Implementation of a Flutter Compensator for DSN Predetection Recording

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Baseband recordings of simulated phase-shift-keyed signals were carried out at CTA 21 in a DSN-compatible environment with the purpose of estimating the data degradation (measured in (ST) symb/N_0) caused by the record/playback process. The major cause of the lower effective signal-to-noise ratio at playback is recorder time-base instability or flutter. Incorporating a digital flutter compensator in the playback scheme significantly reduces the instantaneous phase jitter and hence the overall record/playback degradation. Results of the tests, together with a description of the compensator, are presented.

I. Introduction

A practical scheme for predetection recording of spacecraft telemetry data for use in the DSN with existing standard hardware is described. Results of tests performed on a simulated phase-shift-keyed (PSK) telemetry IF signal at CTA 21 show an estimated data degradation of 5 to 10 dB (ST symb/N_0) introduced by the record/playback process, most of it due to recorder time-base instability at playback (Ref. 1). Addition of a digital flutter compensator in the playback hardware reduced the rms phase jitter by 2 orders of magnitude. Curves of the peak-to-peak and rms phase correction provided by the compensator at different tape speeds are presented.

II. Predetection Recording System

Figure 1 shows the experimental setup for performing baseband recording of 10-MHz telemetry IF. Required additional hardware is a low-pass filter for noise limiting and a linear mixer to add in a sine-wave sync signal at a frequency at least twice the baseband bandwidth. Since the record/playback speed ratio is unity, the tape speed at record is set to the value that provides sufficient bandwidth for accommodating the signal spectrum. Table 1 lists the available tape speeds and associated bandwidths for the Ampex FR 1400 tape units presently installed in the DSN.

Simulated PSK signals using equipment at CTA 21 with a range of 15 to 5 dB were recorded at 76.2 cm/s (30 ips). A medium rate uncoded data signal, at 1024 bits per second (BPS), with a 24-kHz subcarrier was used.

Figure 2 details the playback arrangement, with and without the flutter compensator.

The sync signal is bandpass-filtered from the output signal track and used to clock the data into the compensator. The balanced modulator in the Subcarrier Demodulator Assembly (SDA) retranslates either the compensated baseband signal or the uncompensated low-pass filtered baseband signal back to the 10-MHz IF frequency. The detected data output from the SDA is then sent on to the Symbol Synchronizer Assembly (SSA) and Telemetry and Command Processor Assembly (TCP) computer for calculation of data signal-to-noise ratio (SNR), measured in (ST symb/N_0).

Without the record/playback interruption, the SDA was able to indicate suitable lock at about 1 dB. Using the FR 1400-type unit for both recording and playback, the reproduced baseband was phase- and frequency-modulated to the extent that the SDA was unable to acquire suitable lock with the originally recorded 5-dB baseband signal, and showed only intermittent lock with the 15-dB signal during periods of more linear tape playback. The data degradation during the locked intervals ranged from 5 to 8 dB. The present DSN predetection recording policy involves recording on FR 1400 units with playback on the FR 2000 unit at CTA 21, with estimated degradations of only 1 to 2 dB. Measurements of data degradation with the addition of the compensator are incomplete as yet, although estimates are of 1- to 2-dB loss relating to observations of the correlation indication provided by the SDA when lock is achieved.

III. Flutter Compensator Design

Figure 3 is a block diagram of the flutter compensator, essentially a digital buffer with a variable frequency data rate in and a constant frequency data rate out. Clocking of the analog-to-digital conversion of the baseband signal is performed by the sine-wave sync signal, which on playback is flutter modulated equally with the data signal. The sampled signal is written into the digital buffer at the modulated rate and read out at a constant rate, equal to the frequency of the originally recorded sine-wave sync signal. The output is then passed through a digital-to-analog converter and low-pass filter with a cutoff frequency of half the sync-signal frequency, thus providing a reconstructed and compensated version of the baseband signal.

The present design[1] has a total buffer capacity of 1024 six-bit words, and employs a six-bit analog-to-digital converter with a maximum sampling rate of 200 kHz.

Since readout of data from the buffer commences only after it is half full, the limit on time variations introduced on the data signal by the record/playback process is 512 samples, which if exceeded causes buffer overflow.

