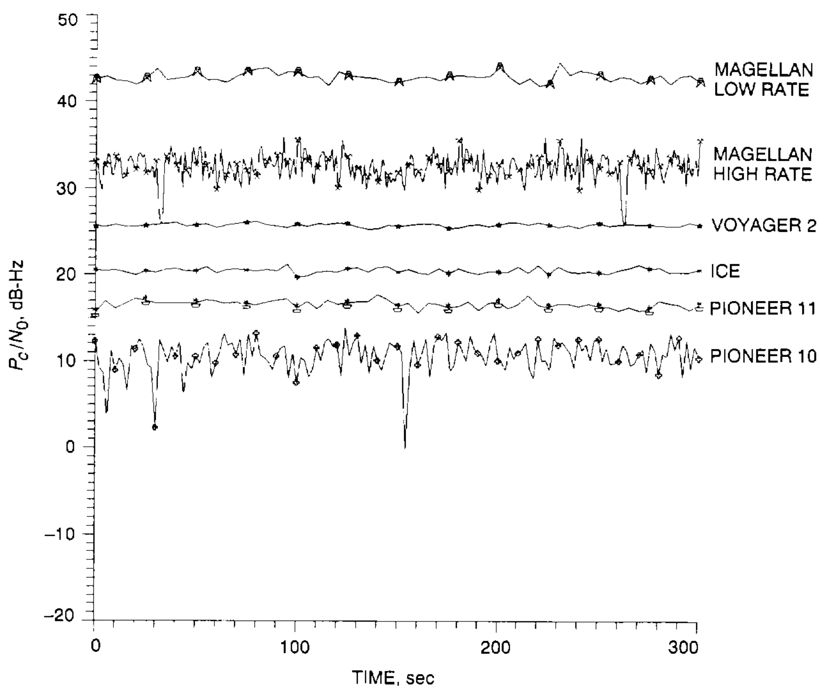

Fig. 3. Summary of test results for carrier-to-noise power (P_c/N_0 for various spacecraft; DOY 293, 299).

