Precise Measurement of Spacecraft Signal Power

J. W. Newton

Communications Systems Research Section

The precision signal power measurement (PSPM) technique is a computer-based method for the automatic measurement of signal powers at the standard DSN receiver. Using sampled-data techniques, a table of spectral estimates is created from which accurate signal/noise ratios are derived and the signal strength computed. The process is continuous, fast, and automatic. Recent improvements give an extended dynamic range running from below −185 dBm to above −125 dBm and accuracies within 0.2 dB over this range.

I. Introduction

Precise and continuous knowledge of the power of received spacecraft signals becomes increasingly important as communication ranges lengthen. Tradeoff of sensitivity margins for range, data rate, or both are possible if the received power can be precisely known and continuously monitored.

The PSPM technique has been shown (Ref. 1) to be capable of an accurate, continuous measure of received power over a range of 30–35 dB, extending from below receiver threshold up to the vicinity of −150 dBm. Its accuracy over this range approaches 0.25 dB. The stability of measurements is closely predictable (Ref. 2) and has been verified in practice.

Simplifications and improvements have been made in the original system both in hardware and software. Field trials at the Mars Deep Space Station (DSS 14) have shown the desirability of operating the system from the 50-MHz intermediate frequency (IF) point rather than from the 10 MHz IF. The mechanism limiting the strong-signal end of the dynamic range has been identified and this limitation overcome, now permitting the range to extend above −130 dBm.

II. System Improvements

Field testing of the initial PSPM system at DSS 14 indicated the advisability of moving the measurement point further upstream in the standard Deep Space Network receiver, out of the area of AGC-controlled amplification. While the PSPM technique is inherently insensitive to gain variations (since it is specifically a measure of signal-to-noise ratio and free of gain-stability constraints), some of the minor nonlinearity discovered at this time was attributable to system parameters changing with the controlled gain. Also, a fully automatic system

requires either the measurement or the tracking of system noise temperature, and this increases the requirements for gain stability. The increased sensitivity of the PSPM to additive noise when operating in the strong-signal region was recognized at this time, as was the necessity for local control of a semifixed gain.

As a result, the decision was made to adapt the PSPM hardware to operate at 50-MHz IF conditions and to connect the equipment to the standard receiver through a directional coupler in the input lead from the antenna.

In Fig. 1 the received spacecraft signal is amplified, down-converted to a 50-MHz intermediate frequency and reamplified before leaving the antenna for the long cable run to the control room. Here, before entering the remainder of the DSN receiver, a small sample is extracted by means of a hybrid coupler for the mutual use of the noise-temperature measurement and the PSPM equipments. It is once more down-converted within the PSPM, band-limited in the anti-aliasing filter, and then sent to the computer for processing. The PSPM now shares with the DSN noise-temperature measurement equipment a connection accurately monitoring antenna signal-to-noise ratio and suitably isolated from downstream perturbations.

The anti-aliasing filter of the PSPM set has been changed from a 2-pole Butterworth to a 6-pole Chebyshev. The sharp cutoff of the new filter makes the bandwidth useable out to 22 Hz and makes it unnecessary to consider any foldover above the 25-Hz sampling bandwidth. The passband ripple of 0.1 dB has been undetectable in the spectra produced.

The initial PSPM computer program first measured the receiver bandwidth shape using a long noise run, and this shaping function was then used to divide all measurement runs, thus normalizing the system frequency response. This precaution has been found unnecessary in practice and has been omitted from recent programs. The upstream frequency-shaping factors in the DSN reception system—maser, preselector, mixer, preamplifier—have such broadband responses that their effect on the 25-Hz passband of the PSPM has been imperceptible. The only noticeable shaping is contributed by the aliasing filter, which is essentially flat over the majority of its range. The sharp cutoff of the new filter also improves performance by extending the flat portion further into the upper range.