IV. Evaluation of Flutter Compensator

Essentially the same record/playback setup was used as outlined in Figs. 1 and 2. The interfacing with the real-time CTA 21 equipment was not required, since a single-frequency sine wave at 50 kHz (coherent with the 200-kHz sync signal) replaced the aforementioned baseband telemetry signal. The originally recorded signal was compared with both the compensated and uncompensated versions of the reproduced signal, with the purpose of establishing peak-to-peak and rms phase differences. Figures 4, 5, and 6 show the instantaneous phase jitter correction provided by the compensator. Peak-to-peak and rms phase errors as measured on a strip-chart recorder connected to the output of a phase meter are plotted versus time for signals recorded at 76.2, 152.4, and 304.8 cm/s. It can be seen that the short-term time-base instability causes phase errors as large as ± 180 deg at several frequencies, corresponding to mechanical nonlinearities of the machine.

Compensated rms phase error plots show variations within 2 deg. The compensated rms phase error trace of Fig. 5 shows an "overflow" region, an interval of about 6 s duration when the time delay between the compensated and uncompensated signals exceeded half the buffer capacity or 512 words. This "drifting" or long-term speed instability of the recorder caused several overflows of duration typically around 10 s. The effect of an overflow is to cause multiple or overlapping versions of the sampled sinusoid to be reconstructed at the output. With a time constant of about 5 to 10 s, the speed servo loop built in the recorder slows up the playback speed sufficiently to allow the buffer to be emptied at a faster rate than filled, until the output/input ratio again approaches unity. In order to overcome this problem, buffer size must be increased by about 30%, or a feedback signal proportional to the output/input sample

[1] Use of breadboard model through courtesy of L. Jung, DSIF Digital Systems Development Section, JPL.

locations in the buffer must be provided as an additional error signal to the speed servo loop.

V. Conclusion

A practical scheme for predetection recording of telemetry with low SNR using existing DSN hardware has been described. Implementation of a flutter compensator in the playback setup allows for use of existing Ampex FR 1400 tape units exclusively, by improving rms phase jitter by 2 orders of magnitude. An advanced prototype designed with increased buffer memory will eliminate the overflow problem with the present breadboard model.

Reference

1. Slekys, A., "Predetection Recording and Dropouts," in *The Deep Space Network Progress Report*, Technical Report 32-1526, Vol. IX, pp. 115–118. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1972.

Table 1. Tape speed vs bandwidth and recording time for the Ampex FR 1400 tape unit

Tape speed, cm/s (in./s)	Recording bandwidth, kHz	Recording time, h
304.8 (120)	1500	0.25
152.4 (60)	750	0.5
76.2 (30)	375	1
38.1 (15)	187	2
19.05 (7½)	93	4
9.52 (3¾)	46	8
4.76 (1⅞)	23	16