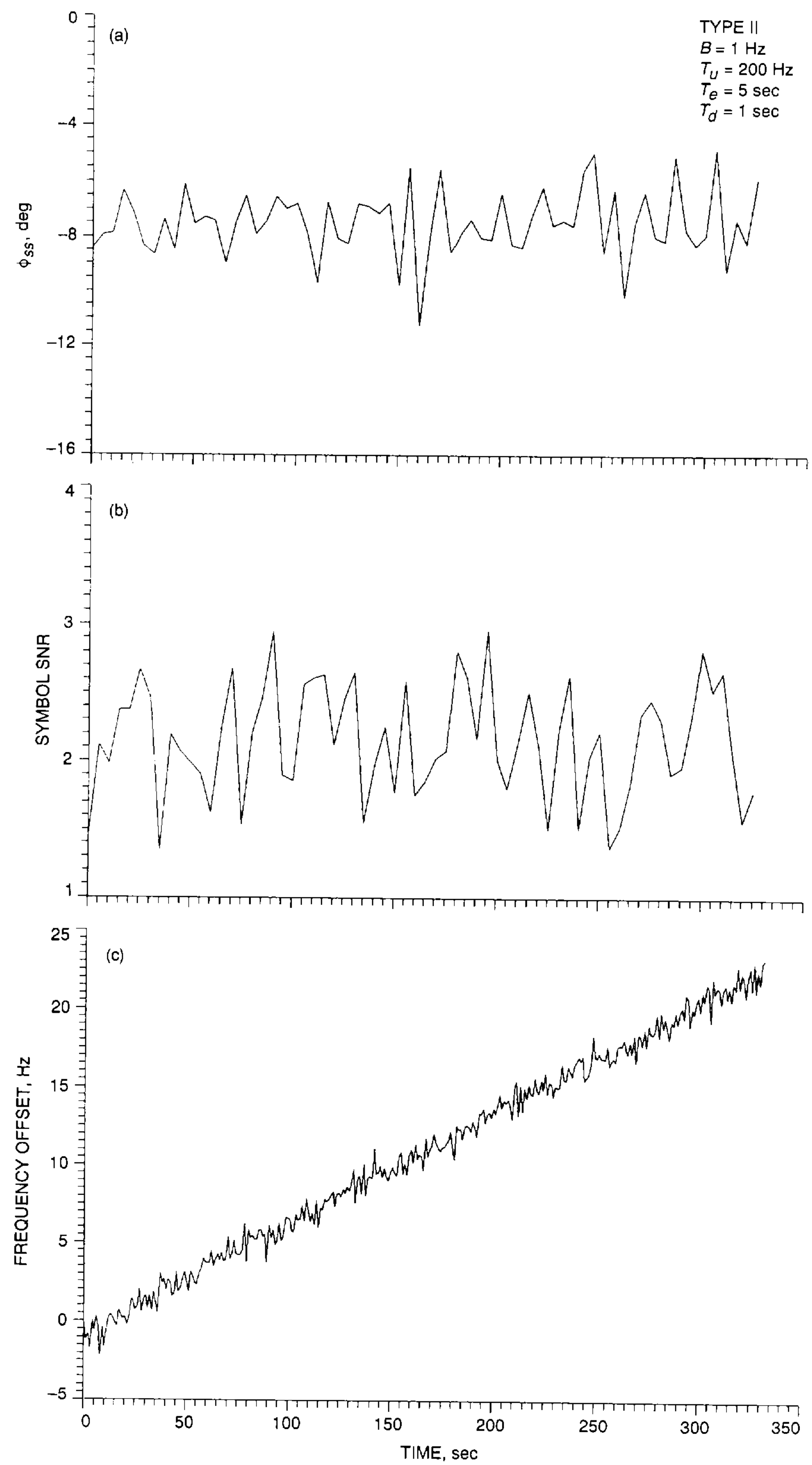

Fig. 4. Pioneer 11 test results on DOY 299: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.

