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Performance Results of a Digital Test Signal Generator

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Performance results of a digital test signal-generator hardware-demonstration unit are reported. Capabilities available include baseband and intermediate frequency (IF) spectrum generation, for which test results are provided in this article. Repeatability in the setting of a given signal-to-noise ratio (SNR) when a baseband or an IF spectrum is being generated ranges from 0.01 dB at high SNR's or high data rates to 0.3 dB at low data rates or low SNR's. Baseband symbol SNR and carrier SNR (P_c/N_0) accuracies of 0.1 dB have been verified with the built-in statistics circuitry. At low SNR's that accuracy remains to be fully verified. These results have been confirmed with measurements from a demodulator synchronizer assembly for the baseband spectrum generation, and with a digital receiver (Pioneer 10 receiver) for the IF spectrum generation.

I. Introduction

A conceptual design description, the general capabilities, and expected performance of a digital test signal generator (DTSG) with immediate application in the DSN was published in [1]. A new method of generating analog test signals with accurate signal-to-noise ratios (SNR's) was described. High accuracy would be obtained by simultaneous generation of digital noise and signal spectra at a given baseband or bandpass-limited bandwidth.

A DTSG hardware system became available in September 1991. Considerable effort was put into the operational, monitor, and control aspects of its operation. At the end of the project, full capabilities for baseband generation of data modulated in a single subcarrier, biphase data, or non-return-to-zero (NRZ) data were completed by December 1991. A limited version for intermediate frequency (IF) generation up to 300 MHz was also completed.

Although some DSN-telemetry standard test cases are available to the operator, it should be understood that the potential of generating precise SNR for conditions defined by the user is an option, although each particular case probably will need special programming to attain the results expected by the experimenter. Simple DTSG operation is provided through a user interface menu. Capabil-

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ities included in both versions of this demonstration unit have been summarized in [1].

A detailed description of the measured performance of a few basic functions has been found necessary in helping the user understand the system limitations.

II. DTSG Description

Figure 1 is a composite of photos of the different pieces of electronic equipment used in the demonstration unit of the DTSG. These pieces of electronic equipment are mounted in a standard DSN rack. From top to bottom, the following equipment can be found:

(1) A commercial 100-Hz to 1.5-GHz spectrum analyzer used to analyze the DTSG analog output at different frequency bands. In Fig. 1, the spectrum analyzer actually shows the DTSG analog frequency response output of a baseband 400-kHz digital filter.

(2) A commercial PC with keyboard and monitor. The monitor shows the actual histogram obtained from an unbiased-noise digital output.

(3) A commercial programmable synthesizer providing a 2- to 20-MHz system clock. This system clock may be varied in accordance with the Doppler effect desired.

(4) DTSG box, which contains all of the special hardware designed at JPL by the Radio Frequency and Microwave Subsystems Section.

Figure 2 shows the PC monitor screen with the menu provided when the DTSG is configured in the baseband mode. Figure 3 is the same monitor screen when the DTSG is configured in the IF mode. Note that all the parameters shown in Figs. 2 and 3 may be changed through the PC keyboard and the user interface menus shown in the figures. After the operator has assigned the values to use as test source parameters, the initialization (INI) command may be entered (operational commands are displayed at the bottom of the DTSG menu on the monitor screen in Figs. 2 and 3). This command directs the PC to initiate all the calculations necessary to generate all the hardware parameters to be later transmitted to the DTSG hardware box. Some of these parameters, generated in the form of ASCII output files, are a system clock to be loaded in the synthesizer, a filter coefficients file, a subcarrier frequency file, a symbol (data coded or uncoded) file, the required noise and signal attenuator factors for the symbol SNR (SSNR) defined, a noise file, and other parameters required by the statistics hardware circuitry.

Execution of the RUN command (see Figs. 2 and 3) will transmit all the required configuration files to the DTSG hardware and will automatically start the measurement and periodic update of the DTSG output statistics in the channel selected. Statistics provided are

(1) instantaneous SSNR, the mean symbol SNR corresponding to an operator-controlled fixed number of symbols

(2) instantaneous SSNR standard deviation (STD), the standard deviation of the 10 previous SSNR's

(3) instantaneous symbol error rate (SER), the SER corresponding to a fixed number of symbols (operator controlled)

(4) average SSNR (AVRGSNR), the continuous average of all the previous measurements of instantaneous SSNR

(5) average SER (AVRGSER), the continuous average of all the previous measurements of instantaneous SER.

III. General Description of Configurations To Be Tested

Figure 4 is a block diagram of the SNR generator box, which contains the high-speed hardware used to synthesize the test signals. A description of the DTSG can be found in [1]. Engineering details on software and hardware are documented.[2]

The DTSG hardware unit (refer to Fig. 4) may be configured to generate different signal spectra. The DTSG modes available are baseband spectrum generation, to generate NRZ data (coded or uncoded), biphase data, or NRZ data modulated in a subcarrier; dual-subcarrier spectrum generation, to generate two NRZ data streams modulated in two subcarriers; quadrature-phase shift key (QPSK) spectrum generation, to generate QPSK data; and IF spectrum generation, to generate an intermediate-frequency phase modulated with or without the carrier. This article will refer only to the baseband spectrum-generation mode and the IF spectrum-generation mode performance test results.

