

GURALP SEISMIC INSTRUMENTATION COMPONENT EVALUATION

Richard P. Kromer, J. Mark Harris and Toby O. Townsend

Sandia National Laboratories

Sponsored by National Nuclear Security Administration
Office of Nonproliferation Research and Engineering
Office of Defense Nuclear Nonproliferation

Contract No. DE-AC04-94AL85000

ABSTRACT

Sandia National Laboratories have tested and evaluated seismic instrumentation from Guralp Systems Limited (GSL), Aldermaston, Reading, United Kingdom. Components evaluated include the DM24-B1 single channel borehole digitizer and the CMG-3V single component short-period vertical borehole seismometer. These two components were then integrated into two subsystems along with the CMG-AM borehole data authenticator modules.

GSL DM24-B1 tests included a response to static and dynamic input signals, data time-tag accuracy and seismic application performance. Configurations tested include:

- DM24 1-channel 40 samples per second GSL CMG3-V short-period seismometer gain
- DM24 1-channel 1 sample per second GSL CMG3-T broadband seismometer gain

The GSL CMG-3V tests included side-by-side testing to determine sensor self noise, seismometer response, seismometer sensitivity, and calibration capability. Dual subsystem installation using Sandia FACT site 'shotgun' boreholes was demonstrated. CMG-AM data streams were connected via the Internet to the Air Force Technical Applications Center (AFTAC) at Patrick Air Force Base in Melbourne, Florida.

The GSL equipment was evaluated for use in the International Monitoring System (IMS). In these cases, IMS data surety requirements and guidelines must be met for station certification. GSL CMG-AM data surety was tested to verify correct operation in the station environment and to ensure that data surety requirements are met. These tests included data authentication (CD-1.1 format), intrusion monitoring, remote command authentication, and remote key management operations. Connections to the AFTAC Operation and Maintenance Subsystem (OMS) were demonstrated.

This paper describes the evaluation of the GSL seismometer, digitizer, authenticator/formatter components and performance within the subsystem.

OBJECTIVES

Introduction

AFTAC is tasked with monitoring the compliance of existing and future nuclear test treaties. To perform this mission, AFTAC uses several different monitoring techniques to sense and monitor nuclear explosions, each designed to monitor a specific physical domain (e.g. space, atmosphere, underground, oceans, etc.). Together these monitoring systems, equipment and methods, form the United States Atomic Energy Detection System (USAEDS). Some USAEDS seismic stations may be included in the International Monitoring System (IMS).

Sandia National Laboratories tested and evaluated seismic instrumentation from Guralp Systems Limited (GSL) including the DM24-B1 single channel borehole digitizer and the CMG-3V single component short-period vertical borehole seismometer. These two components were then integrated into two subsystems along with the CMG-AM borehole data authenticator modules. The GSL equipment was evaluated for use in the International Monitoring System.

Evaluations Performed

Sandia evaluated the overall technical performance of the GSL DM24-B1 borehole digitizer component of the Guralp instrumentation. Distortions introduced by the high-resolution digitizers were measured. The results of these evaluations were compared to relevant IMS application requirements or specifications.

Sandia evaluated the overall technical performance of the GSL CMG-3V short-period vertical borehole seismometer component of the Guralp instrumentation. GSL CMG-3V tests included side-by-side testing to determine sensor self noise, seismometer response, seismometer sensitivity, and calibration capability. The results of these evaluations were compared to relevant AFTAC and IMS application requirements or specifications.

Sandia will evaluate the data surety performance of the GSL CMG-AM authenticator module component of the Guralp instrumentation. GSL CMG-AM data surety will be tested to verify correct operation in the station environment and to ensure that data surety requirements are met. These tests will include data authentication (CD-1.1 format), intrusion monitoring, remote command authentication, and remote key management. These tests are intended to verify correct operation of the CMG-AM and the OMS in an IMS station environment.

RESEARCH ACCOMPLISHED

Guralp DM24-B1 Borehole Digitizer

The DM24-B1 borehole digitizer was manufactured by Guralp Systems Limited. The input to the digitizer is single-ended with an input impedance of 3,000 ohms. GSL provided two DM24-B1 digitizers to be part of a 2-element demonstration system that will include two CMG-3V seismometers and a CMG-AM data authenticator/communications modules. The DM24-B1's were configured to acquire data at 40 samples per second and 1 sample per second concurrently. GSL provided 'Scream' data acquisition software for each DM24-B1 digitizer. Scream is operated on a PC laptop computer and communicates with the DM24-B1s through a direct-connect serial connection. Data were acquired in Guralp Compressed Format (GCF) flat-file records. Selected tests were performed at 1 sample per second to demonstrate that capability.