The incoming signal may be assumed to appear in the receiver passband precisely at 50 MHz since the receiver operates so as to phase-lock the signal to this frequency using a local reference. If the sampling process is con-trolled by a pulse synchronously derived from this same reference, then the signal's position in time and frequency is rigidly fixed with respect to this reference and may be shifted across the sampled spectrum by adjustment of a second local oscillator (LO). With the second LO set for 49,999,987.50 Hz, the received signal falls within the center of the derived power spectrum, namely at 12.5 Hz. The signal area is now defined quite closely. Presently 10% of the spectrum is assigned to signal area and 5% at each end of the spectrum discarded to avoid end effects, leaving 80% of the record to be used to define the mean noise spectral density. This amounts to almost a doubling of the stability of the process compared to the previous practice of dividing the spectrum fifty-fifty between signal and noise regions.

The laboratory testbed generator has been modified and upgraded to reflect this change in design. The stable noise source has been reduced in power, band-shaped, and suitably shielded from extraneous noise pickup to approximate the frequency, power level, and bandwidth seen at the measurement point in the Block III DSN receivers. The 50-MHz signal source is simulated by a frequency synthesizer operating at a low output power level. These noise and signal generators have been tested for stability and the entire system tested for linearity and isolation. Signal-to-noise ratios of high accuracy may be generated by mixing in a hybrid transformer appropriate increments of signal and noise obtained from step attenuators connected to these generators.

The interim PSPM set is a new design employing considerable local gain at 50 MHz and at baseband, and care has been taken to minimize the addition of noise at either frequency band. The set has been carefully tested to assure good gain linearity over the expected operating range.

Preliminary measurements at Goldstone indicate that the new PSPM set meets all practical requirements and that the new testbed generator correctly models the behavior of the DSN receiver front end.

III. Range Extension

Concurrently with these changes and improvements, effort was expended to identify and overcome the mechanism blocking the upward extension of the dynamic range of the PSPM technique. As the initial PSPM system was operated in the range above −150 dBm, the process seemed to approach a limit asymptotically, and no manipulation of program or hardware materially improved upon this limit.

The PSPM employs techniques specifically developed to work best in the weak signal region. At the weak signal limit the process can be seen to disintegrate as the signal records become statistically indistinguishable from the adjacent noise records. In the strong-signal region, no such obvious mechanism operates to limit the measurement process. In the investigation of the strong-signal limiting effect, extensive use was made of output line-printer histograms of the spectra under study. In the strong-signal case two effects were observed: (1) the presence of a perceptible ripple superimposed upon the noise records, and (2) insufficient resolution in a 24-bit word to characterize adequately noise records of small amplitude.

The observed ripple arises from a basic property of the Fourier transform when it is applied to data containing a strong periodic signal observed for a limited period of time. This describes the PSPM strong-signal case precisely. The technique begins to depart from linearity as the signal record begins to predominate over the adjacent noise records. The Fourier transform of such a signal will possess sin x/x ripples adjacent to the signal record which swing above and below zero. The presence of this ripple will be obscured if the signal is mixed with sufficient noise, and the power in the spectral noise records will bias the ripple above the baseline. As these 'aids' disappear with increasing signal, the ripple will constitute the majority of the noise record; since its amplitude does not change, the PSPM process appears to limit.

This ripple effect is removed from the PSPM system by controlling the location of the signal record within the derived power spectrum and by evaluation of the transform at those points in the spectrum where the ripple has nulls. If the number of frequency evaluation points of the discrete Fourier transform is chosen to equal the number of lags over which the original sampled correlation table was taken, then the nulls will occur at a frequency spacing equal to the Nyquist frequency divided by the number of frequency points. Arranging the second LO offset from 50 MHz to be equal to some integral multiple of this fre-quency spacing will put the totality of the signal power into one signal record; the nulls will fall at the adjacent points and the ripple will disappear.

The remaining small nonlinearities were removed by optimizing the mathematical resolution, particularly in the transform subroutine. A 24-bit fixed-point single-precision computational capability will encompass the 60-dB range of the improved PSPM program, but no loss of significance can be permitted. Such a loss occurred in the use of the cosine subroutine. To obtain the desired strong-signal performance it was necessary to round off the cosine arguments, to modify the subroutine itself to round off, and to do similar fine-tuning throughout the transform computation. For any future program a floating-point capability would be more desirable.