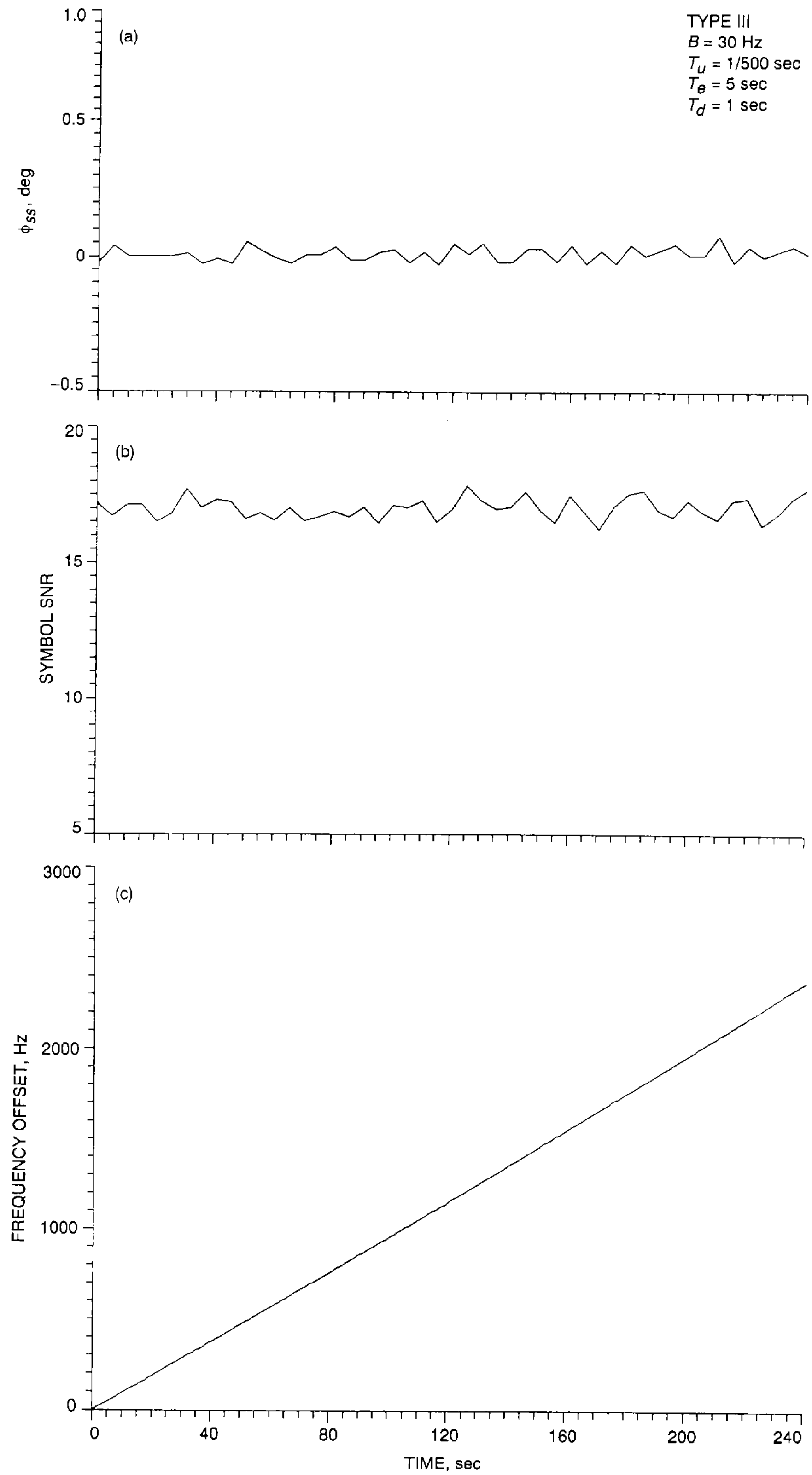

Fig. 5. Magellan low data rate test results on DOY 293: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.

