THE WHITE SANDS MISSILE RANGE TELEMETRY VALIDATION SYSTEM (TVS)

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ABSTRACT

The purpose of this paper is to briefly discuss the evolution and history of the White Sands Missile Range (WSMR) Telemetry Validation System (TVS). Ongoing development of an automated TVS is discussed in terms of system philosphy, configuration, and operation.

INTRODUCTION

Use of large scale digital computers for real-time data processing began experimentally at WSMR in the late 1950's. By the early 1960's, the use of such computing equipment was common for providing a complicated test program with range safety displays and command/ control support.

The interface of range instrumentation to computers for real-time support produced a dramatic, sometimes painful, change in the means by which countdown readiness testing was conducted. Automated diagnostics were developed for individual instrumentation systems and configurations and, for the first time, discrete results could be evaluated. These early diagnostics, however crude by todays standards, were the seeds from which the sophisticated instrumentation test methods of today were produced.

The changes of the 1960's, and the more readily availability of low cost data processing equipment, produced a change in philosphy by which individual instrumentation systems would be readiness tested. The concept of a Telemetry Validation System (TVS) has been with us, both in practice and planning, for a number of years.

The WSMR TVS is a three part program:

1. On-Site, subsystem (equipment) alignment.

This is a preliminary validation testing designed to insure that site equipment (i.e. telemetry receivers, converters, tape recorders, etc.) are performing to the nominal specifications required to pass the validation (diagnostic) process.

2. On site-system validation.

This is a station (site) validation. These are tests designed to insure that individual station components are performing together within the required tolerances of the validation process.

3. Total system validation.

The total telemetry system at WSMR involves telemetry receiving, microwave relay, and recording from three fixed and seven mobile general purpose tracking systems. Figure 1 is a block diagram depicting the flow of information through both the mobile (transportable) and fixed Telemetry Acquisition Systems (T)TAS) / (tracking systems). Figure 2 is a block diagram of the flow of data through a fixed or mobile microwave station (Transportable Telemetry Acquisition and Relay System (T)(TARS). Additional equipment available includes two mobile display vans and several specially configured support vans. This total system validation will insure that the system is in optimum readiness for mission support. Results from these diagnostic procedures will also be utilized to build a data base for system operational readiness and possible quality assurance usage.

This 3rd phase of the validation process, now undergoing final development, is the primary subject of this paper.

VALIDATION TESTING PHILOSOPHY

Currently, most telemetry validation procedures at WSMR are performed manually. However, validation testing procedures should be automated to the maximum practical extent possible. Automated testing provides the most efficient utilization of time and personnel. It also ensures maximum accuracy and repeatability of test results - two of the most important parameters in the compilation of statistical data for the establishment of realistic operational standards (means) and GO-NO-GO tolerances (weighted standard deviations).

With this criteria in mind, validation test equipment procurements and test procedures are being directed toward automation.

SYSTEM DESIGN

The Telemetry Validation System is designed to verify TM operational readiness from the most remote acquisition site to the final terminal interface and to identify operational deficiencies - be they hardware, software, or procedural - before they become mission support critical. As mentioned previously, to accomplish this task the validation testing shall be conducted in three phases.

1. Subsystem (bench or in-rack) testing

2. Station testing

3. System (or end-to-end) testing

All phases of testing shall be conducted under computer control so that test results can be input into a data base to develop a test profile. This test profile shall be used to establish acceptable deviation tolerances from the theoretical nominal values.

Each telemetry site will do subsystem and station testing using its own operational/ validation microprocessor. These tests will be conducted according to specifications contained in IRIG document 118-79, volumes I-IV, as modified to allow automated testing. The on-site microprocessors will be linked to the central validation processor (CVP) (see Figure 3). The CVP will monitor station validation testing and conduct total system validation testing to verify telemetry mission support readiness.

The CVP will monitor all real-time mission support systems to identify any support deficiencies and correct those deficiencies, in real-time, if possible. The real-time mission support parameters will be logged on magnetic tape for post flight analysis and to establish a project support data base. The results of the analysis will be used to reconfigure and/or improve telemetry support.

