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DIGITAL TEST SIGNAL GENERATION: AN ACCURATE SNR CALIBRATION APPROACH FOR THE DSN

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ABSTRACT

In support of the on-going automation of the Deep Space Network (DSN) a new method of generating analog test signals with accurate signal-to-noise ratio (SNR) is described. High accuracy is obtained by simultaneous generation of digital noise and signal spectra at the desired bandwidth (base-band or band-pass). The digital synthesis provides a test signal embedded in noise with the statistical properties of a stationary random process. Accuracy is dependent on test integration time and limited only by the system quantization noise (0.02 dB). The monitor and control as well as signal-processing programs reside in a personal computer (PC). Commands are transmitted to properly configure the specially designed high-speed digital hardware. The prototype can generate either two data channels modulated or not on a subcarrier, or one QPSK channel, or a residual carrier with one biphase data channel. The analog spectrum generated is on the DC to 10 MHz frequency range. These spectra may be up-converted to any desired frequency without loss on the characteristics of the SNR provided. Test results are presented.

Key Words: Signal-to-noise ratio, testing automation, space-telecommunications performance

1. INTRODUCTION

Spacecraft link performance optimization has always been a requirement for missions supported by the Deep Space Network (DSN). This optimization relies on accurate predictions for the degradations (and losses) encountered in the different modulation and detection processes in use in the telecommunication link. Mathematical models for these processes usually are available beforehand to be later verified by tests run at the Telecommunications Development Laboratory (TDL), Compatibility Test Area (CTA-21) and sometimes at the DSN Stations. Also, the DSN has extremely high availability requirements for telemetry support of deep space missions. This requirement (as high as 99%) imposed on the Ground Data System (GDS) as a whole, immediately translates into extremely tight performance requirements on the test signals to be used as performance verification tests ("pre-track").

Parameters of a telecommunication link that need to be precisely known (Ref. 1) are: carrier signal-to-noise ratio (SNR), symbol SNR, and bit SNR for coded transmissions. Variables implicit in above measurements are: telemetry filtered wave shape, modulation index, total transmission bandwidth, orbit profiles (doppler), system noise temperature,and carrier phase jitter, as well as the telemetry and tracking receiving systems performance. Availability and performance of the entire system (GDS) is usually verified before a scheduled spacecraft pass ("pre-track tests").

These "pre-track tests" have traditionally been performed with the well known Y-factor method. Different error sources come into play depending on whether the test is performed in the carrier or in the modulated part of the transmitted spectrum. Reported accuracy of the manual method in use today varies from 0.3 dB, in a rigidly controlled environment, to 1 dB at the DSN stations.

2. GENERAL DESCRIPTION

To improve the accuracy and reliability, and to automate the measurement process, a digital test signal generator (DTSG) has been developed at the Jet Propulsion Laboratory (JPL) to digitally synthesize the highly precise test signal. Then, the signal-to-noise ratios obtained are independent of gain variations, consequently full knowledge and control of above variables can be achieved.

The DTSG main components are: a JPL built SNR generator box (SGB) with block diagram shown in Figure 1, a personal computer (PC), and an off-the-shelf frequency synthesizer. The SGB generates signals with different spectra, including IF, dual subcarrier, or quadrature phase-shift-key (QPSK). The monitor and control, as well as other signal-processing programs, resides in the PC. The PC transmits configuration commands to the SGB, which in turn configures the special high-speed digital hardware needed to generate the output calibrated signals. A programmable frequency synthesizer generates the variable system clock (2 to 20 MHz) needed by the high-speed hardware.

Figure 1 shows in block diagram form the main functions assigned to each board residing in a Multibus-I chassis in the SGB. Three digital paths with identical hardware (pattern generator, filter, and attenuator) are used to generate two base-band filtered data channels (channels 1 and 2) of subcarrier binary phase-shift keyed data (BPSK) and one channel of base-band filtered noise ("Noise Channel") to be subsequently added to produce the analog output

$$S_T(t)=d_1(t)\,\mathrm{Sin}\,\omega_{sc1}t+d_2(t)\,\mathrm{Sin}\,\omega_{sc2}t+N_{BB}(t) \qquad (A)$$

where: $\omega_{sc1,2}$=the first or second subcarrier frequency, $d_{1,2}$=the first or second base-band filtered data process, N_{BB}=the base-band filtered noise process, and Sin x=sign[sin(x)] or sin (x).