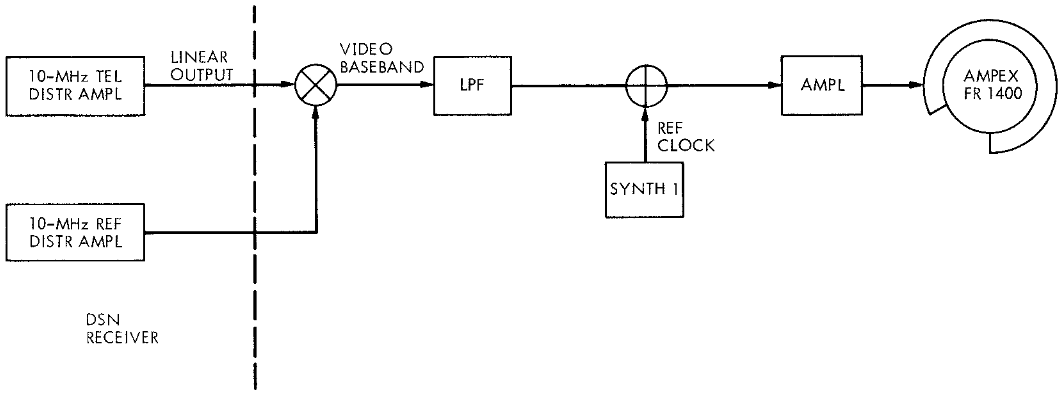

Fig. 1. Predetection recording system block diagram

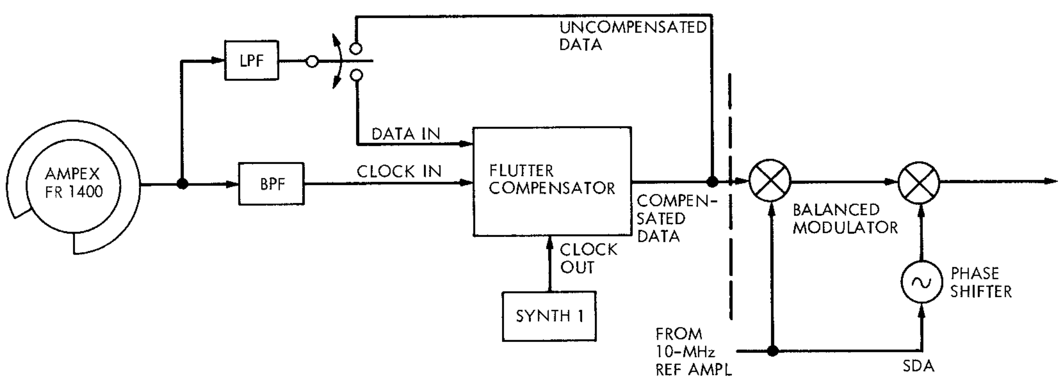

Fig. 2. Playback scheme with/without compensator

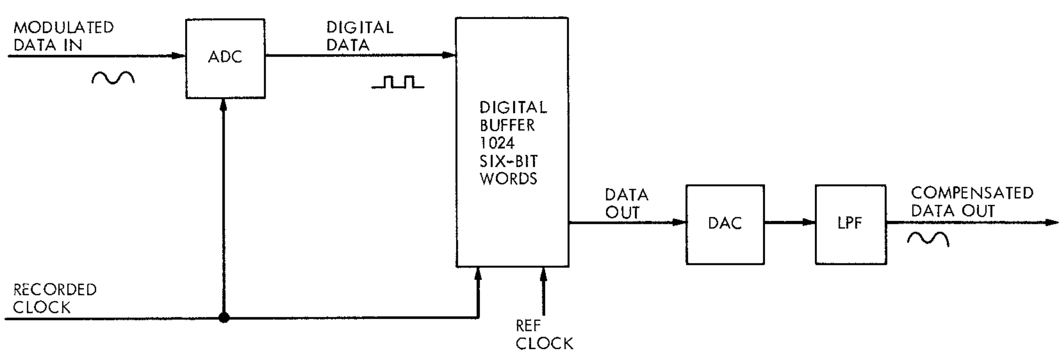

Fig. 3. Flutter compensator block diagram