The major telemetry subsystems which will be tested are:

1. Tracking antenna subsystem
2. RF subsystem
3. Microwave relay subsystem
4. Record subsystem
5. Validation processors, validation communication link and validation data link

The telemetry tracking antenna subsystems will be validated using a boresite as a signal source. These subsystems are composed of the seven Transportable Telemetry Acquisition Systems (TTAS) and the three fixed Telemetry Acquisition Systems (TAS).

A fixed error signal is introduced into the TTAS servo loop causing the antenna to slew 360°. The resultant data is used to verify antenna feed systemtry, pedestal gear train soundness and syncho servo operation. Next, the TTAS is subjected to a “Twang” test to verify auto track performance. To verify maximum slew rate performance the digital remote pointing interface is used. In each tracking subsystem, a Tracking System Interface (TSI) is included. The TSI provides selectable subsystem tests. After a TTAS has been transported across the range to a support site, the TSI is used to verify antenna feed symmetry. Using the ± 90 degrees azimuth and − 5 degrees to + 85 degrees elevation slew tests, the tracking receivers’ AGCs are recorded vs time. If the results indicate asymmetry, the feed supports are adjusted until symmetry is achieved.

Since the point source’s effective radiated power and its coordinates as well as the tracking site’s coordinates are known, the relationships:

$L_s = 96.6 + 20 \log_{10} F + 20 \log_{10} Dd$
L_f = sum of all fixed losses in dB
L_m = maintenance margin in dB
$P_R (dBm) = P_T (dBm)\ G_R (dB)\ G_T (dB) - L_s - L_f - L_m$
$F = L/D = 0.42$

where

F	=	frequency in GHZ
Dd	=	distance between antennas in miles
dBm	=	dB with respect to a milliwatt
P_R	=	received power
P_T	=	transmitted power
G_R	=	receiving antenna gain
G_T	=	transmitting antenna gain
L	=	focal distance
D	=	aperture diameter

are used to re-center and re-focus the antenna.

The antenna is then slew 360 degrees to verify the front-to-back ratio. Next, the “Twang” test is performed by first pointing the tracking antenna at the radiation source. The received signal strength is measured and the acquisition threshold sensitivity is set to a

3 dB level above the tracking antenna's side lope level. The tracking antenna is manually positioned 5 degrees right off the radiation source signal axis. The "auto-track" mode is selected. Using the azimuth control knob on the antenna control panel, the antenna is rapidly slewed, "Twang", toward the signal axis. The measured servo obtained is compared to the second (2nd) order ideal theoretical response.

The theoretical response of a second order s stem has a transfer function of the form:

$$T(s) = \frac{\omega_\eta^{\,2}}{s^2 + 2\zeta\omega_\eta s + \omega_\eta^{\,2}}$$

Where the damping factor Zeta (ζ) is of the range $0 \leq \zeta \geq 1$ and the undamped natural frequency (ω_η)is of the range $\omega_\eta > 0$

From transient response analysis, the step response may be calculated by:

$$= \frac{1}{s}\left(\frac{\omega_\eta^{\,2}}{s^2 + 2\zeta\omega_\eta s + \omega_\eta^{\,2}}\right)$$

transforming to time domain

$$C_{step}(t) = \left[1 - e^{-\zeta\omega_\eta t} \sin \frac{(\omega_\eta \sqrt{1-\zeta^2}\, t + \cos^{-1}\zeta)}{\sqrt{1-\zeta^2}}\right] 1(t)$$

The angular frequency (ω_d) of the oscillations can be computed by:

$$\omega_d = \omega_\eta \sqrt{1-\zeta^2}$$

Since the magnitude of the oscillations decreases as exp ($-\zeta\omega_\eta t$), the second - order system time constant (τ) is given by:

$$\tau = \frac{1}{\zeta\,\omega_\eta}$$

and the settling time by:

$$t_s = 4\tau = \frac{4}{\zeta\omega_\eta}$$

Another important characteristic to consider is the time and magnitude of the first peak given by:

$$t_p = \frac{\pi}{\omega_\eta\sqrt{1-\zeta^2}}$$

$$C_{step}(t_p) = 1 + \exp\left[-\left(\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right)\right]$$