Non-return-to-zero-level (NRZ-L) uncoded data modulated in a subcarrier make up one of the types of data generated in the baseband mode. Data files are created

[2] *Digital Test Signal Generator Software Operator's Manual/User's Guide* (internal document), Jet Propulsion Laboratory, Radio Frequency and Microwave Subsystems Section, Pasadena, California, September, 1991.

in the PC by defining the different parameters available, which are given on the PC monitor (as shown in Fig. 2). The generation of these files is started after the INI command is executed. Thus, an NRZ-L data file, a subcarrier file, a noise file, a digital filter file, channel-1 attenuator and noise-channel attenuator files, and a statistics monitor file are created in the controlling PC.

The RUN command will configure the hardware with the files previously generated with the INI command. Therefore the data 64K RAM of channel 1 is loaded with the NRZ-L data file; the subcarrier 64K RAM of the same channel 1 is loaded with the subcarrier file; the digital filters are loaded with the appropriate coefficients, and the statistics-monitor hardware gain is properly scaled.

Statistical measurements of instantaneous SNR, SER, average SNR, and average SER are automatically provided and periodically updated. These statistical measurements may correspond either to the analog output or the digital output, as chosen by the operator by using the appropriate command (see Figs. 2 and 3).

Also, a real-time (20-MHz) histogram accumulator of 512 bins with a total of 10^6 samples is available in a file returned to the controlling PC. This file can be further processed in the PC or made available to any outside computer through a magnetic diskette. By this means, histograms requiring more than 512 quantized values may be produced (see Section IV).

IF spectra with residual carrier and NRZ-L data modulated in a subcarrier make up the type of data being generated in the IF mode. A limited capability for this configuration has been provided in the present software version. Only Magellan, Galileo, Voyager, and Pioneer 10 telemetry rates and characteristics may be simulated, although any modulation index or carrier suppression can be provided.

Following the same approach as described previously for the baseband mode, the PC will create the required hardware configuration files from the parameters specified in the PC monitor, as shown in Fig. 3. Therefore, different files will be generated after the INI command. The following files will be loaded in the SNR generator box after the RUN command is executed (refer to Fig. 4). The subcarrier 64K RAM of channel 1 will be loaded with a file to produce an output frequency of 5 MHz with a relative phase of 0 deg. No data file is required in channel 1. The subcarrier 64K RAM of channel 2 will be loaded with a file to produce an output frequency of 5 MHz with a relative phase of 90 deg. The data 64K RAM will be loaded with the baseband telemetry data of either Magellan, Galileo, Voyager, or Pioneer 10. The filter files will now correspond to bandpass filters centered at 5 MHz.

The capabilities of providing histograms and statistics are also available for this case with the added capability of being able to obtain statistics either from channel 1 (carrier statistics, P_c/N_0) or channel 2 (telemetry statistics, SSNR).

IV. Noise-Generation Characteristics

As discussed in [1], the noise 64K RAM of the noise channel is loaded with a discrete Gaussian distribution of data bytes (8-bit representation), to be sequentially read by a random-address generator. The DTSG has been provided with a histogram accumulator that allows acquisition of real-time histograms (20-MHz sampling clock) consisting of 10^6 samples in total.

Two histograms to cover the whole distribution of the unfiltered output of the noise memory were obtained and analyzed. The percent deviation of the discrete Gaussian distribution generated by the noise channel from a theoretical Gaussian discrete probability distribution with identical standard deviation, s, was defined as follows:

$$\text{deviation }(x_d; s) =$$

$$\frac{\{[P_d \text{ actual } (x_d; s) / P_d \text{ gauss } (x_d; s)] - 1\}}{100} \quad (1)$$

where

$$x_d \in \{-127, ..., -1, 0, 1, 2, ..., 127\}, s = 32$$

and

deviation $(x_d; s)$ = percent of deviation for value x_d

P_d gauss $(x_d; s)$ = discrete probability function of a Gaussian distribution; see Eqs. (7) through (15) of [1]

P_d actual $(x_d; s)$ = measured discrete probability function of actual unfiltered noise being generated by the noise memory

Results showed the deviation to be less than 1 percent.

Figure 5 is the result of 8 histograms of the output of the memory when baseband-filtered with a 4-MHz filter with the digital frequency response as shown in Fig. 6. Note that the set of integers now propagated through the hardware and the discrete probability function standard deviation will be

$$x_d \in \{-2047, ..., -1, 0, 1, 2, ..., 2047\}$$

$$s = 512$$

Also displayed in Fig. 5 is a fit of a theoretical Gaussian probability function of the same standard deviation. Note the excellent agreement of the fit with the actual filtered noise.

The analog responses of the digital filters used were in complete agreement with the expected digital frequency response (i.e., Fig. 6) when observed in the spectrum analyzer.

V. Repeatability

Several independent readings of the digital SSNR measurement of the baseband output were obtained as follows. The DTSG was configured to provide a given set of parameters, such as noise bandwidth (BWDTH), subcarrier frequency (Sc), symbol rate (Data), and the desired symbol signal-to-noise ratio (Nom.SSNR). The DTSG statistics monitor was obtained as the digital measurement of signal-to-noise ratio (Dig.SSNR) after a given integration time (Int.Time). The standard deviation (Std.Dev.) of a given number of measurements (Number of points) was also computed. Table 1 shows a summary of those results for different baseband configurations.

When the analog output SSNR was measured, the results were very similar to those shown in Table 1 for the digital measurement. (This similarity is further shown in Fig. 11, where SERSSNR refers to symbol error rate SSNR.)