Testing was performed at the SNL Facility for Acceptance, Calibration and Testing (FACT) site (Figure 1).

Two DM24-B1s were tested:

1. DM24-B1 S/N DA62, 1-channel, 40/1 samples per second, CMG-3V [1]
2. DM24-B1 S/N DA63, 1-channel, 40/1 samples per second, CMG-3V [1]

This paper presents a sampling of the test results from these configurations.

DM24-B1 Digitizer Performance Tests and Results

The following tests were conducted on the DM24-B1. This is a subset of tests as outlined in the Sandia Ground-based Monitoring R and E Technology Report [2].

Static Performance Tests

Input Terminated Noise (ITN) test: Measure the input terminated noise of the DM24-B1.

ITN test results: Figure 2 indicates that the DM24-B1/DA 62 has < 0.87 count RMS noise at 40 sps. Figure 3 indicates that the DM24-B1/DA 62 has < 0.34 count RMS noise at 1 sps.

Maximum Potential Dynamic Range (MPDR) test: Compute maximum potential dynamic range using data from the ITN test.

Table 1. DM24-B1 MPDR

DM24-B1 Serial No.	RMS Noise μ V 0.033 to 20 Hz	RMS Full-Scale Volts	MPDR
DA62	1.624	7.07	132.8 dB
DA63	1.642	7.07	132.7 dB

MPDR test results: Table 1 indicates that the DM24-B1 40 sps maximum potential dynamic range was greater than 132.7 dB.

Tonal dynamic performance tests:

Total Harmonic Distortion (THD) test: Measure the linearity of the DM24-B1 digitizers using total harmonic distortion.

Table 2. DM24-B1 THD

DM24-B1 Serial No.	THD
DA62	-116.4 dB
DA63	-114.2 dB

THD test results: Figure 4 and Table 2 indicate that the DM24-B1 total harmonic distortion was better than -114.2 dB.

Timing tests:

Time-Tag Accuracy (TTA) test: Determine the accuracy of the time-tags of the DM24-B1 data samples.

TTA test results: Figures 5 and 6 indicate that the DM24-B1 can time tag data samples to within 148 microseconds with a jitter standard deviation of 0.61 microseconds.

Time-tag accuracy drift

Time-tag Drift (TTD) test: Determine the impact of GPS loss on the ability of the DM24-B1 to correctly time-tag data samples.

TTD test results: Figure 7 indicates that the DM24-B1 time-base/clock drifts at a rate of approximately 76 microseconds per hour when GPS is lost and recovers at 49 microseconds per hour after GPS restoration.

Broadband Dynamic Performance Tests

Seismic Application Tests

Seismic System Noise (SSN) test: Determine ability of the DM24-B1 to resolve the expected seismic background using a CMG-3V seismometer.

SSN test result: Figure 8 indicates that the noise of the DM24-B1 digitizer was at least 8 dB below the USGS New Low Earth Noise Model (NLNM) between 0.033 and 18 Hz when used with a CMG-3V seismometer. Digitizer noise was at least 3 dB under the CMG-3T (the CMG-3V noise model is not available yet) sensor self-noise.

Guralp CMG-3V Short-period Vertical Borehole Seismometer

The GSL CMG-3V short-period vertical borehole seismometer was manufactured by Guralp Systems Limited. The sensor has a flat response from 30 seconds to 50 Hertz. GSL provided two CMG-3V seismometers for evaluation.

Testing is being performed at the SNL Facility for Acceptance, Calibration and Testing site (Figure 9).

Sandia will evaluate the overall technical performance of the GSL CMG-3V short-period vertical borehole seismometer component of the Guralp instrumentation. GSL CMG-3V tests include side-by-side testing to determine sensor self noise, seismometer response, seismometer sensitivity, and calibration capability. The results of these evaluations will be compared to relevant AFTAC and IMS application requirements or specifications.

Data Surety

Data Surety Requirements

The Provisional Technical Secretariat (PTS) has developed requirements to ensure that data from IMS stations is reliable and authentic. These requirements cover data surety aspects of the station, including data authentication, command authentication, key management operations, and intrusion monitoring. Our tests are intended to verify correct operation of the GSL CMG-AM equipment in an IMS station environment. IMS station data surety requirements, summarized from PTS documents [3], are listed here.