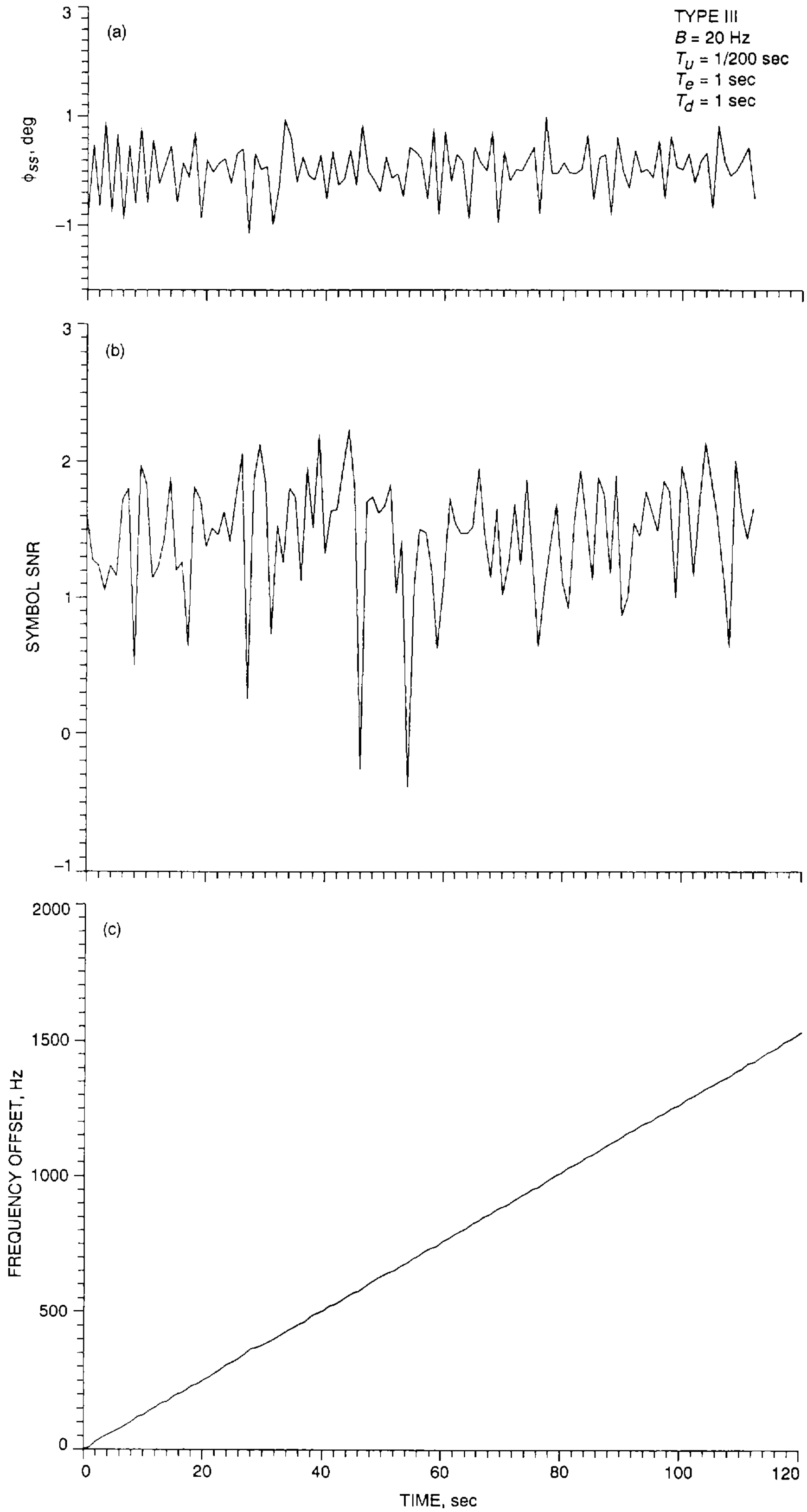

Fig. 6. Magellan high data rate test results on DOY 293: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.

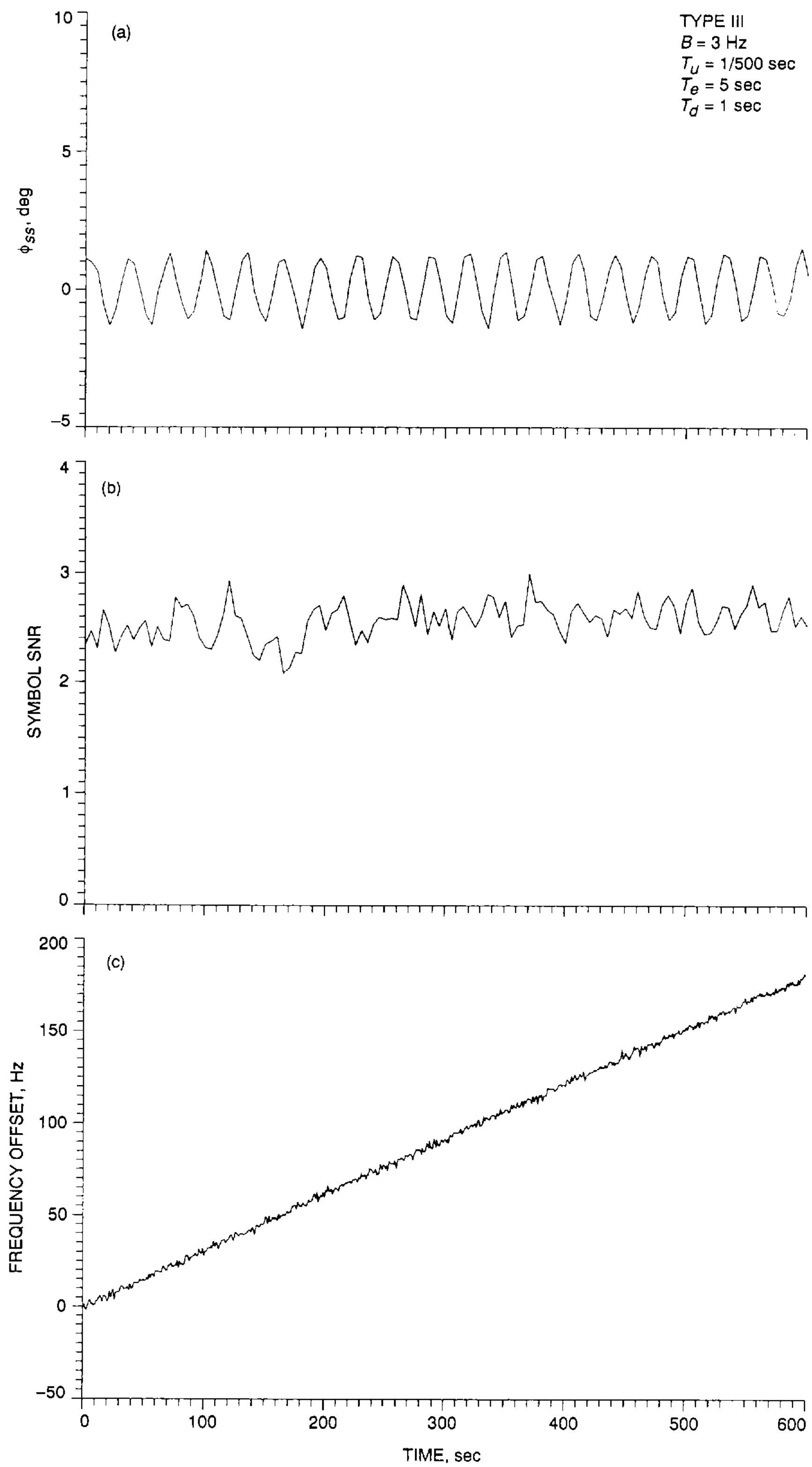

Fig. 7. Voyager 2 test results on DOY 293: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.