The above procedure was repeated for the IF configuration. The DTSG was configured to generate a given set of parameters such as IF noise bandwidth at a center frequency of 5 MHz, with a carrier SNR (Nom.P_c/N_0). Results obtained in the digital output have been summarized in Table 2. (Similarities between the digital and analog measurement for the carrier SNR measurement, P_c/N_0, may be verified in Fig. 12.)

Several different configurations were used to test the setting accuracy of the given configuration of the DTSG in baseband mode. Figure 7 shows the results for a typical configuration.

Different configurations of IF filters were tested in the DTSG IF mode. A typical setting-accuracy error curve can be found in Fig. 8.

VI. Channel Isolation

Channel isolation (of in-phase and quadrature channels) was measured in the analog output of the DTSG in the IF mode, with a 5-MHz IF carrier frequency being generated in each channel with a 90 deg phase difference and $P_c/N_0 = 40$ dB/Hz. Results show an isolation of at least 45 dB between channels.

VII. Baseband Testing

Several baseband configurations were tested at Goldstone's Signal Processing Center (SPC 10) by feeding the output of the DTSG configured in baseband mode through the baseband patch panel to telemetry groups 4 (TG4) and 5 (TG5) (see Fig. 9). Each demodulator synchronizer assembly (DSA) was configured with a medium loop bandwidth, and the mean SSNR (<SSNR>), mean SER (<SER>), and standard deviations were obtained every 30 sec. SER refers to symbol error rate, and CER refers to carrier error rate. A summary of the results obtained is shown in Table 3.

This summary shows the capabilities of the DTSG as an SSNR source to measure telemetry-equipment performance with a high degree of accuracy. Extensive testing of the different signal-processing configurations in use at the DSN can now be performed with substantial savings in test-preparation time. Also, existing theoretical models can now be confirmed with the required accuracy.[3]

VIII. IF Testing

During acceptance testing of the Pioneer 10 receiver development unit (PN10Rcvr) at Goldstone, the DTSG 5-MHz IF output was upconverted to 300 MHz in the PN10Rcvr test equipment and fed to the PN10Rcvr (see Fig. 9). The DTSG was configured in the IF mode, providing a carrier and the corresponding telemetry modulation. The results obtained from the PN10Rcvr carrier detection

[3] *Deep Space Network Flight Project Interface Design Handbook*, JPL 810-5, Rev. D (internal document), Jet Propulsion Laboratory, Pasadena, California, July 15, 1991.

and the demodulator synchronizer assembly (DSA) symbol detection are shown in Table 4. In that table, BBA refers to baseband assembly, and L.B. refers to receiver loop bandwidth. Note that in Fig. 9 the parameters estimated throughout the system are represented by the convention <x>.

Another PN10Rcvr test was run with the DTSG in the IF mode with the carrier channel only. The telemetry channel was switched off for this test. The results have been plotted in Fig. 10 (solid line) for a Pioneer 10 one-sided receiver loop bandwidth of 1 Hz.

The expected P_c/N_0 degradation may be expressed as follows. The phase error variance may be linearly approximated by [2, p. 60]

$$\sigma_\phi{}^2 = \frac{W_L}{2P_c/N_0} \tag{2}$$

where W_L is the two-sided loop bandwidth. Assuming the phase error probability distribution $p(\phi)$ to be Gaussian with

$$p(\phi) = \frac{1}{\left(\sigma_\phi\sqrt{2\pi}\right)\ e^{-(\phi/\sigma_\phi)^2/2}} \tag{3}$$

the carrier SNR P_c/N_0 degradation may be approximated by

$$P_c/N_0 \text{ degradation (dB)} = 10\ \log\left[\int_{-\infty}^{\infty}\cos^2(\phi)\,p(\phi)\,d\phi\right] \tag{4}$$

$$= 10\ \log\left[\frac{\left(1+e^{-2\sigma_\phi{}^2}\right)}{2}\right] \tag{5}$$

Results of the above equation have been plotted (the dashed line) in Fig. 10 with a bias of 0.2 dB, assumed to be due to PN10Rcvr system degradation. Also, the results of a computer simulation (asterisks) of the PN10Rcvr closed phase lock loop have been represented in Fig. 10.

IX. Accuracy

The normal (or Gaussian) distribution obtained in the noise generation is used to confirm the accuracy of the SSNR output of the DTSG. Note that the deviation between the symbol SNR (SSNR) and the symbol error rate SNR (SERSNR) for each particular case of the digital and the analog measurements will be a direct indication of the accuracy obtained in the generation of the SSNR in those particular circumstances (noise with Gaussian distribution).

DTSG accuracy was tested in the baseband mode for different baseband filters, subcarrier frequencies, symbol rates, and symbol SNR's. Fig. 11 represents a typical result. The deviation observed for each measured point is probably affected by quantization errors present throughout the high-speed hardware. Unfortunately, because of the lack of time and resources at the present time, these deviations have not been quantified. For the baseband mode, if the SSNR's to be generated are above −15 dB, a worst case of −0.15 dB in the generator accuracy can be identified. From Fig. 11, the accuracy of the SSNR generation can be stated to be better than 0.05 dB for SSNR greater than −5 dB. Note that this lower limit corresponds to most usual baseband testing conditions.

The above conclusions are also supported by the results presented in Section VII. Note that for high symbol rates, the telemetry degradation measured was on the order of 0.01 dB. These results comply with the most optimistic expectations and with the predicted results described in [1].

For the DTSG IF mode, carrier SNR measurement (P_c/N_0) is performed by integration of the carrier detection process for a period of 1 msec. (The carrier has a frequency of 5 MHz.) Also, the number of 5-MHz half-cycles in error (180 deg out of phase) is counted, converted to the equivalent SNR, and plotted in Fig. 12 as carrier-error-rate SNR.