In case of residual carrier generation, channel 1 generates the carrier, channel 2 generates the modulation, and the noise channel generates the band-pass filtered noise. The filtered analog output of the DTSG in this configuration becomes

$$S_T(t)=\cos\Theta(t)\sin\omega_c t+m(t)\sin\Theta(t)\cos\omega_c t+N_{BP}(t) \qquad (B)$$

where: ω_c=the carrier frequency, Θ=the modulation index, N_{BP}=the band-pass filtered noise process, and m(t)=the modulation signal.

A QPSK output is similar to (A) with

$$\omega_{sc2}t=\omega_{sc1}t+\pi/2 \qquad (C)$$

3. DIGITAL SIGNAL GENERATION (Ref. 1)

Referring to figure 1, the digital synthesis method consists in the generation of a gaussian digital noise ("Noise Channel") by sequentially reading a random access memory ("Data or Noise 64K RAM") at a very high speed (20 MHz). The RAM has been loaded with data bytes conforming to a quantized gaussian distribution function deduced from the analog probability function

$$f(x;u,\sigma)=1/(\sigma\sqrt{2\pi})\,e^{-[(x-u)/\sigma]^2/2} \qquad (D)$$

with u=0 for unbiased noise and σ=standard deviation.

The sequential address to the RAM is determined by a random address generator with inherent uniform distribution and a very long period (longer than 24 hours). Therefore, the distribution function of the data bytes in the RAM determines the final distribution function of the digital noise. This digital noise is subsequently filtered by a digital filter with operator defined frequency response. Figure 2 is an example of the frequency response of a band-pass (IF) filter. Any type of coded or uncoded data and subcarrier frequency as well as any data pattern (frames and sub-frames) can be mapped and simultaneously generated in a similar RAM ("Channel 1"). This output is subsequently filtered by an operator defined digital filter. Digital addition of these two outputs properly attenuated ("Filter and Attenuator") will provide the desired SNR. This digital result is further converted into an analog representation ("Digital-to-analog Conversion") and up-converted to the desired frequency band to be tested. The SNR of this output is truly stationary. This property is very important because long integration times can therefore be used to obtain the accuracy and precision required by a particular test. Limits will only be imposed by the inherent generator quantization noise (0.02 dB).

The DTSG will be used to calibrate SNR measurements and also losses on other signal processes. Several statistical measurements have been implemented ("Statistics Monitor"). The same statistical measurements have been implemented in the digital output as well as in the analog output.

The symbol SNR is continuously evaluated using the statistical results of the "Symbol Squared Accumulator" ($\langle S^2 \rangle$) and the "Symbol Value Accumulator " ($\langle S \rangle$) by

$$SNR_M(dB)=10\log_{10}\{\langle S\rangle^2/[2(\langle S^2\rangle-\langle S\rangle^2)]\} \qquad (E)$$

The last measurement made in this output is the symbol error count, using the statistics accumulated in the "Symbol Error Accumulator". From these symbols in error, a Symbol Error Rate (SER) is calculated. This SER is further converted into the equivalent symbol SNR and compared to the previous measured SNR_M to verify the accuracy (i.e. 0.1 dB) of the generated SNR.

In order to characterize the hardware performance and DTSG accuracy, a "Histogram Accumulator" has been implemented providing therefore a straight forward method to confirm the actual probability density function of the filtered or unfiltered noise. Figure 3 is the histogram ($8\ 10^6$ samples) of a white gaussian noise generated in the "Pattern Generator" of the "Noise Channel" after filtering by the same filter with frequency response shown in figure 2. Also displayed in figure 3 is a fit of the theoretical gaussian probability function of identical standard deviation. Note the excellent agreement of the fit with the actual filtered noise.