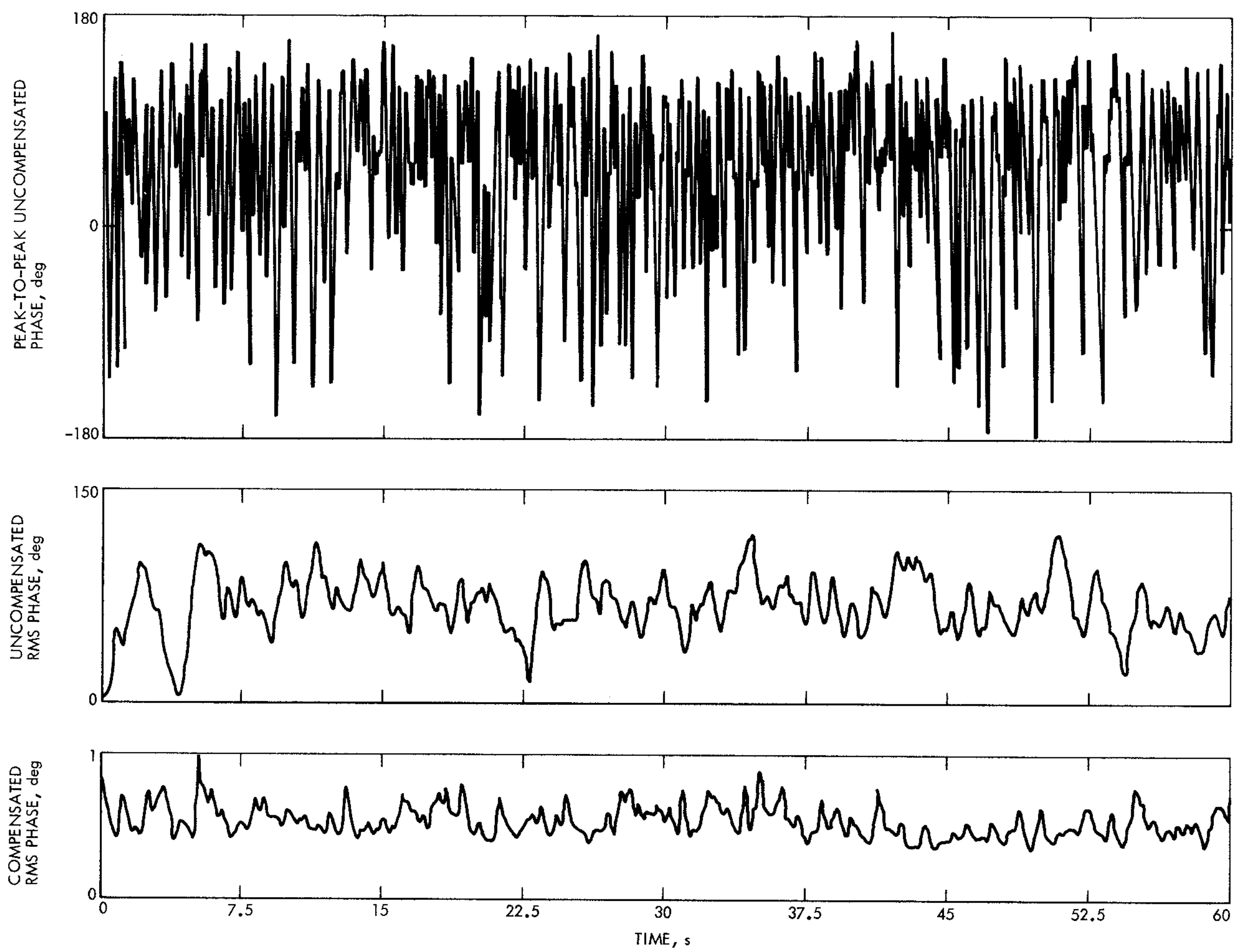

Fig. 4. Phase difference plots for signal reproduced at 76.2 cm/s (30 ips)

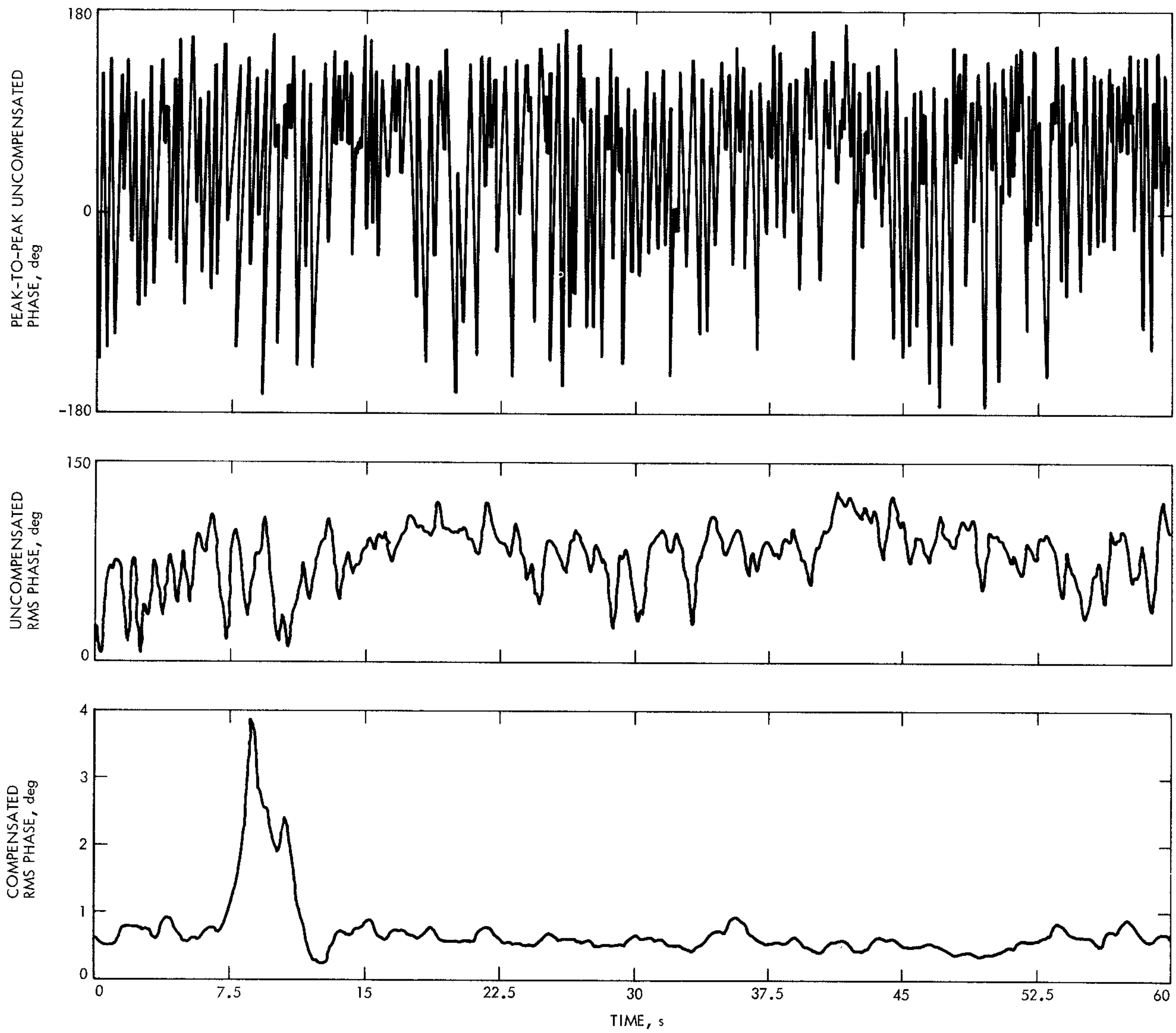

Fig. 5. Phase difference plots for signal reproduced at 152 cm/s (60 ips)