- (1) All IMS data must be signed at the sensor sites.
- (2) Data must be digitized and signed within a secure (tamper-detecting) environment.
- (3) Signature must be calculated within a dedicated, tamper-indicating hardware authentication device.
- (4) Data must be formatted for signing as specified by an approved protocol.
- (5) DSS (DSA with SHA-1) must be used with 1024-bit public key.
- (6) Signature device must generate DSA keys internally.
- (7) Signature device must provide public key components to user.
- (8) Signature device must not disclose private key directly to user or leak private key during operation.
- (9) Commands originating remote from the station must be signed by the originator and verified at the station.
- (10) A remote key change command must be supported for each authentication device; the authentication device must securely generate a new key pair and securely transmit the new public key.

Also, the PTS strongly recommends that a PC card device, certified to FIPS 140-1 Level 2, be used for DSA operations and private key storage.

Test Configuration

Testing of the GSL equipment will be performed during July and August 2003. The following test environment will be assembled at the Sandia National Laboratories in Albuquerque, NM.

The DC Simulator is a computer at SNL that is configured with software to parse the “Frame Store” files. It displays the CD-1.1 data format in a readable format, checks the validity of the format, and verifies authentication signatures using the *authd* program.

Data Surety Tests

System Design Review

Determine that the GSL CMG-AM, as part of the station environment, is designed to meet IMS surety guidelines; that system security, data authentication, and command authentication are incorporated in the equipment design and meet the minimal criteria.

Data Authentication

Determine that the GSL CMG-AM correctly calculates DSA signatures for sensor data in CD-1.1 format; that the station equipment transmits signed data that can be verified using the public key retrieved from the station.

Intrusion Monitoring

Determine that intrusion detection hardware is monitored correctly by the GSL CMG-AM; that the GSL CMG-AM sets the appropriate intrusion flags in the signed data; that the data transmitted from the station has these flags set correctly.

Remote Key Change Command

Determine that the key change operation works correctly on the GSL CMG-AM.

Remote Command Authentication

Determine that all commands issued remote from the station are signed at the remote location and verified at the station.

CONCLUSIONS AND RECOMMENDATIONS

DM24-B1 Digitizer Performance Tests

Table 3. DM24-B1/CMG-3V SP digitizer evaluation summary

II. Minimum requirements for station specifications			
Table 3. Specifications for primary and auxiliary seismic stations			
	Characteristics	Minimum Requirements	Guralp DM24-B1-CMG-3V/USGS LNM
1	<i>Array Pass Band</i>	SP: 0.5-16Hz	SP: 0.5-18Hz
2	<i>Seismometer noise</i>	<= 10 dB below minimum-earth noise at the site over the pass band	For CMG-3T sensor noise model: below the LNM minimum-earth noise model between 0.5 and 12 Hz; above the LNM minimum-earth noise model between 12 and 18 Hz
3	<i>Calibration</i>	within 5% in amplitude and 5 degrees in phase over the pass band	DC accuracy errors were within 0.4% for nominal and full-scale; -4% for over-scale
4	<i>Resolution</i>	18 dB below the minimum local seismic noise	Hz for calib (resolution) = 0.0148 nm/count @ 1 sec; resolution > -17 dB for 0.5 to 16 Hz.
5	<i>System noise</i>	<= 10 dB below the noise of the seismometer over the pass band.	<8 dB below the USGS LNM between 0.5 and 16 Hz; <4 dB below the CMG-3T seismometer noise
6	<i>Dynamic range</i>	>= 120 dB	better than 132.7 dB
7	<i>Relative timing accuracy</i>	<+ 1 ms between array elements	better than 146 microseconds

The DM24-B1 digitizer met IMS requirements as defined in Table 3.

CMG-3V Seismometer Performance Tests

At the time of this writing, the seismometer performance tests have not been completed. We expect to complete testing of the seismometers by September 2003.

Data Surety Tests

At the time of this writing, data surety tests have not been completed. Hardware, software, and documentation are needed to complete the evaluation.

REFERENCES

Evaluation of the Guralp DM24-B1 Borehole Digitizer for CMG-3V Application, Ground-based Monitoring R and E Technology Report, June 19, 2003.

Test Plan for the Evaluation of Digitizing Waveform Recorder Subsystems for Ground-based Geophysical Monitoring, Ground-based Monitoring R and E Technology Report, February 26, 2002.