With the changes noted—optimized mathematical computation, synchronous sampling, and the null-cancellation technique—the PSPM system now makes stable, accurate measurements into the region above −130 dBm.

IV. Summary

The PSPM interim set has been improved by moving the operating frequency to 50 MHz and by removing internal noise and gain compression. The new operating frequency eliminates effects attributable to the AGC-controlled stages within the DSN receiver. A measurement testbed has been provided which models the performance of the DSN receiver and permits testing and development to proceed in the laboratory under field conditions. The sampling of data is now accurately timed by pulses synchronous with the station frequency base. By arranging that these pulses are also coherent with the sampling computations and with the frequency offset, the dynamic range of the system has been extended from below receiver threshold to above −130 dBm under one set of operating conditions. The dynamic range now extends over a 60-dB interval.

References

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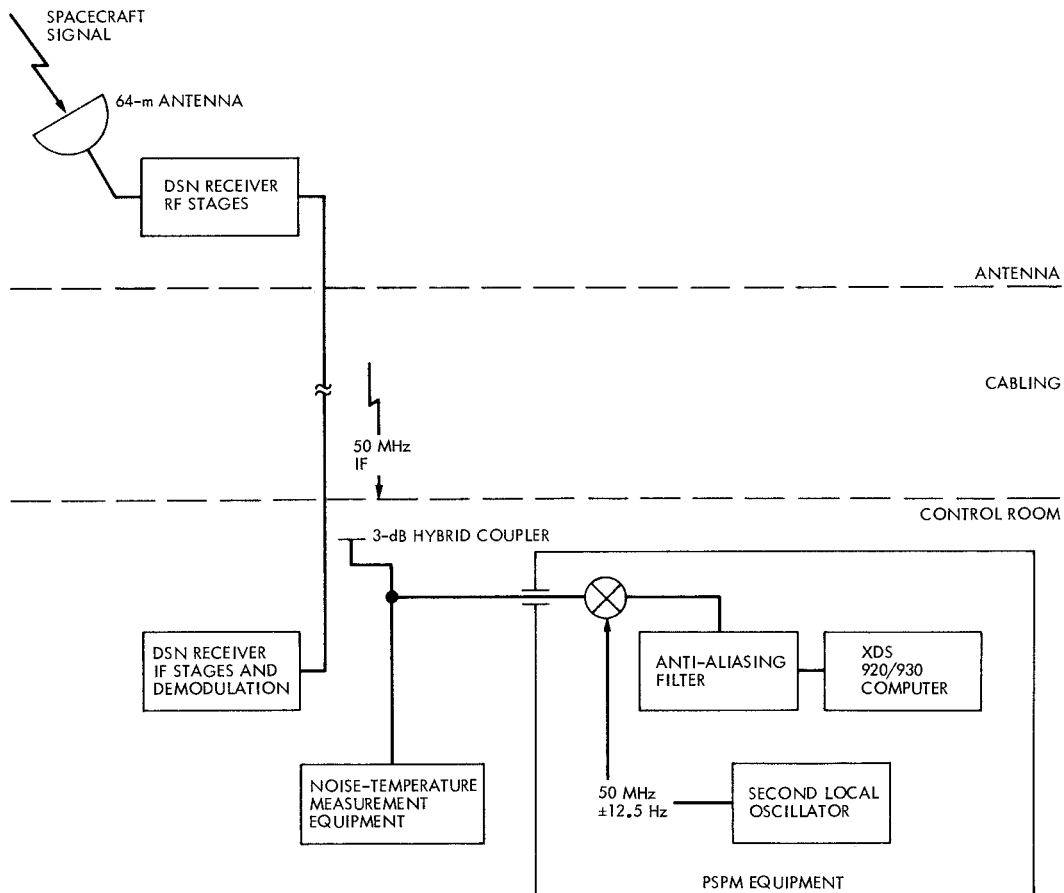
Fig. 1. PSPM equipment and measurement point