Therefore

Overshoot (0_s) = peak value - final value

and

$$\% \text{ Overshoot} = \frac{\exp\left[-\left(\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right)\right] *100}{\text{Final Value}}$$

Thus we can see that the % 0_s is a function of the damping factor only. For practical purposes the damping factor should be in the range

$0.3 \leq \zeta \geq 0.7$

The “auto-track” mode is also tested by first pointing the antenna at the sun. The acquisition sensitivity thresholds are set to the proper levels, the subsystem “auto-track” mode is selected and the subsystem must “track” the sun for two (2) minutes or the subsystem must be repaired and reverified.

The RF subsystem performance is validated using the sun as a data source and applying the solar calibration technique. The RF front end, the tracking receivers and the data receivers are tested to verify subsystem sensitivity, noise temp, bandwidth, and figure of merit. (See Appendix)

Each hop (transmit/receive station pair) of the microwave subsystem will be validated using a microwave deviation calibrator, a spectrum analyzer, a microwave frequency counter, and a power meter to verify subsystem performance. Once each hop has been validated, the microwave subsystem will be mated with the tracking antenna and RF subsystems and end-to-end system testing will be conducted using noise power ratio (NPR) tests, bit error rate (BER) tests and simulated FM/FM composites tests for system transparency.

To conduct microwave BER tests, pseudo random bit pattern generators were constructed. These generators can be used to directly modulate the microwave baseband channels or used to modulate an RF transmitter. The signal is received through the tracking subsystems' antennas and RF subsystems' receivers. The receivers' outputs drive bit synchronizers which in turn modulate the microwave baseband channels.

Using the criterion developed by D. A. King in Technical Publication TP-76-6, namely:

	NRZ		DM	
	F/S	I/D	F/S	I/D
P-P RF transmitter deviation	$0.8f_B$	$0.9f_B$	$1.6f_B$	$1.8f_B$
IF filter bandwidth (or equivalent pre- and post-recording IF bandwidth)	$1.0f_B$	$1.0f_B$	$2.0f_B$	$2.0f_B$
Premodulation filter bandwidth	|<----------- $0.5f_B$ to $1.0f_B$ ---------->|			

where f_B = bit rate

The subsystems are tested for a bit error probability (BEP) of 10^{-6} at an RF power level of -87 dBm.

Currently, the channels which will carry FM/FM data are tested by injecting a test tone at the source and observing the tone at the terminal end with an oscilloscope. The channel power levels are set to provide the best channel-to-noise power ratio for the given combination in use.

Notch filters will be installed to monitor the microwave baseband. One filter will measure above the baseband to detect changes in thermal and intermodulation noise in the RF and

IF sections. The other filter will measure below the baseband to detect changes in the multiplex and demultiplex equipment.

In addition to the subsystem and station tests, the recording subsystems at each hop will be validated by recording the link BER and FM/FM test data. The data will be played back and compared with the original test data to verify record subsystem performance.

The validation communication link will allow the central validation processor to interrogate the stations' microprocessors for station validation tests results. The CVP will also be able to remotely configure a subsystem and/or station validation test(s) if deemed necessary by the validation system's engineer.

The validation data link will make available the following parameters to the CVP.

1. Tracking site indentification
2. Tracking bandwidth selected
3. Tracking mode selected for azimuth and elevation servos
4. Tracking status indicating tracking data selected-Left Handed or Right Handed Circular Polarization (LHCP or RHCP) or combined and data validity
5. Tracker indentification
6. LHCP tracking receiver AGC data
7. RHCP tracking receiver AGC data
8. Azimuth shaft encoder data
9. Azimuth tracking error signal
10. Elevation shaft encoder data
11. Elevation tracking error signal
12. Microwave relay subsystem I.D.
13. Data receivers AGC (10 ea)
14. Microwave subsystem status bits (256) indicating subsystem configuration of each hop and subsystem operational status
15. Special TTL compatible bits (64)
16. Twenty (20) digital to analog channels

Items 15 and 16 will be used to carry mission unique data such as PCM bit sync status, inside/outside ambient temperatures, microwave back-up battery voltage levels, power generator's fuel levels, intruder alarms, etc.

