FIELD TESTING OF TELEMETRY SYSTEMS

R. B. PICKETT
ITT/Federal Electric Corporation
Vandenberg Air Force Base, California

Summary Tests have been developed and implemented at the Western Test Range for calibration of telemetry receiving systems. The tests serve an additional function as diagnostic aids.

Introduction It is often difficult to obtain current estimates of telemetry receiving system parameters for use in mission planning. It is also difficult to verify that support systems will meet expected levels of performance for specific missile programs. For example, little definitive information is available on the degradation resulting from recorder incompatibilities inherent in the transfer of the magnetic tapes from the field to a central reduction facility.[(1)] Therefore, mission planners may allow up to 10 db excess signal margin to compensate for receiving station uncertainties. However, with the advent of S-band telemetry, providing such margins becomes costly and difficult to achieve, and it becomes important to implement a test program which provides current estimates of system Performance capabilities.

Recognizing this need, SAMTEC has directed the establishment of an improved calibration and checkout Program at Western Test Range sites. The program has been developed along lines suggested by Dr. W. H. Hedeman and Dr. M. H. Nichols,[(2)(3)(4)] and the program parallels recommendations now being considered by the IRIG. This paper presents a summary of the tests utilized, practical techniques developed in actual field use, testing achieved to date, examples of test results, and future plans. Additional detail is available in reference 9.

Field Test Program Testing of a system begins with the visit of a specially trained field team. A complete test sequence, as described below, is conducted in order to verify sub-system performance and establish baseline parameters. Concurrent with the testing, briefings are held for site personnel and on-the-job training provided. Also, step by step procedures are written to meet special site requirements.

Preliminary Testing In order to establish sub-system -performance, several preliminary tests are performed. (Refer to figure 1.) The antenna is pointed at the sun, and the down converter output monitored on a spectrum analyzer. Ideally, the noise spectrum would be “flat” in the VHF range corresponding to S-band. Humps, dips, or spikes indicate possible problems. An unusually bad spectrum is shown in figure 2. The problem was traced to faulty feed cables.

Next, the antenna is pointed at “cold sky,” and the receiver switched to the manual mode. Bias voltage is adjusted to provide the saw IF power level as produced in the AGC mode. IF power drift is then monitored and should be less than ± 0.25 db for a well functioning system.

The system is then switched to the calibrate mode, and the signal generator level increased until sufficient signal is available to tune all receivers. After tuning, the signal generator output is reduced, and the IF and recorder Pre-D playback noise spectrums monitored. Spectrums are again checked under “low” and ‘high” signal conditions. Examples of “typical” and “abnormal” units are shown in figure 3. This type of test can be performed in post-flight by monitoring the Pre-D flight tapes during the portion of tape used for signal calibration. This provides a check of receiver quality, tuning accuracy, and tape recorder performance on the actual mission.

Solar Calibrations Having determined that the sub-systems are operating normally, system calibration tests are begun. The first step is to measure the parameters required to compute the system signal to noise ratio, S/N, versus received signal strength. Subsequent test results are related to S/N, so these parameters are required to relate data quality directly to received signal strength.

Referring to figure 1,

$S/N = (\text{received signal})\, G_R/KT_sB$
where
G_R = receiving system antenna gain at the antenna feed
K = Boltzman’s constant = 1.38×10^{-23}
B = effective system noise bandwidth, HZ
T_s = system noise temperature referenced to the antenna feed, K°

For S-band antennas pointing above 10° in elevation and well away from the sun,
$T_s = 290\,(L_1\,NF - 0.9)$ (5) (6) (7)
where
L_1 = the power loss ratio between the antenna feed and pre-amplifier input (lossy elements at ambient temperature)
NF = the combined pre-amplifier, down converter, Multicoupler, and receiver noise figure

S/N can be determined if G_R, L_1, and NF are known, as K is known, and B can be determined by monitoring the system noise spectrum. In the past, these parameters were obtained individually by laborious and time consuming testing. Fortunately the ratio, G_R/T_S, called the system figure of merit, M, can be obtained directly from solar measurements on S and L-band systems.