4. REPEATABILITY (Ref. 2)

Several readings of the digital SSNR measurement of the base-band output were obtained. Table I shows a summary of those results for different base-band configurations. The different parameters used in the test were: the base-band bandwidth (BB-BW), the subcarrier frequency (Sc), the data symbol rate (Data), the desired symbol SNR (Nom. SSNR), the measured SSNR (DTSG SSNR), and the repeatability standard deviation (σ).

Identical tests were repeated for the IF configuration case with the results summarized in Table II. In this case the variables were: the total radio frequency bandwidth (RF-BW), the intermediate frequency for the test (IF), the desired carrier SNR (Nom. Pc/No), the measured carrier SNR (DTSG-Pc/No) and the repeatability standard deviation (σ).

Note the excellent repeatability obtained in both cases ant its dependency on the SNR generated (Ref. 1).

5. BASE-BAND TESTING (Ref. 2)

Several base-band configurations were tested at Goldstone's "Deep Space Station 12" by feeding the output of the DTSG configured in "Base-band Mode", to a Demodulator Synchronizer Assembly (DSA).The DSA was configured with a loop bandwidth of "Medium" and the mean SSNR (<SSNR>) and standard deviation were obtained every 30 seconds. A summary of results obtained are shown in Table III.

Table III shows the capabilities of the DTSG as a 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 almost no test set up time. Also, existing theoretical models may now be confirmed with the needed accuracy.

6. RADIO FREQUENCY TESTING (Ref. 2)

A Digital Receiver in development at JPL was used to confirm the DTSG capabilities of accurate and repeatable radio frequency SNR generation. The DTSG 5MHz IF output (signal and noise) was up-converted to 300MHz and fed to the Digital Receiver. The DTSG was configured in the "IF Mode", providing a carrier and the corresponding telemetry modulation. The results obtained from the Digital Receiver carrier detection and the Demodulator Subcarrier Assembly (DSA) are shown in Table IV. For the DTSG configuration the variables in Table IV are: the radio frequency bandwidth used in the DTSG at 300 MHz IF (RF-BW), the measured carrier SNR (Pc/No), the subcarrier frequency (Sc), the symbol rate (Data), and the measured symbol SNR (SSNR). For the Digital Receiver configuration: the one sided loop bandwidth (B_l), and the measured carrier SNR (Pc/No) with the standard deviation of the measurement (σ). Finally, the DSA measured symbol SNR (SSNR) with the standard deviation of the measurement (σ).

Comparison of symbol SNR results of Tables III and Table IV show very good agreement. Small differences are probably due to system degradation.

Another Digital Receiver test was run with the DTSG in the "300 MHz IF Mode", a RF bandwidth of ±150 KHz, and an unmodulated carrier. The carrier SNR (Pc/No) was decremented in 5 dB steps from 50 to 10 dB/Hz. Mean values of the Digital Receiver Pc/No measurements showed a maximum of 0.2 dB degradation. The standard deviation of the carrier SNR measurement of the Digital Receiver varied from 0.1 dB at Pc/No=50-20 dB to 0.5 dB at Pc/No=10 dB. A 0.5 dB degradation with a standard deviation of 0.6 dB was measured at 8 dB of Pc/No. Results again show an outstanding agreement, with a probable very small system degradation.

7. STABILITY (Ref. 2)

The DTSG is intended to be used as a precise SNR test generator at any frequency band used at the DSN (S, X, or K-band). Testing capability of processes involving frequency, phase, and amplitude stabilities, such as doppler or ranging measurements and radio science experiments, should also be a desired feature.

Tests were performed with the DSN Radio Science equipment using the same testing configuration previously described in 6. RADIO FREQUENCY TESTING. Post-real-time Allan variance measurements on a strong Pc/No (approximately 50 dB/Hz) were made showing frequency stabilities very close to the expected theoretical results (10^{-15} for an integration time of 300 seconds). An amplitude stability test performed in this configuration showed a maximum standard deviation in the signal power measurement of less than 0.01 dB.