The central validation processor and the station microprocessors will be validated daily using the manufacture's delivered self test software. The computer interfaces and communication link will be validated by having the stations' microprocessors output known data and having the CVP compare the received data against a stored data file. The validation data link will be verified by having the CVP inputting and analyzing a station test and comparing its results with the results supplied by the respective station's microprocessor.

Any subsystem or system test discrepancies will cause subsequent lower level testing to be initiated until the faulty component is identified and corrected. The failed test will be repeated to ensure all problem areas have been identified and corrected.

APPENDIX

The solar calibration concept is described in IRIG Document 118-79, "Test Methods for Telemetry Systems and Subsystems - Volume 1: Chapter 1".

The solar calibration technique makes use of the fact that all physical objects radiate energy. At radio frequencies, this radiated energy is directly proportional to the absolute temperature of the object in degrees Kelvin.

By relating the uncorrected solar flux readings obtained daily from the National Bureau of Standards to the on-off power ratio, the tracking subsystem noise temperature can be computed. The on-off power ratio is the power ratio obtained when pointing the tracking antenna directly at the sun (radiating source) and then pointing at the cold sky (away from radiating source).

Subsystem sensitivity, acquisition sensitivity and a subsystem figure of merit describing the "goodness" of the subsystem can be determined from the subsystem temperature measurement.

The standard system temperature equation is:

$$T_s = \frac{F_0 \, (f_b/f_d)^{\frac{1}{2}} \, G\lambda^2}{8 \pi K} \left[\frac{1}{\frac{P_2}{P_1} - 1} \right]$$

where

F_0 = uncorrected flux; 1 flux unit = 10^{-22} watts M^{-2} H_z^{-1}
f_b = test frequency
f_d = frequency at which solar flux measurement is made
f_a = frequency at which solar flux density was measured
G = tracking system's antenna gain

λ = wavelength of f_b
K = Boltzmann's constant
$\frac{P_2}{P_1}$ = on/off power ratio (hot sky:cold sky)

we have modified this equation from

$$F_0(f_b/f_d)^{\frac{1}{2}} \quad \text{to} \quad \left(\frac{F_0\ (2695)}{F_0\ (1415)}\right)^s * F_0\ (1415) * L$$

where

F_0 (2695) = uncorrected solar flux density measured at 2695 MH_z
F_0 (1415) = uncorrected solar flux density measured at 1415 MH_z
s = log (f_b /1415) / log (2695/1415)

and

$$L = \left(1 + 0.18\left(\frac{\Theta_d}{\Theta_b}\right)^2\right)^2$$

where

Θ_d = .53
Θ_B = 3 dB beamwidth of the sum channel

System sensitivity (S_s) is computed by

$S_s = KT_sB_e$ (S/N)

where

K = Boltzmann's constant = 1.38 x 10^{-3} watts $^0K^{-1}$ H_z^{-1}
T_s = System temperature in ^{0}K
Be = Equivalent bandwidth in H_z
S/N = Minimum signal required at the error detection input for servo operation

Equivalent bandwidth for post-detection

$$B_c = \sqrt{2 B_r B_v}$$

where

B_r = RF bandwidth
B_v = Video bandwidth

with

$B_v << B_r$ and $\frac{B_r}{B_v} > 10$

Acquisition sensitivity is the actual threshold AGC sensitivit

$A_s = KT_sB$ (S/N)

where

B = Bandwidth of the receiver final IF.