There are at least three techniques in use - all of which require linear gain characteristics for the pre-amp/down converter/multicoupler over the range of power levels experienced during solar measurements. One technique requires directional couplers at the pre-amp input, and another requires a receiver with linear gain characteristics. The third technique, using a matched attenuator as described below, has been adopted at SAMTEC/WTR due to equipment limitations. The test is simple to perform, but prone to error unless the conditions discussed below are met.

The solar measurement begins by pointing the antenna at the "cold sky" at about the same elevation as the sun and about 10 beamwidths behind the sun. The IF power is noted in the AGC mode. The receiver is then switched to the manual mode, and bias adjusted until the IF power level is restored to the value obtained in the AGC mode. This assures that the receiver will have constant gain, and that it is operating in a fairly linear manner.

The antenna is then pointed at the sun, preferably in the autotrack mode, and the matched attenuator adjusted so that the IF power level returns to its previous value.

Under these conditions

$$\frac{G_R}{T_S} \cdot \frac{K_1}{L} \cdot F_o \approx \left(\frac{1}{N} - 1\right)\left(1 - \frac{NF_R}{G_1\left(NF - \frac{0.9}{L_1}\right)}\right) \quad (7)$$

where

F_o = the solar flux density reported daily on the Solar Observing and Forecasting Network (SOFNET)

K_1 = a constant to convert Fo to the corresponding flux density at S-band or L-band

L = aperture corre factor for antenna systems with beamwidths less than 1° [2][4]

N = attenuation required to set the IF power on the sun to the "cold sky" IF power level (i.e. attenuator output/attenuator input)

NFR = receiver noise figure

G_1 = the power gain at the attenuator input

For G_1 NF >> NF_R, $$\frac{G_R}{T_s} \approx \left(\frac{1}{N} - 1\right)\left(\frac{L}{K_1 F_o}\right) = M\text{, the figure of merit}$$

To complete the solar calibration, the current value of F_o is obtained by phone and entered with the attenuator setting, in db, on a specially constructed nomograph which solves for G_R/T_s.

The entire procedure takes about 30 minutes and requires no calculations in the field. Typical results are shown in figure 4.

Bit Error Rate Test Solar measurements provide the data required to compute S/N versus received signal strength. The bit error rate test measures the error rate corresponding to a particular SIN. Combining the two measurements provides error rate versus received signal strength, the information required for effective planning.

The test requires a PCM simulator, a pre-mod filter, an RF generator, a bit error rate monitor and bit synchronizer. If the error monitor and synchronizer are not available in the field, tests can be made by shipping tapes to a central reduction facility.

The first step is to adjust the bit rate, PCM format, pre-mod filter settings, and generator deviation [(8)] to approximate the expected missile parameters. The RF signal is injected, preferably at the pre-amp input or at the receiver input, if equipment limitations dictate. The receive/record station is set to a typical operational support configuration, and the RF level increased until the IF power increases 3 db above its noise level. This corresponds to a 0 db S/N. Recordings are then made and appropriately voice annotated.

During tape playback the simulator clock is derived from the bit synchronizer, and the inputs to the error monitor synchronized by manually breaking lock until the signals are aligned within the range of the error monitor delay register. For registers of ± 2 bit delay, a 32 bit pseudo-random code can be conveniently synchronized. If additional register delay is available, a longer code should be used. The tape can be played back on any suitable recorder, thus providing information on machine to machine incompatibilities. Typical results are shown in figure 5.

Intermodulation Distortion Measurements Specialized test equipment, the Marconi TF 2091 transmitter and TM7730 receiver, are used to obtain a measurement of system intermodulation distortion. As the tests are not general in nature, it is suggested that the reader refer to reference 9 or the manufacturer's manuals.

Antenna Tracking Tests The most important single operational consideration is to ensure that the antenna tracks the missile. Many of the “standard” tests are employed e.g., moon tracks, satellite tracks, aircraft tracking tests, and boresight “lock on” tests. In addition, antenna pointing position and time are recorded on missile operations and compared to the best estimate of trajectory.