Implementation Plan for IMS Authentication, CTBT/PTS/INF.100/Rev.1, 4 February 1999.



Figure 1. DM24-B1 Testing at FACT site

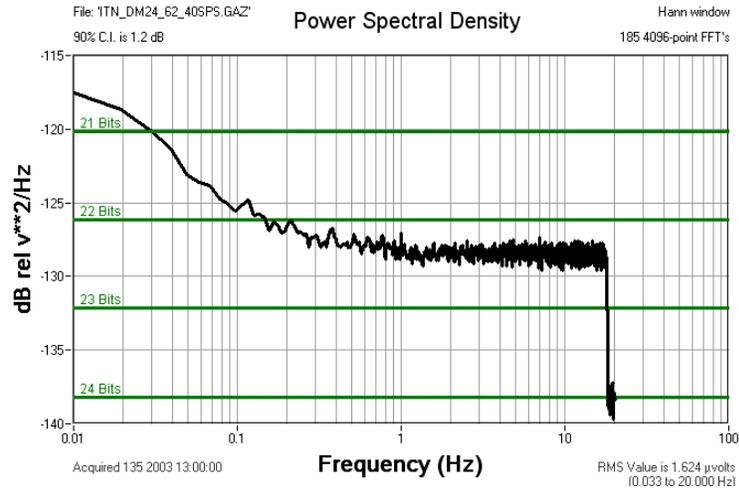


Figure 2. DM24-B1/DA 62 40 SPS input terminated noise

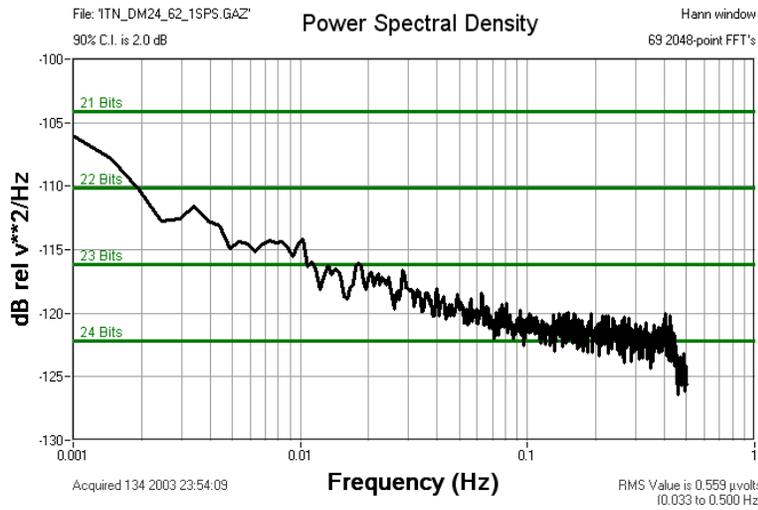


Figure 3. DM24-B1/DA 62 1 SPS input terminated noise