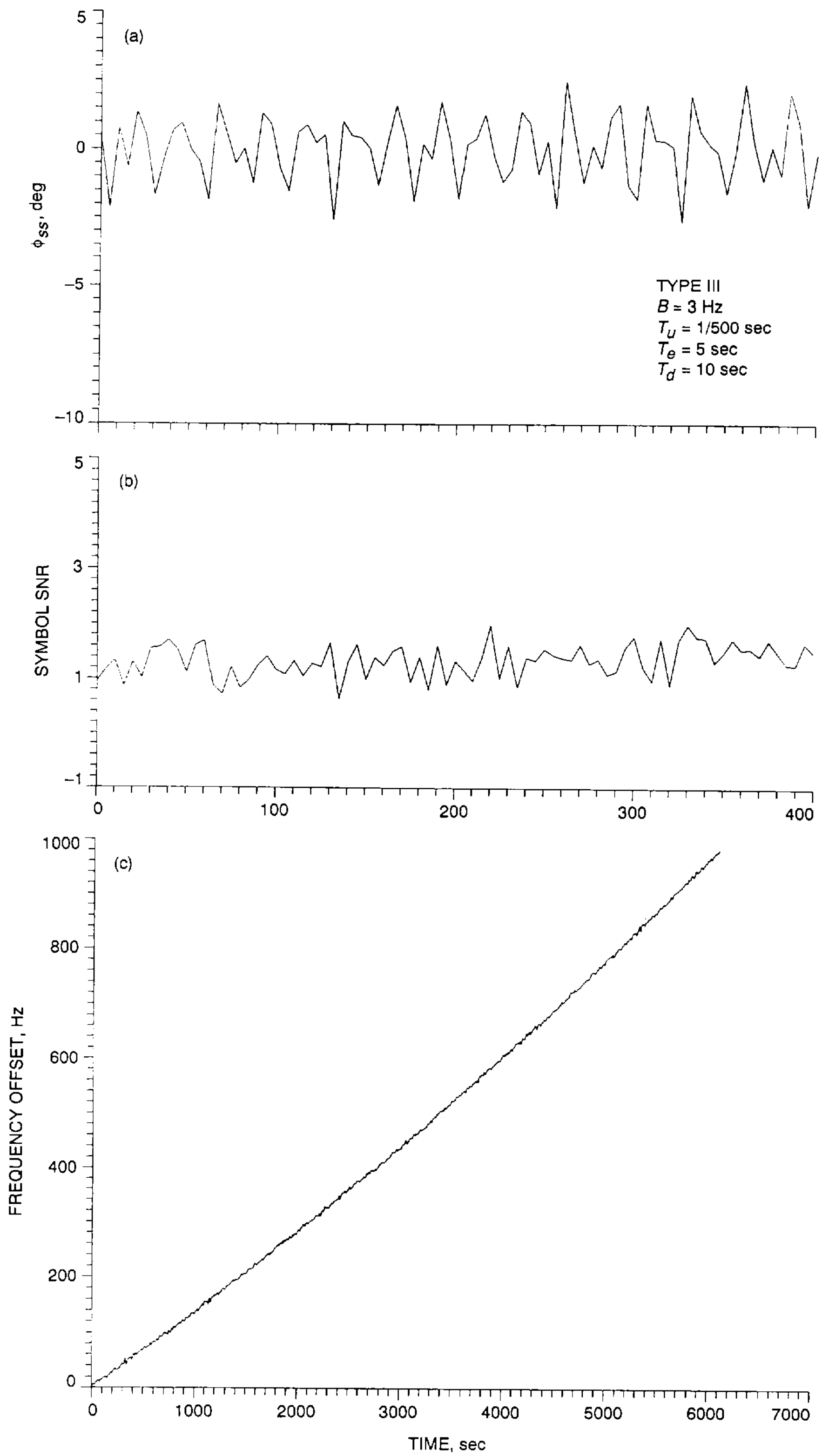

Fig. 8. ICE test results on DOY 293: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.