Figure of merit (FM) is given by:

$FM = 10 \log G/T_s$

where

G = Tracking system's antenna gain
T_s = System temperature

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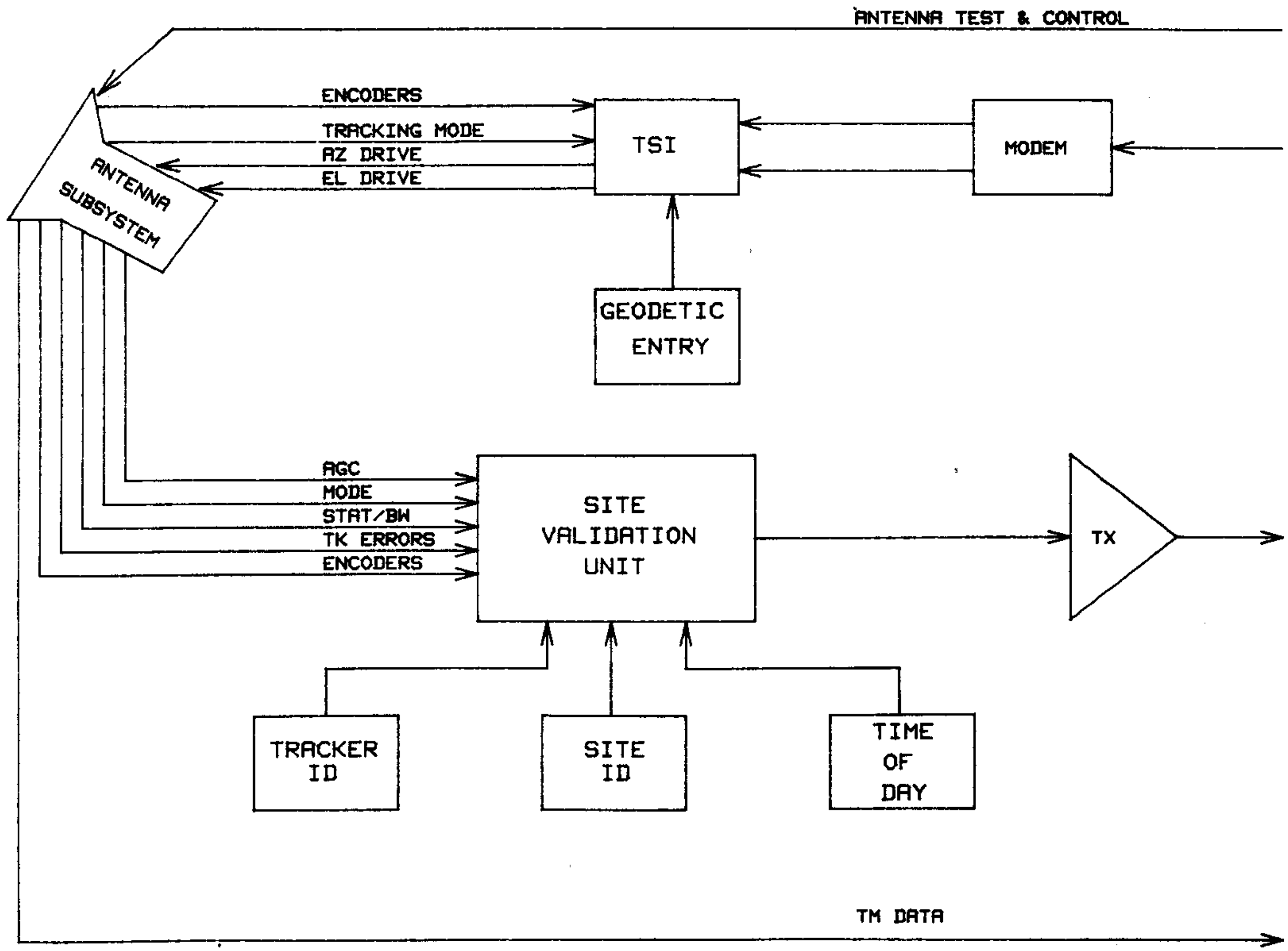
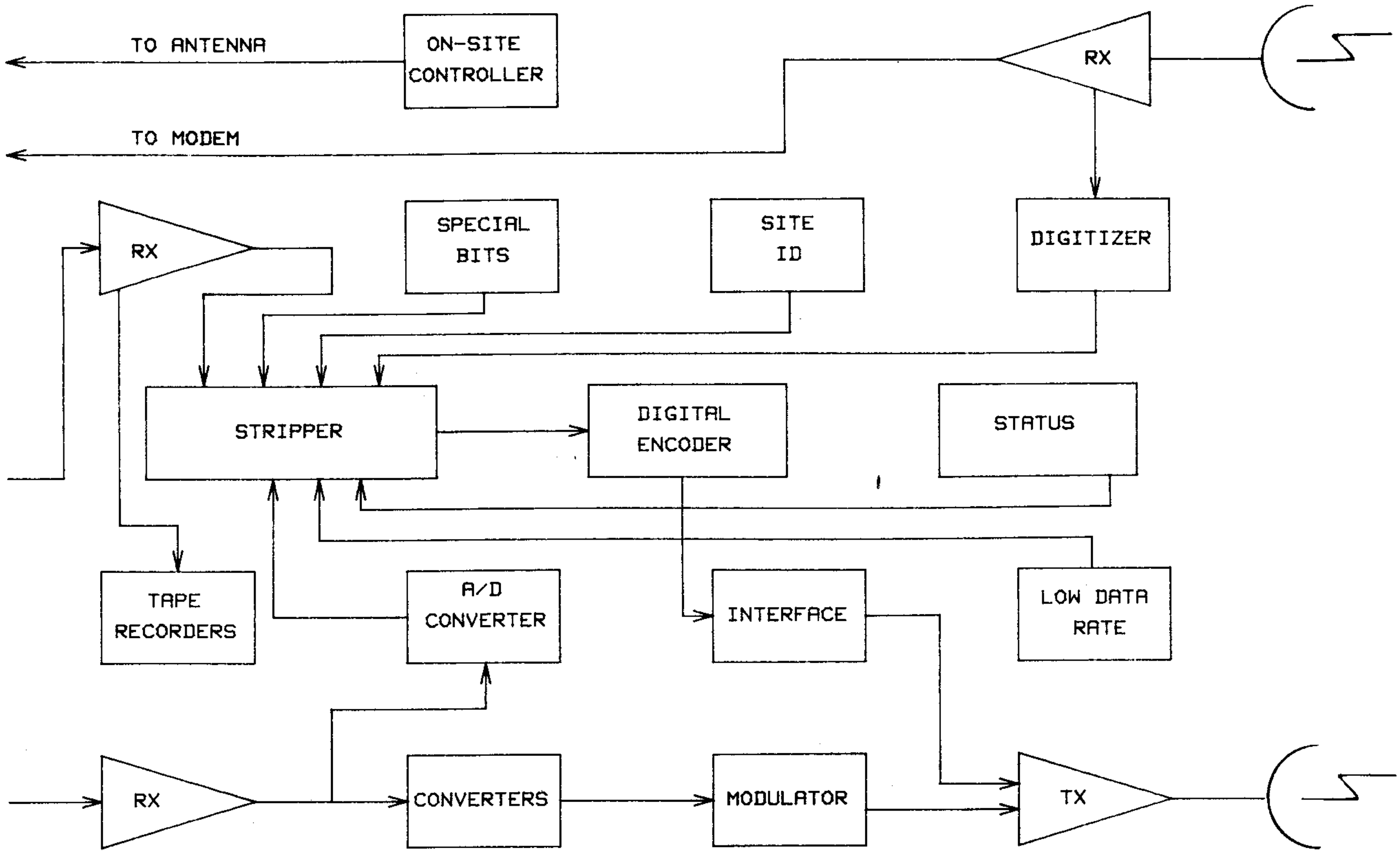