From Fig. 12 it may be deduced that the divergence of both carrier SNR measurements of the analog output follows the same general trend as that of the measurements of the digital carrier error rate SNR, suggesting therefore a common problem. This common point of error seems to be introduced in the statistics hardware, with several contributing factors that remain to be fully explained.

From the P_c/N_0 results obtained in Section VIII and shown in Fig. 10, an approximate 0.2 dB degradation when they are measured with the PN10Rcvr is apparent. Expected PN10Rcvr degradation measurements at the lower end of P_c/N_0 are in good agreement with the actual carrier-SNR DTSG digital measurements. A more precise test using the radio science receiver remains to be performed. These tests are expected to help identify the cause of the DTSG inaccuracies observed in the measurements of the DTSG analog output.

X. Conclusions

DTSG accuracy and repeatability at baseband (baseband mode) have been verified through different tests with the baseband assembly (BBA) part of the SPC 10 telemetry system. Results confirm the capability of providing calibrated symbol signal-to-noise ratios (SSNR's) accurate to 0.1 dB over a wide range of DSN telemetry requirements.

DTSG precise and repeatable generation of carrier and telemetry signals (IF mode) at 300 MHz has been demonstrated, although more tests are necessary to confirm the expected 0.1-dB accuracy.

Acknowledgments

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References

[1] B. O. Gutierrez-Luaces, "Digital Test Signal Generation: An Accurate SNR Calibration Approach for the DSN," *The Telecommunications and Data Acquisition Progress Report 42-104*, vol. October–December 1990, Jet Propulsion Laboratory, Pasadena, California, pp. 161–174, February 15, 1991.

[2] J. H. Yuen, ed., *Deep Space Telecommunications Systems Engineering*, JPL Publication 82-76, Jet Propulsion Laboratory, Pasadena, California, July 1982.

Table 1. Baseband repeatability.

BWDTH, MHz	Sc, kHz	Data, symbols/sec	Nom.SSNR, dB	Dig.SSNR, dB	Std.Dev., dB	Int.Time, sec	Number of points
4	360	43,200	3	2.94	0.007	30	18
4	360	230,400	3	2.90	0.002	30	18
4	960	537,600	0	−0.37	0.002	30	10
0.4	32	32	0	−0.23	0.14	60	10
0.4	32	32	5	5.39	0.14	60	10
0.4	32	32	11	11.57	0.05	60	7

Table 2. IF repeatability.

BWDTH, MHz	IF, MHz	Nom.P_c/N_0, dB/Hz	Dig.P_c/N_0, dB/Hz	Std.Dev., dB	Int.Time, sec	Number of points
±4	5	50	49.84	0.01	60	3
±1	5	30	30.00	0.01	60	3
±1	5	17	17.36	0.12	60	8
±0.15	5	40	40.38	0.01	30	11
±0.15	5	20	19.59	0.10	60	10
±0.15	5	15	14.85	0.20	30	10
±0.15	5	8	8.14	0.28	60	10

Table 3. DSA performance verification.

DTSG configuration				SPC 10 telemetry results		
BWDTH, MHz	Sc, kHz	Data, symbols/sec	Dig.SSNR,[a] dB	TG4 SSNR, dB	TG5 SSNR, dB	Number of points
4	360	43,200	2.94	2.89 ± 0.10	2.90 ± 0.1	4
4	360	43,200	−0.06	−0.20 ± 0.15	− 0.16 ± 0.12	5
4	360	268,800	−0.08	−0.02 ± 0.05	− 0.14 ± 0.04	5
4	360	268,800	−3.12	−2.99 ± 0.06	− 3.02 ± 0.06	8
4	968	537,600	−3.36	−3.33 ± 0.08	− 3.36 ± 0.06	4
0.4	22.5	160	2.87	2.46 ± 0.05	2.63 ± 0.05	18
0.4	32.8	32	10.68	—	10.02 ± 0.26	8
0.4	32.8	32	5.78	—	4.23 ± 0.20	4
0.4	32.8	32	3.09	—	1.25 ± 0.40	7

[a] Standard deviation of DTSG output smaller than 0.1 dB.

Table 4. Pioneer 10 receiver results.

DTSG configuration					PN10Rcvr and BBA results			
BWDTH, MHz	P_c/N_0,[a] dB/Hz	Sc, kHz	Data, symbol/sec	SSNR,[a] dB	L.B., Hz	P_c/N_0, dB/Hz	SSNR, dB	Number of points
±4	40.5	360	268,800	0.86	5	40.30 ± 0.25	0.60 ± 0.01	5
±4	32.5	360	43,200	1.10	5	32.20 ± 0.40	0.78 ± 0.01	11
±0.15	40.4	32.8	32	10.0	1	40.20 ± 0.32	8.54 ± 0.1	5
±0.15	13.0	32.8	32	3.0	0.25	12.60 ± 0.20	1.88 ± 0.25	7

[a] Standard deviation of DTSG output smaller than 0.1 dB.