Two additional tests have been developed which have proven valuable. The first test compares the antenna pointing position, while autotracking the sun with the sun’s computed position. It was initially expected that an antenna would not track the center of the sun but would instead wander. Experience has shown that a properly working system tracks the center of the “quiet sun” smoothly with variations apparently less than 0.056°, the least significant bit of the shaft encoder 1 PPS readout. Consequently, comparison of tracking position with the sun’s position provides a direct indication of tracking quality, and also shows shaft encoder biases.

The second test consists of moving the antenna off the sun’s center in azimuth and elevation by one-half of the 3 db beamwidth. Autotrack is then selected, and tracking response noted. A properly functioning system will pull onto the sun’s center with little overshoot or hunting.

Test Program Status With the exception of notch noise testing, the above tests have been completed at Vandenberg AFB and Pillar Point, California stations; and the Barking Sands, Hawaii station. Also, briefings have been held with personnel at Point Mugu, Kwajalein, and the Hawaii Tracking Station at Kaena Point. Development of similar testing is now underway at these facilities.

Systems tested to date include 80', 40', 30', 8' and 7' antenna systems with “monopulse” and conical scan tracking, systems; many variations of pre-amplifier/receiver combinations, and CEC-VR-3600, Ampex FR-1400 and FR-1900, and HP 3950 recorders. Pre-D and Post-D tapes were made using PCM/FM NRZ at 44K bit -rate and PCM/FM bi-phase at 345K bit data rate. Results have been compiled in reference 9.

Future Plans Bit error rate testing will be conducted on combiners and conical scan systems slightly mispointed from boresight.

SAMTEC/FEC Operations Planning is now integrating the tests into preventative maintenance and check out routines.

Conclusions and Observations The value of solar measurements as a diagnostic 90 has been well proven. Field personnel are enthusiastic, as they are able to perform a valid system check in a short time. Although a more extensive data base is required, data indicate that the uncertainty in a properly conducted G/T_s measurement is less than 2 db. This compares favorably with errors accumulated in antenna gain, cable loss, and noise figure tests. The main problem in solar tracking is the difficulty in "finding" the sun so that autotrack can be obtained. Consequently, a table of look angles has been prepared for each participating site. There are a number of considerations before attemDtina solar measurements, and it is suggested that references (2)(4)(7)(9) be studied carefully prior to actual testing.

Copies ok references 7, 8, and 9 are available on request. Also, yearly solar look angles will be provided to legitimate users. Specify site longitude and latitude. Address requests to CAO, Attention: Mr. S. Garouttev Headquarters, Space and Missile Test Center (AFSC) Department of the Air Force, Vandenberg Air Force Base, California 93437

The primary problem with the bit error rate test is that a repetitive pseudo-random pattern does not adequately represent the type of signal received on a missile launch. However, equipment limitations presently preclude a more comprehensive test. Additional analysis will be required to determine the errors involved. Meanwhile a 1 db uncertainty in test results is considered reasonable.

It should not be assumed, however, that the results will correspond closely to PCM theory. The results represent the system in the launch support configuration which may, by direction, differ significantly from. the optimum configuration used in developing error rate theory.

Notch noise testing has been conducted only at the Vandenberg AFB station. Additional tests are planned to develop a suitable data base for analysis purposes.

References

1. "Weak Link in Telemetry Communications Systems," Telemetry Journal, Volume 4, Number 6, October/November 1969.

2. W. R. Hedeman, "The Sun as a Calibration Signal Source for L- and S-Band Telemetry," Proc. of the International Telemetry Conference, Vol. IV (1968), pp 330.

3. M. H. Nichols, "Requirements for a Data Quality Assurance Program," Proc. of the International Telemetry Conference, Vol. II (1566), pp 535.

4. W. R. Hedeman, "Solar Calibration of Telemetry Receiving Systems," a tutorial lecture given by Dr. W. R. Hedeman, Jr., at the September 1969 ITC.

5. E. L. Gruenberg et al. Handbook of Telemetry and Remote Control, McGraw-Hill, New York, New York, 1967, pp 4-93.

6. E. L. Gruenberg et al. Handbook of Telemetry and Remote Control, McGraw-Hill, New York, New York, 1967, pp 4-109.

7. R. B. Pickett, "Solar Flux Measurements," Systems Performance Analysis Directorate Report 4000-70-09.

8. R. B. Pickett, "Calibration of FM and PM Signal Generators for PCM Modulation," Systems Performance Analysis Directorate Report 4000-70-39.