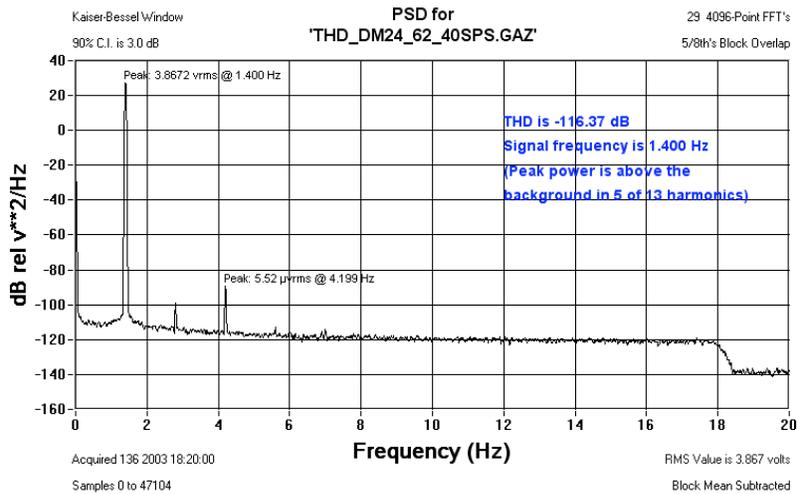


Figure 4. DM24-B1/DA62 Total harmonic distortion

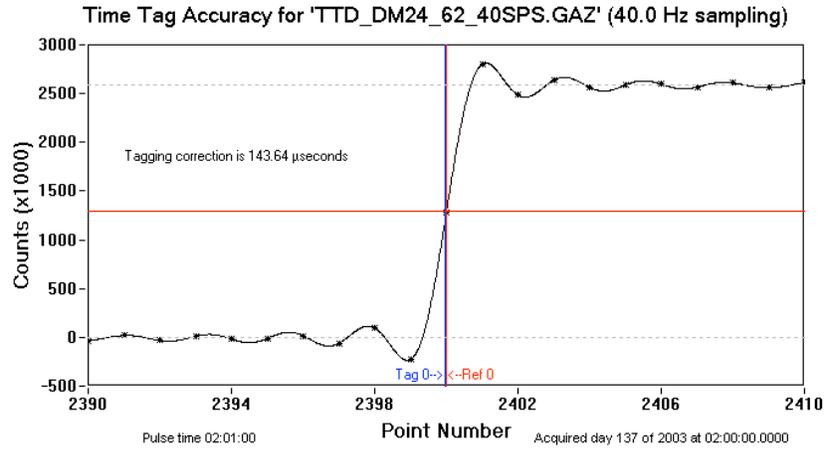


Figure 5. DM24-B1/DA62 Time-tag accuracy

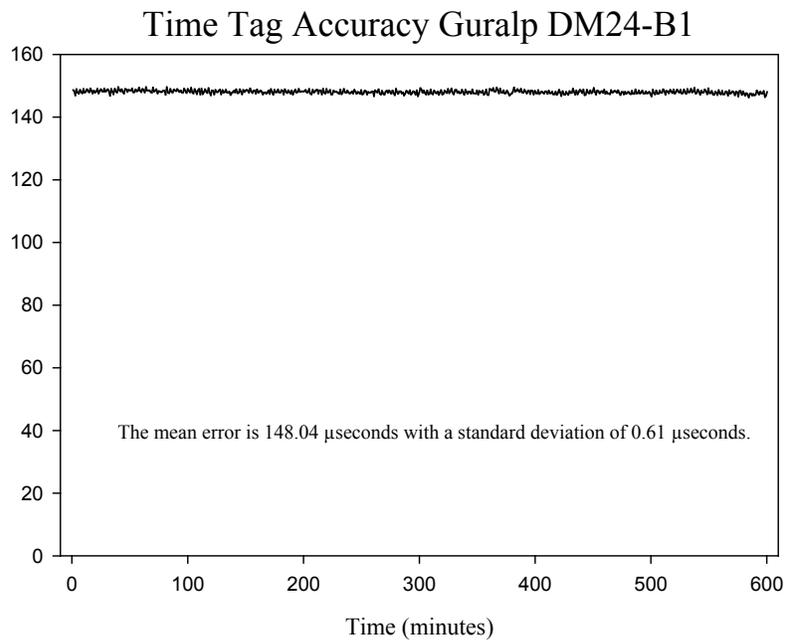


Figure 6. DM24-B1/DA62 Time-tag accuracy stability