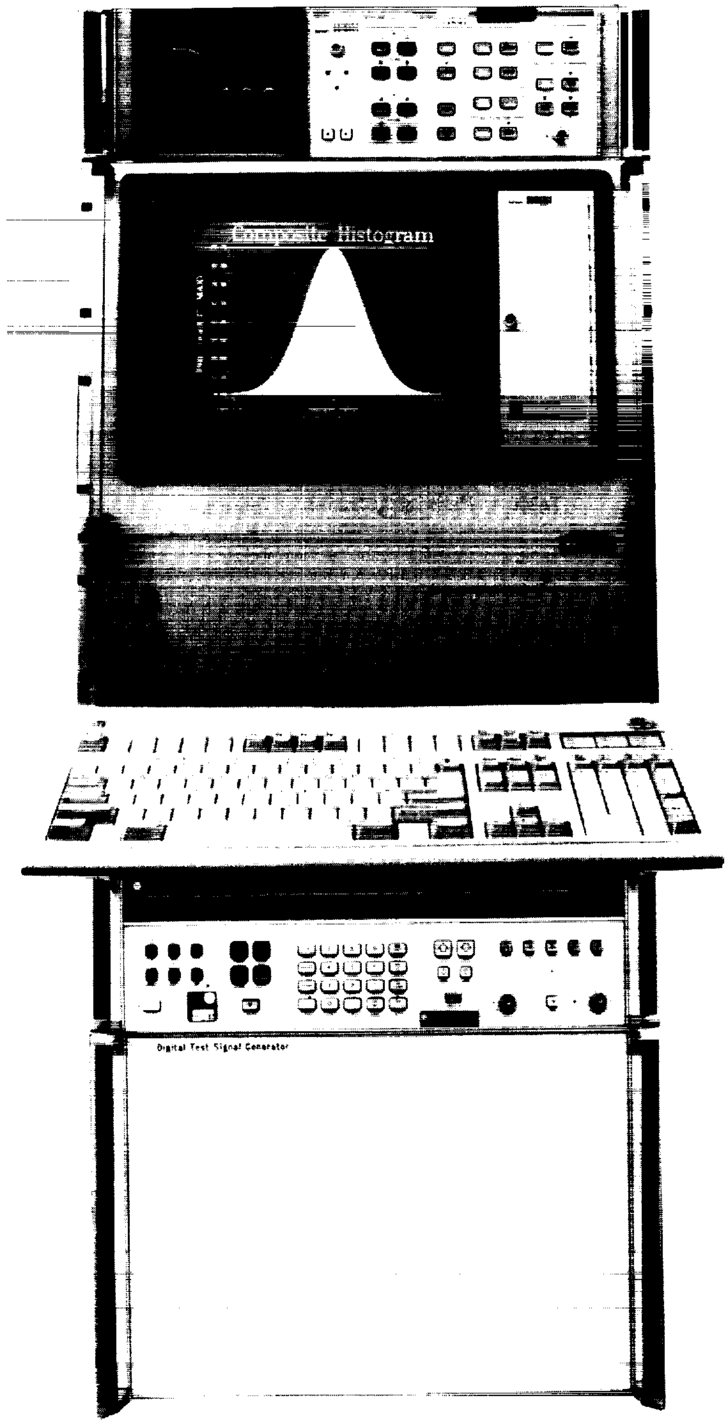

Fig. 1. DTSG rack-mounted main components.

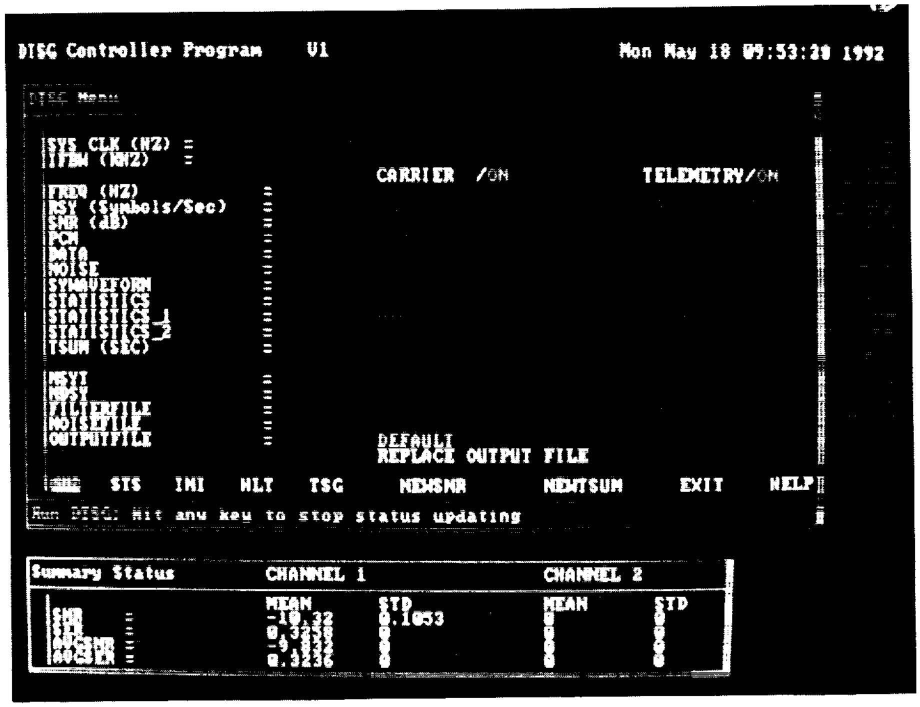

Fig. 2. User interface menu: DTSG baseband mode.