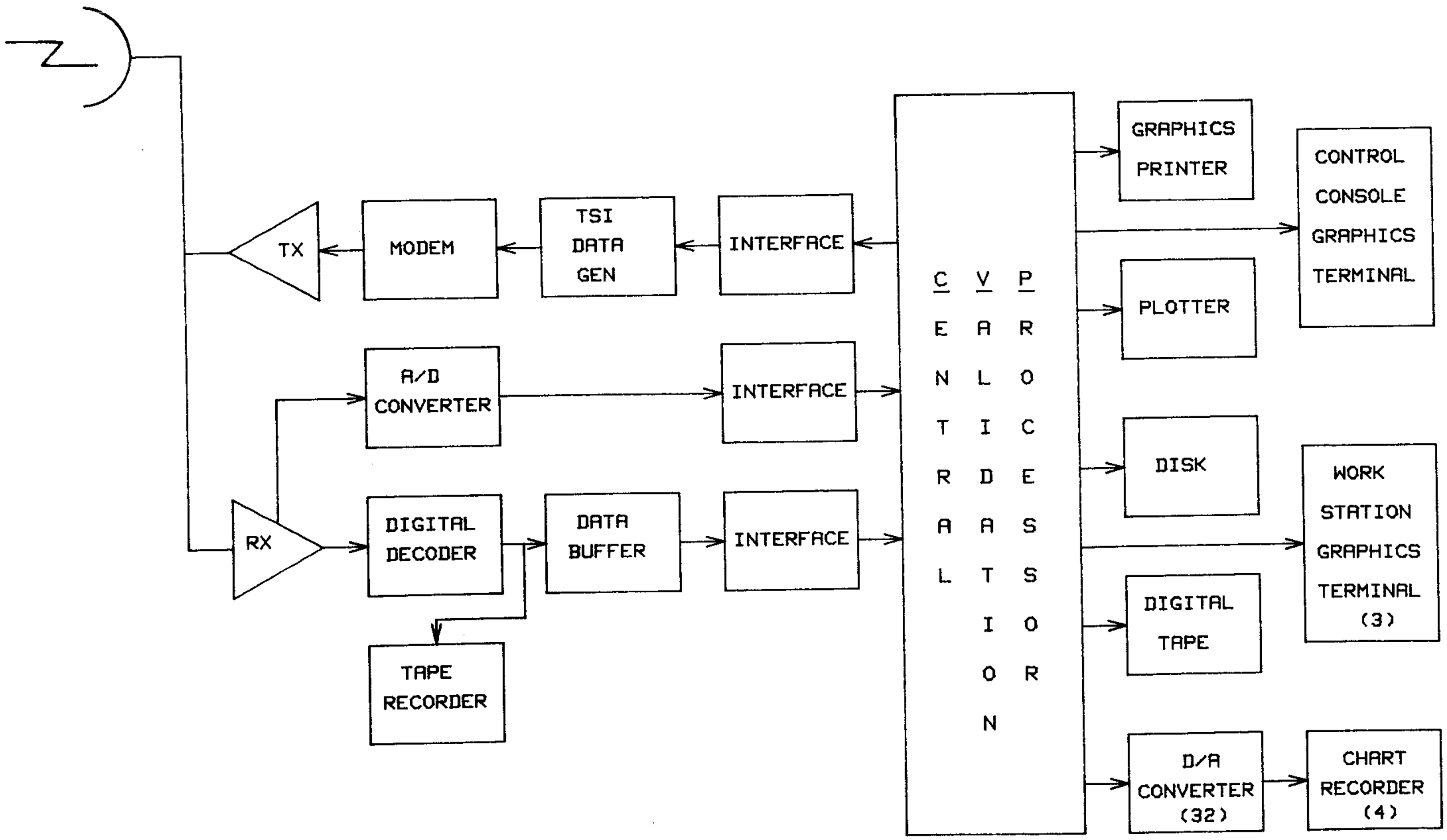


(T) TRS
Figure 1



(T) TARS
Figure 2



CENTRAL VALIDATION STATION
Figure 3