9. R. B. Pickett, W. S. Crane, G. L. Ward, "Telemetry System Testing," Systems Performance Analysis Directorate Report 4000-70-40.

Figure 1
Test Confirmation

Figure 1A Solar Calibration Block Diagram

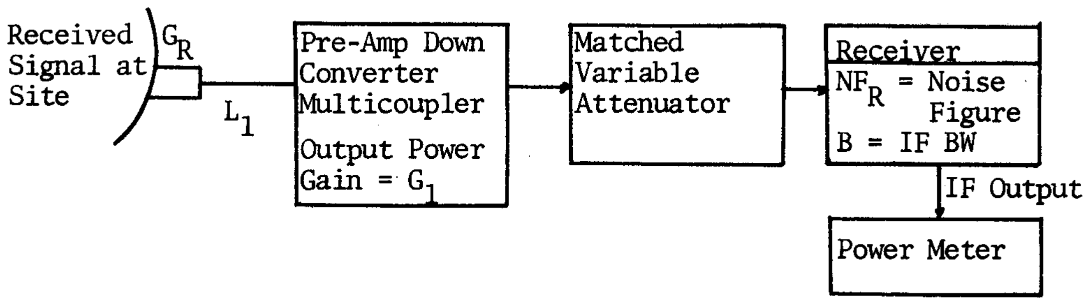


Figure 1B Bit Error Rate Test Block Diagram

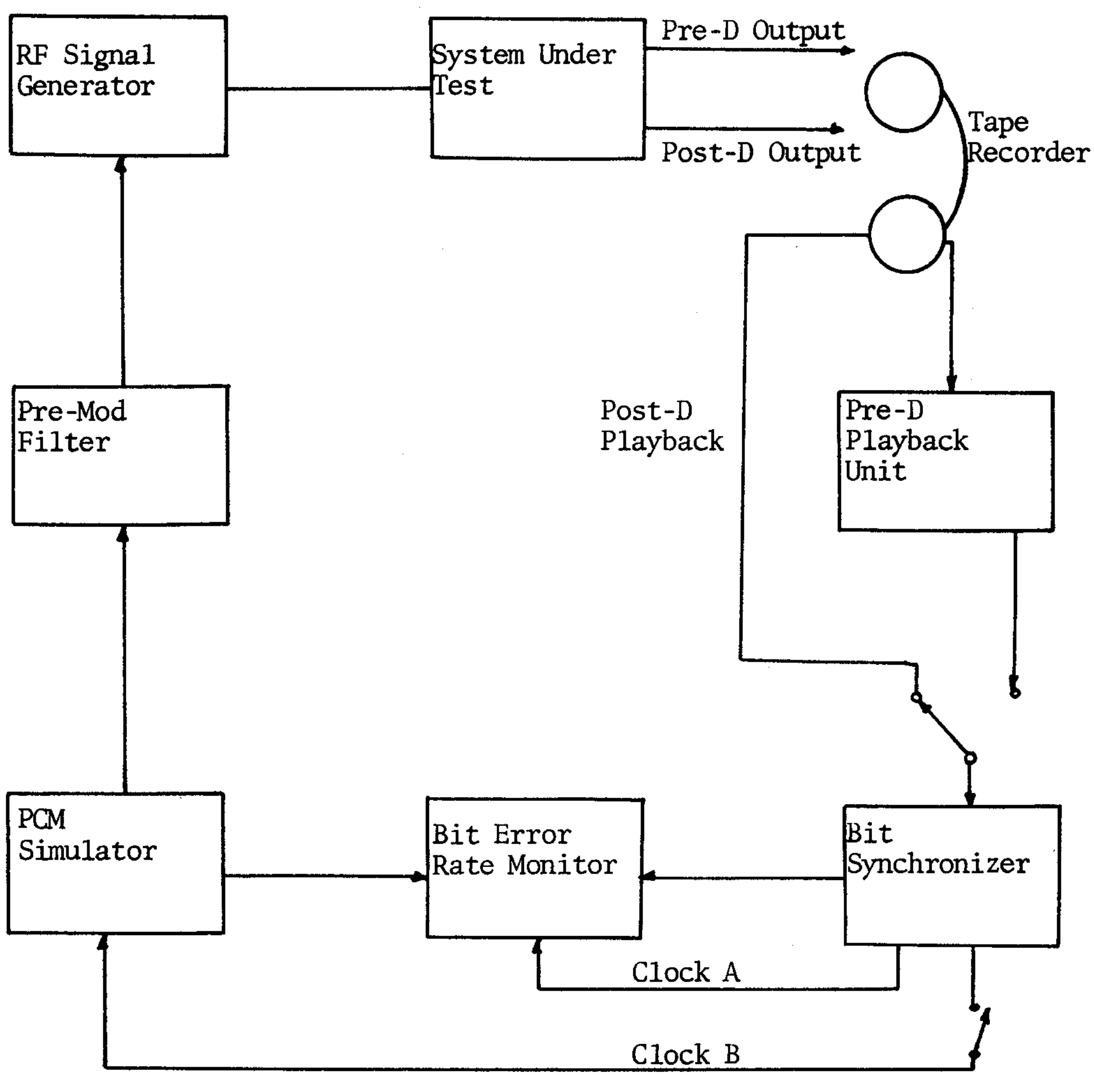
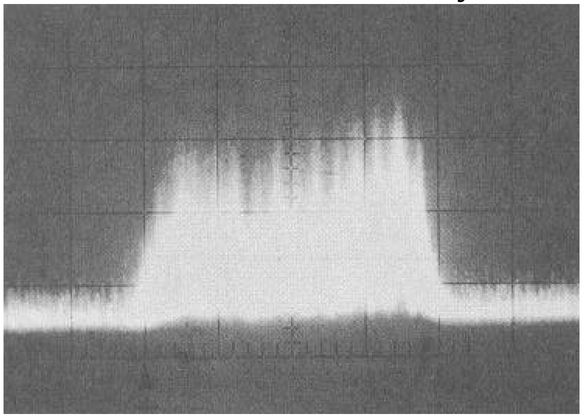