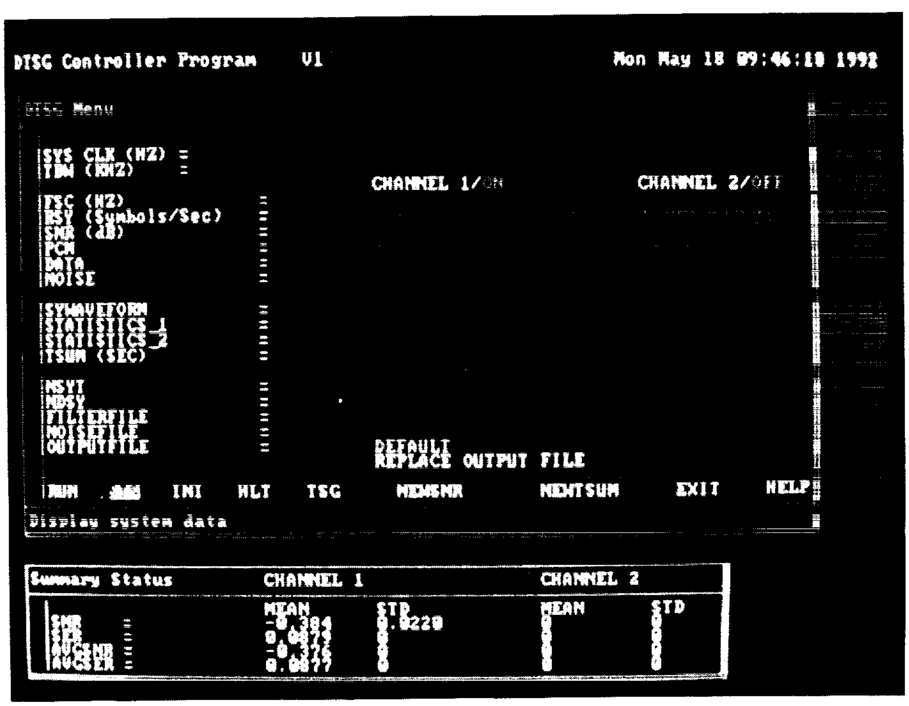

Fig. 3. User interface menu: DTSG IF mode.

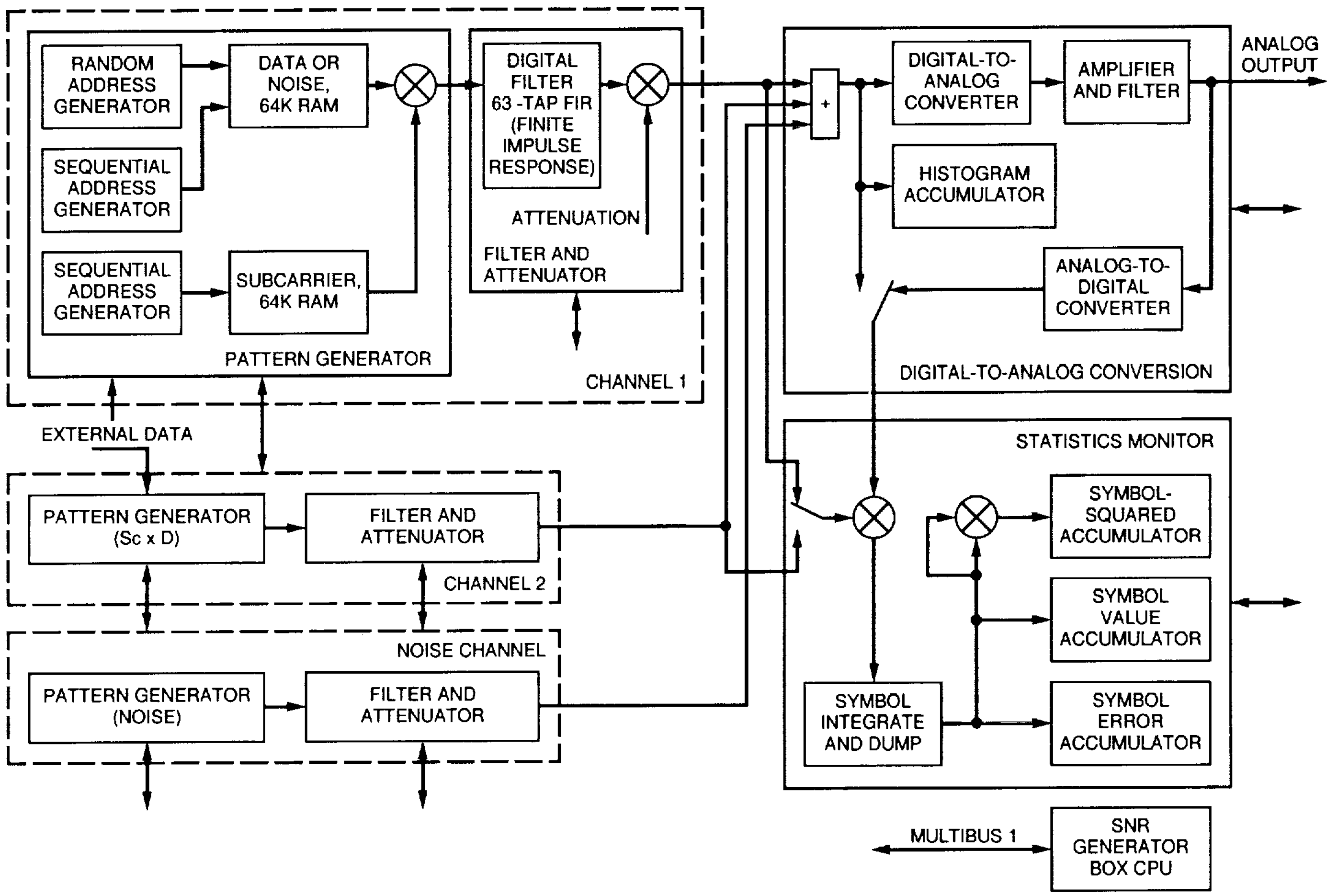

Fig. 4. DTSG hardware block diagram.