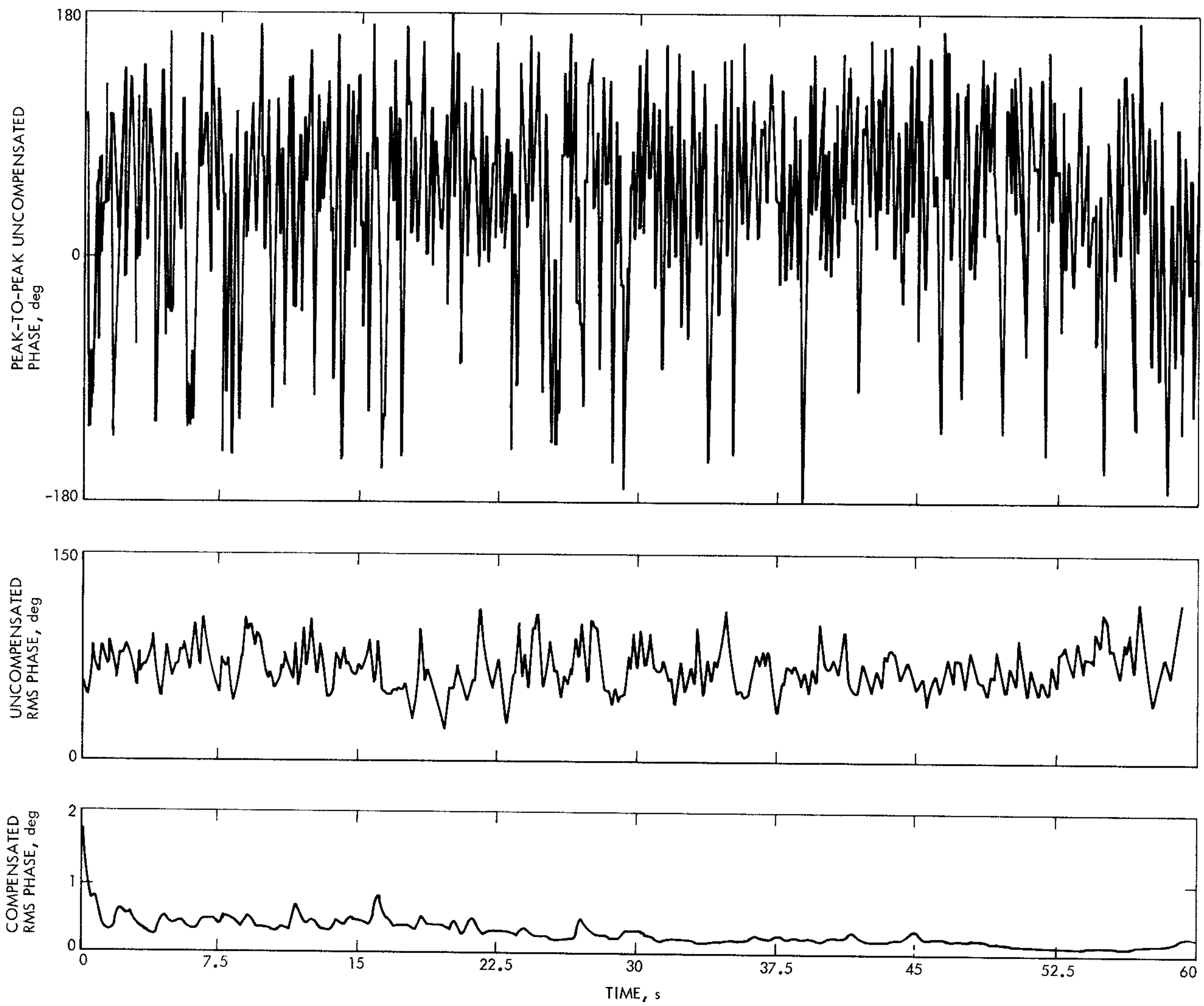

Fig. 6. Phase difference plots for signal reproduced at 304.8 cm/s (120 ips)