8. REFERENCES

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Table I. Base Band Repeatability

BB-BW (MHz)	Sc (KHz)	Data (S/s)	Nom. SSNR (dB)	DTSG SSNR (dB)	σ (dB)
4	360	43200	3	2.94	0.007
4	360	230400	3	2.90	0.002
4	960	537600	0	-0.37	0.002
0.4	32	32	0	-0.23	0.14
0.4	32	32	5	5.39	0.14
0.4	32	32	11	11.57	0.05

Table II. IF Repeatability

RF-BW (MHz)	IF (MHz)	Nom. Pc/No (dB/Hz)	DTSG Pc/No (dB/Hz)	σ (dB)
±4	5	50	49.84	0.01
±1	5	30	30.00	0.01
±1	5	17	17.36	0.12
±0.15	5	40	40.38	0.01
±0.15	5	20	19.59	0.10
±0.15	5	15	14.85	0.20
±0.15	5	8	8.14	0.28

Table III. DSA Performance verification

DTSG configuration (Standard deviation<0.1dB)

BB-BW (MHz)	Sc (KHz)	Data (S/s)	DTSG SSNR (dB)	DSA SSNR,±σ (dB)
4	360	43200	2.94	2.90±0.10
"	"	"	-0.06	-0.16±0.12
"	"	268800	-0.08	-0.14±0.04
"	"	"	-3.12	-3.02±0.06
"	968	537600	-3.36	-3.36±0.06
"	0	800000	0.03	0.50±0.03
"	0	1200000	0.01	1.25±0.03
0.4	22.5	160	2.87	2.63±0.05
"	32.8	32	10.68	10.02±0.26
"	"	"	5.78	4.23±0.20
"	"	"	3.09	1.25±0.40

Table IV. Digital Receiver Test Results

DTSG configuration(σ<0.1dB)					Digital Receiver		DSA
RF-BW (MHz)	Pc/No (dB/Hz)	Sc (KHz)	Data (S/s)	SSNR (dB)	B_1 (Hz)	Pc/No,±σ (dB/Hz)	SSNR,±σ (dB)
±4	40.5	360	268800	0.86	5	40.30±0.25	0.60±0.01
±4	32.5	360	43200	1.10	5	32.20±0.40	0.78±0.01
±0.15	13.0	32.8	32	3.0	1	11.60±0.50	1.06±0.42
±0.15	13.0	32.8	32	3.0	0.25	12.60±0.20	1.88±0.25