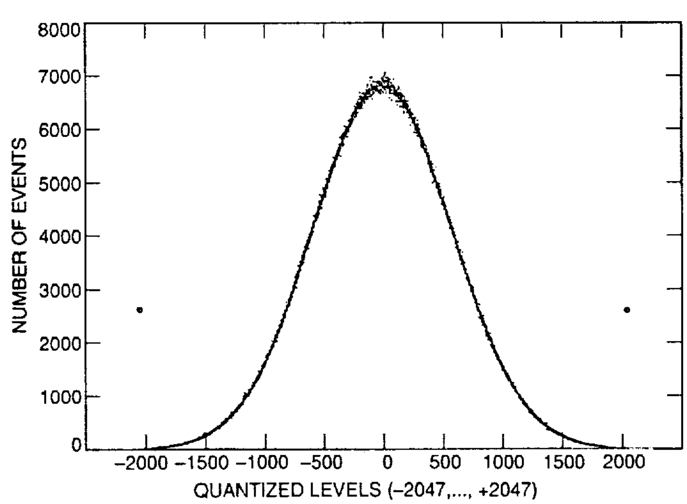

Fig. 5. A 4 M-Hz filtered discrete probability function with Gaussian fit (8 × 10^6 samples).

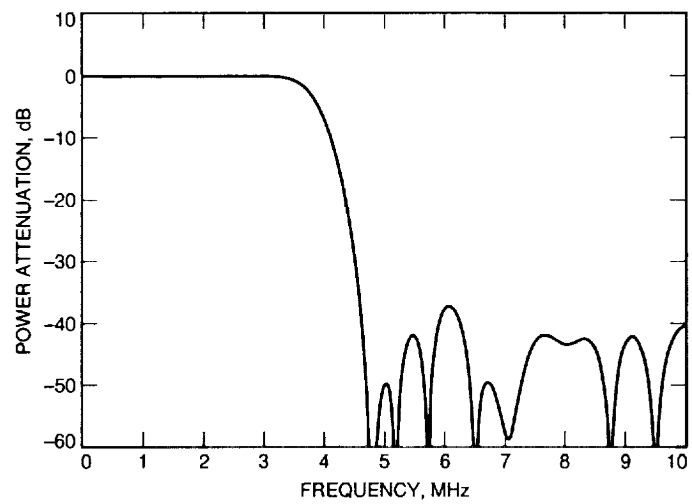

Fig. 6. Normalized frequency response of a 4-MHz digital filter.

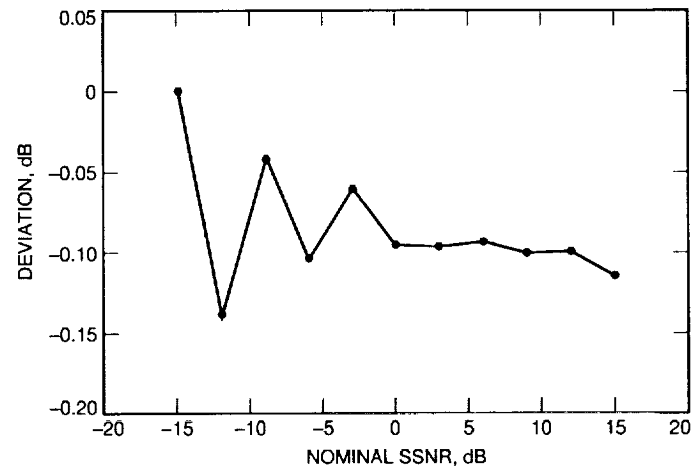

Fig. 7. Baseband SSNR setting accuracy (digital). Bandwidth = 4 MHz, subcarrier frequency = 354 kHz, symbol rate = 230.4K symbols/sec, and integration time = 30 sec.

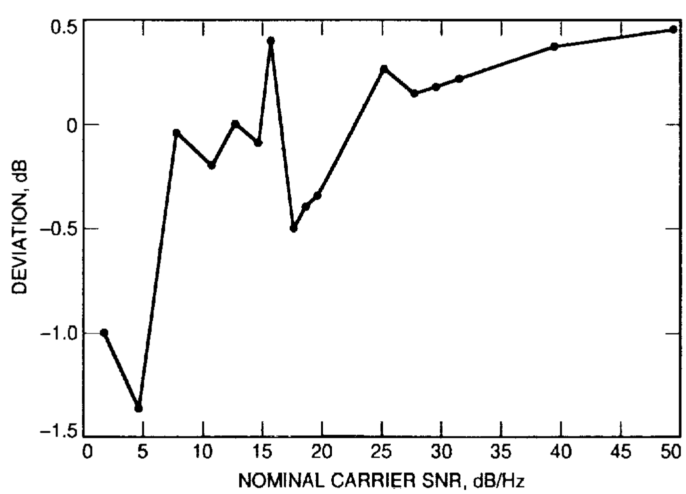

Fig. 8. IF carrier SNR (P_c/N_0) setting accuracy (digital). IF = 5 MHz, bandwidth = ±150 kHz, and integration time = 0.1 msec.