Figure 2

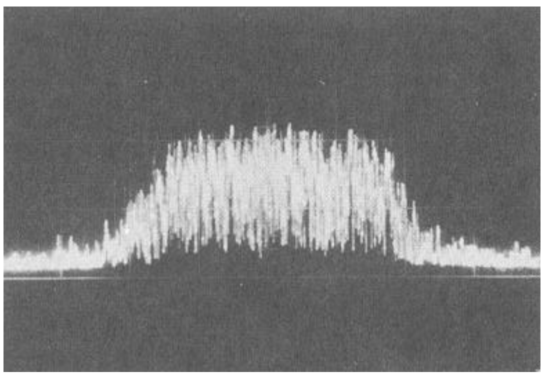
S-band spectrum down converted to VHF, 40' antenna system.



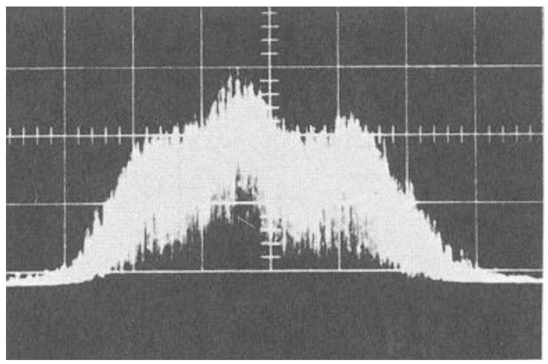
215-315 MHz, 300 kHz/division, log vertical scale, 10 db/division
The spectrum variations with frequency are excessively large.

Figure 3

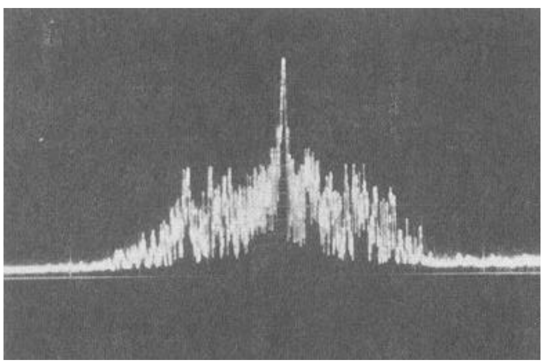
Pre-D tape recorder playback spectrum, up converted to 10 MHz.
Receiver IF BW is 300 kHz. Displays are 100 kHz/division with a log vertical scale, 10 db/divisions.