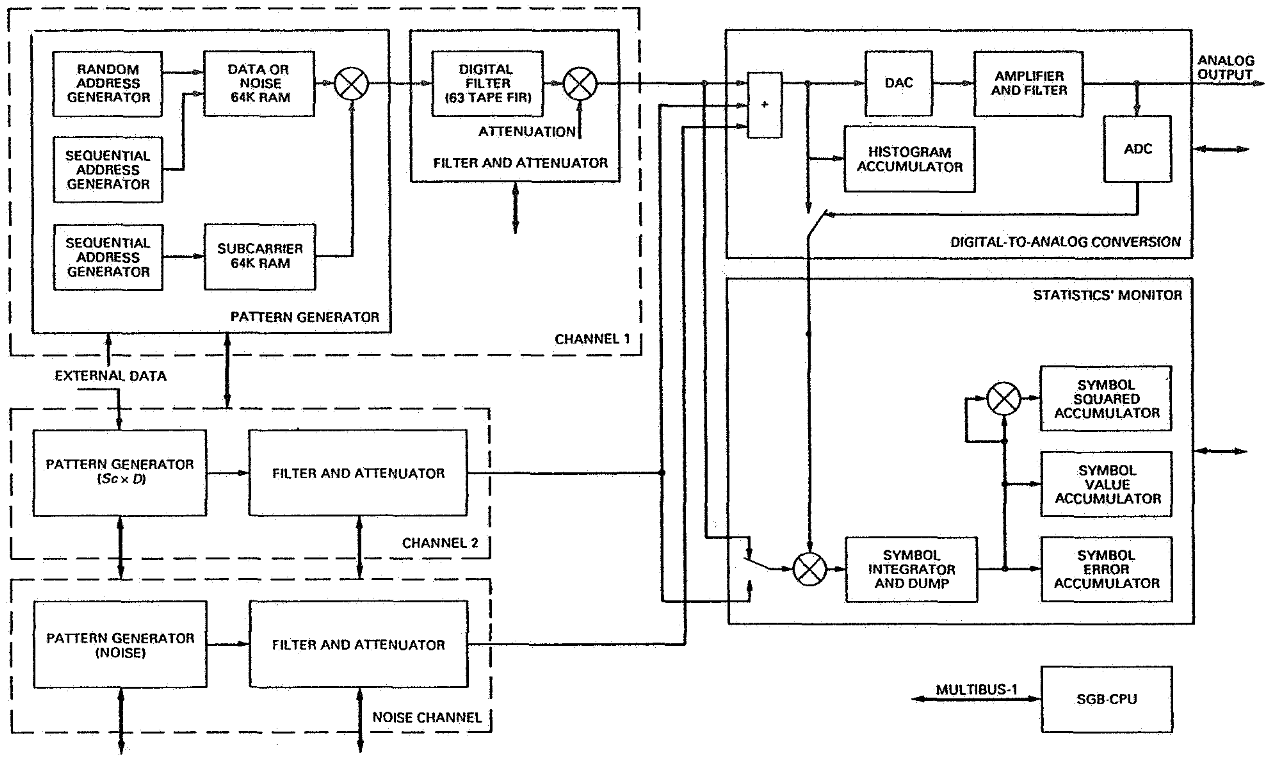

Figure 1.- SNR generator (SGB) block diagram

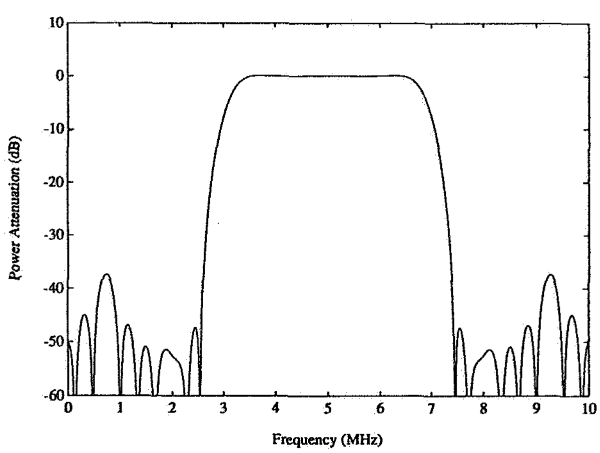

Figure 2.- Frequency response of ±2MHz IF filter

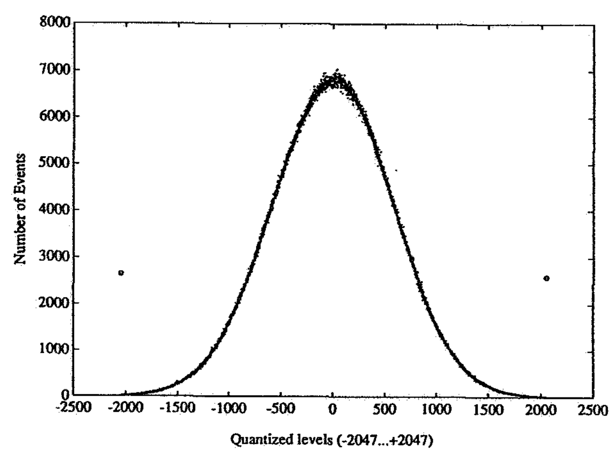

Figure 3.- Filtered discrete probability function with gaussian fit