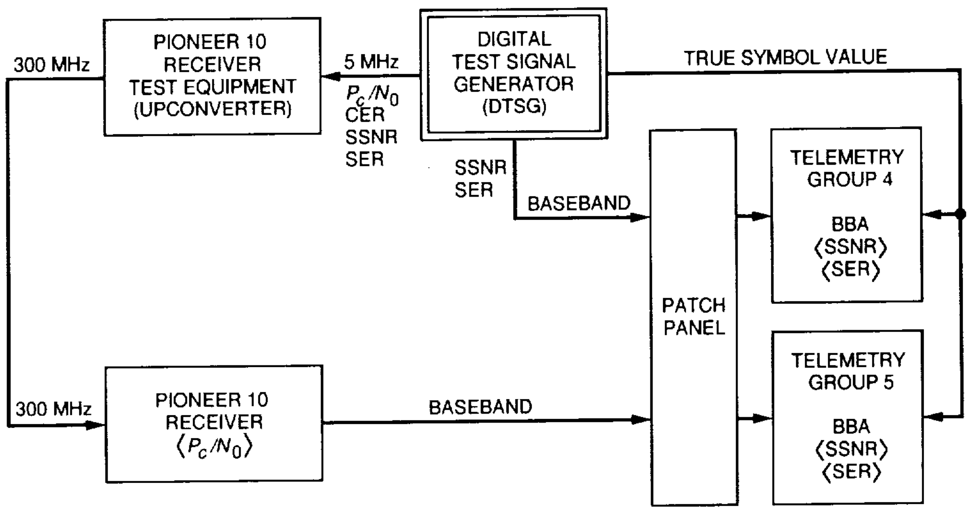

Fig. 9. SPC 10 testing configurations.

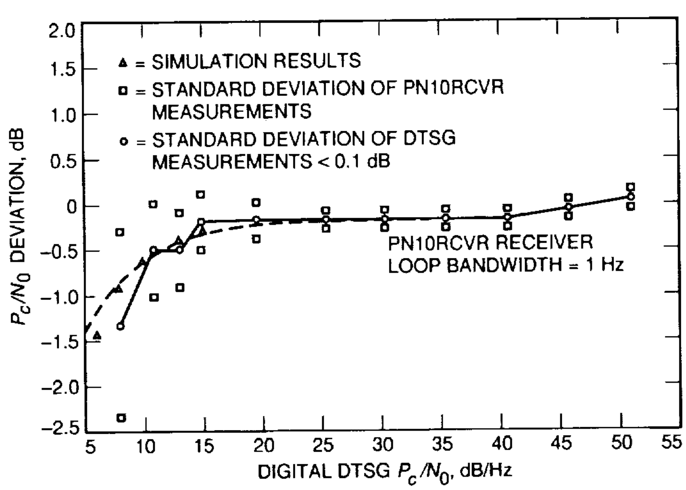

Fig. 10. Measurements of the 300-MHz PN10Rcvr carrier SNR (P_c/N_0). IF = 5 MHz and bandwidth = —150 kHz.

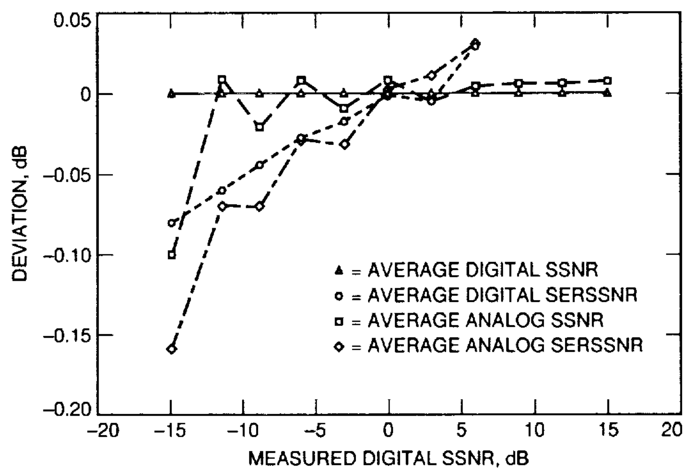

Fig. 11. Baseband SSNR measurements (σ = 0.01 dB). Bandwidth = 4 MHz, subcarrier frequency = 356 kHz, symbol rate = 43,200 symbols/sec, and integration time = 30 sec.

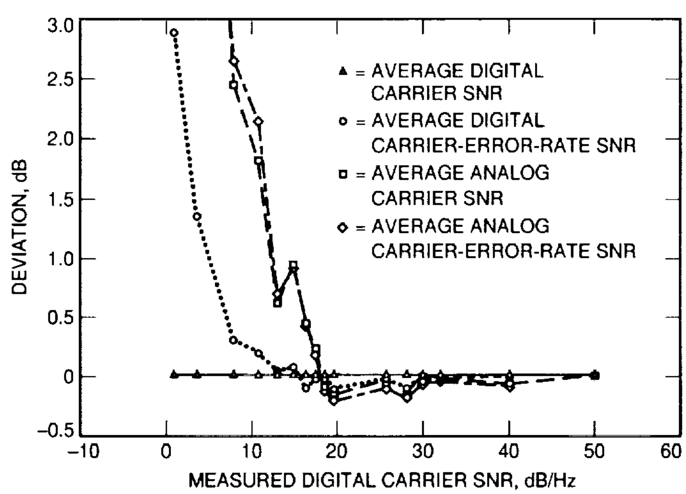

Fig. 12. IF carrier SNR (P_c/N_0) measurements (σ = 0.01 dB). IF = 5 MHz, bandwidth = ±150 kHz, and integration time = 0.1 msec.