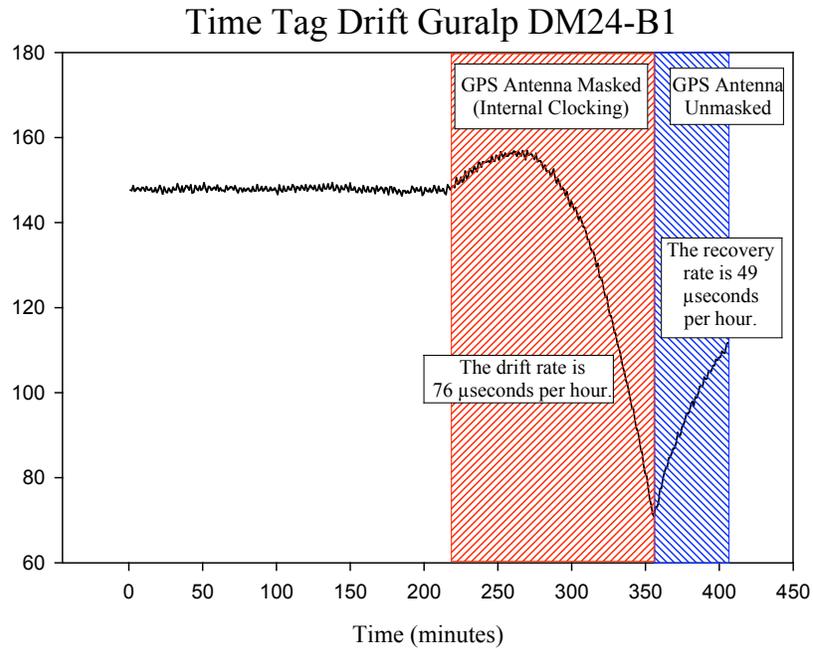


Figure 7. DM24-B1/DA62 Time-tag accuracy drift

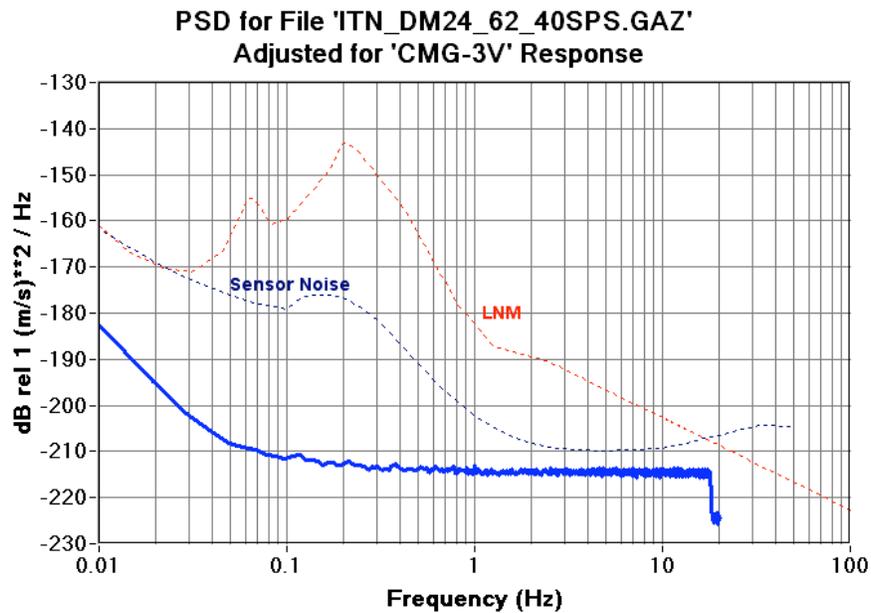


Figure 8. DM24-B1/DA 62 seismic system noise



Figure 9. CMG-3V testing at FACT site

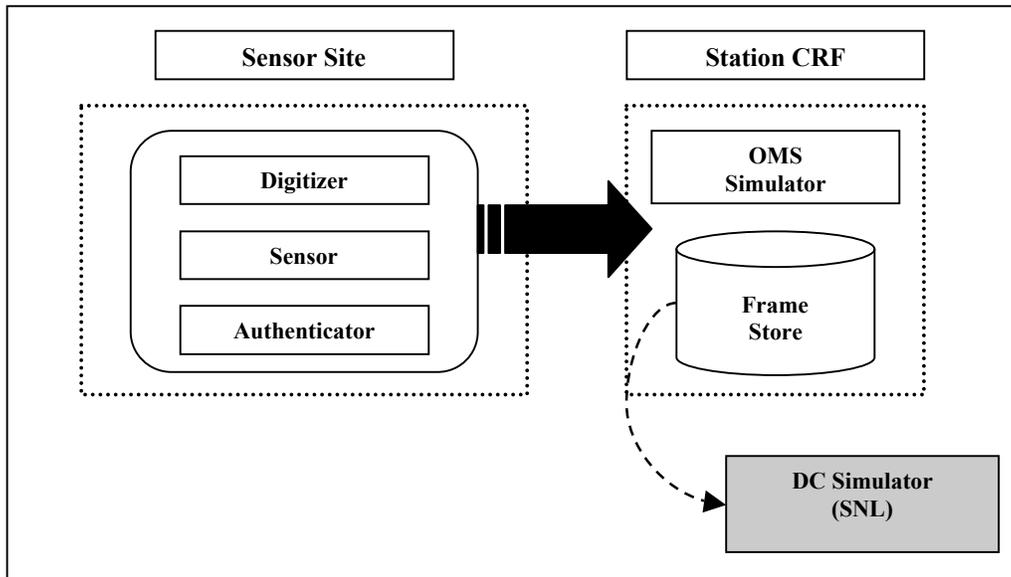


Figure 10. FACT site test configuration