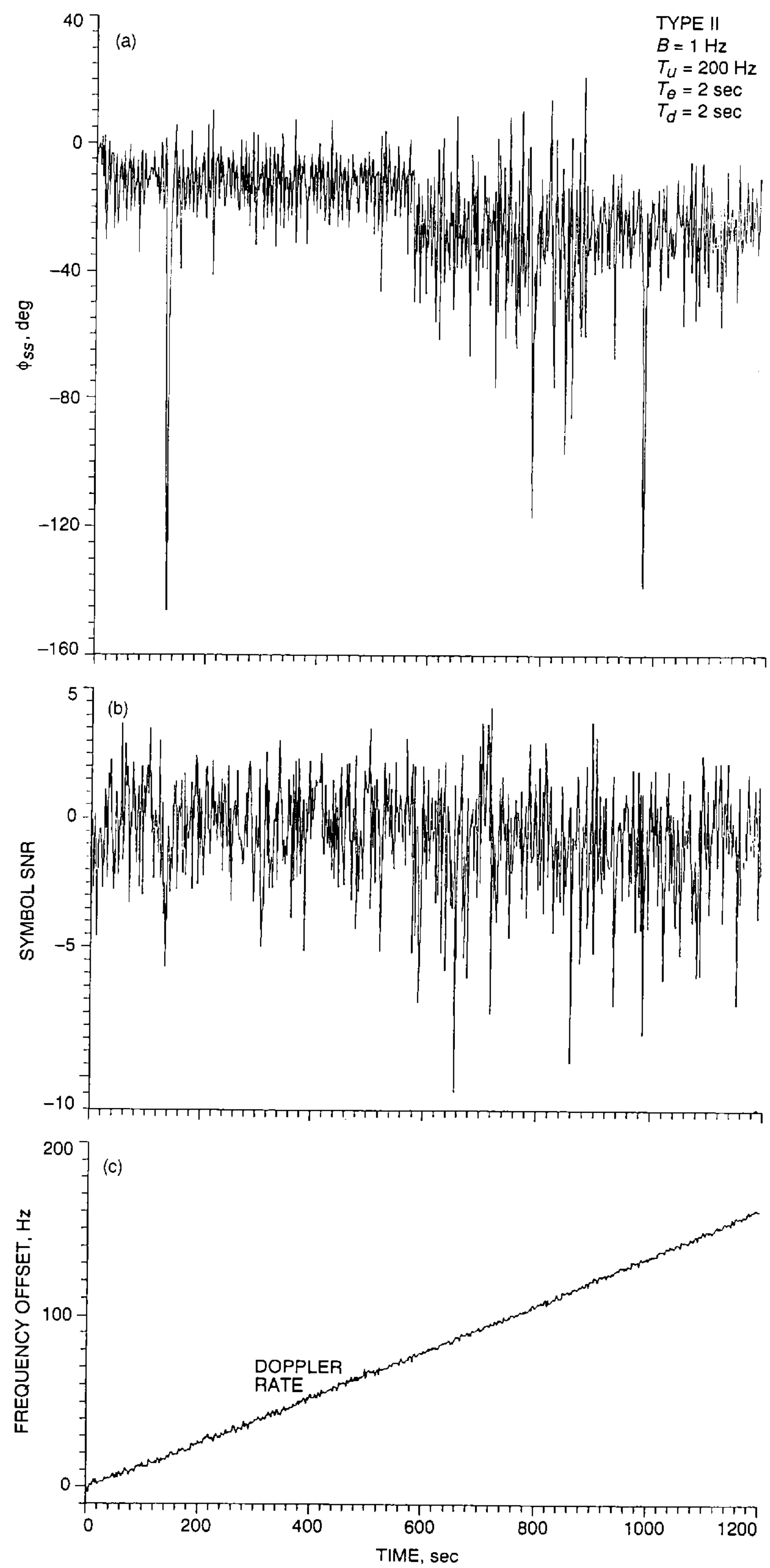

Fig. 9. Pioneer 10 test results on DOY 299: (a) ϕ_{ss}; (b) SSNR; and (c) ΔF.