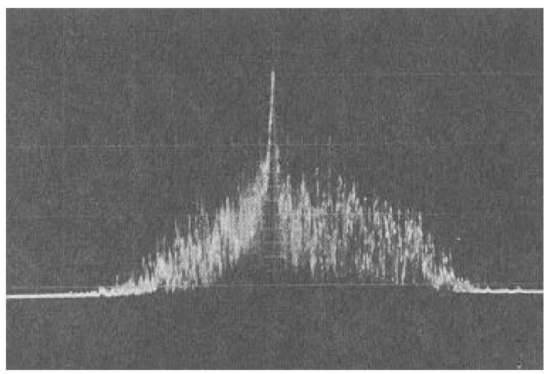
3A. "Typical" System Noise Spectrum



3B. Abnormally Aligned System Noise Spectrum



3C. Properly Tuned System



3D. Improperly Tuned System

Figure 4
SOLAR CALIBRATION RESULTS

System Tested Tracking Mode Date	80' Pillar Point "Monopulse"		30' VAFB Conical Scan		8' VAFB Manual	
Frequency, MHz 1 MHz IF BW	RHC	LHC	V	H	RHC	LHC
	10 $\log_{10}$ G/T_s					
2200	22.7	23.8	9.5	8.0	0.9	2.3
2205	22.2	23.4	9.5	8.7	0.5	1.5
2210	22.9	23.4	9.5	9.5	0.9	1.3
2215	24.0	23.5	9.7	10.0	1.1	1.3
2220	23.2	23.5	9.6	9.4	0.9	0.7
2225	23.1	23.3	9.6	9.0	1.3	1.0
2230	23.9	23.4	9.7	8.8	1.4	1.2
2235	23.2	23.3	9.0	8.5	1.0	1.2
2240	23.3	23.6	9.0	8.1	0.8	1.4
2245	23.6	23.9	9.4	8.5	1.0	1.2
2250	23.8	23.9	9.9	8.5	0.6	1.0
2255	23.7	23.9	10.0	8.2	0.6	1.0
2260	23.9	24.1	9.5	8.1	0.9	1.1
2265	23.8	24.3	9.7	8.1	1.1	1.1
2270	24.1	24.7	9.8	8.8	1.7	1.3
2275	24.0	24.5	9.6	8.0	1.7	1.3
2280	23.8	24.4	9.7	8.9	1.3	1.3
2285	23.8	24.8	9.5	9.2	1.7	1.5
2290	23.3	25.3	9.6	9.2	1.3	1.7
2295	23.1	25.2	9.5	8.5	1.4	1.5
2300	22.8	25.8	9.5	8.5	1.4	1.0

Figure 5
BIT ERROR RATE TEST RESULTS

System Tested: 80' Antenna Pillar Point, 3/10/70

Configuration: RHC, Microdyne 2200-R, 300 kHz IF BW
50 kHz Video BW, CEC-VR-3600 Recorders

Signal Parameters: PCM-NRZ 44 K bit
Pattern 10101001010110100101100101010001
PCM/FM @2250 MHz, 32 kHz peak dev. Pre-mod filter 36 db/oct. roll-off at 400 Hz and 50 kHz

S/N in 300 kHz IF	Errors per Million, in 4 Million Bit Sample				
	Receiver output during record cycle	Average of 4 tracks pre-D play-backs on site re-corders	Average of 6 tracks pre-D played back at VAFB processing station	Average of 4 tracks post-D played back at VAFB processing station	Average of 4 tracks played back on HP 3950 (no speed-lock)
6	3500	3520	9500	9850	12,000
7	900	1200	3500	3990	5500
8	260	265	980	1275	1500
9	25	50	250	325	380
10	3	4	80	45	65
11	0	0	4	3	4
12	0	0	0	1	0