DITEST SHM™

Structural Health Monitoring based on distributed Strain & Temperature Monitoring

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Technical Specifications

Version 1.0, February 2010

Riond Bosson 3 – 1110 Morges, Switzerland

E-mail: sales@omnisens.com
Internet: //www.omnisens.com

Omnisens is ISO9001:2008 certified.

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2 DITEST-SHM™ General

2.1 Introduction

This document provides a description of the essential items that comprise a DITEST-SHM™ System, together with additional and optional items that can be used to tailor the system to a specific deployment or to allow further functionality to be utilised.

2.2 Basic System Description

The DITEST-SHM™ is a fiber optic-based distributed **strain & temperature** monitoring solution to monitor structural behaviour of large civil engineering structures.

The DITEST-SHM™ combines OMNISENS DITEST distributed **strain & temperature** measuring technique, herein referred to as DITEST interrogator, with “best-in-industry” dedicated sensing cable, data processing, user-friendly interface and application oriented visualization tools.

A typical installation of a DITEST-SHM™ system consists of the following key major components:

- DITEST distributed **strain & temperature** interrogator units.
- Fiber Optic Sensing Cable
    - Strain sensitive fiber optic cables (SMC) designed for optimized strain transfer from cable outer sheath to the sensing fiber while making it also suitable for harsh environment applications. Efficient interlocking system between metal loose tube and plastic layer has been developed to guarantee linear strain response and perfect measurement reproducibility.
    - Standard telecommunication or specialty single-mode optical fiber cables acts as the “temperature sensing element“ - hereafter referred as “Temperature Monitoring Cable” (TMC).
- DITEST-SHM™ Software – gathers information from single or from multiple DITEST interrogator units in a centralized database for storing, data processing and analysis (to identify and classify target events) and visualization. This software is the key graphical user interface of the system allowing operators to monitor system status, to monitor structure status and to visualize measurements.
- DITEST-SHM™ server to host the DITEST-SHM™ Software and database.

Multiple interrogator units can be used to monitor very long lengths of sensing fiber or a single interrogator can be linked to dedicated multiple channels fiber optic switches (up to 20 channels/switch) to cover a radial configuration. There are no intrinsic limits to the number of DITEST interrogator units that can be deployed on a specific installation.

The DITEST-SHM™ system can be used to interface with customer SCADA data centres and/or control room monitoring systems using TCP/IP predefined communication protocols.

DITEST-SHM™ applications

DITEST-SHM™ provides **distributed strain and distributed temperature monitoring capabilities** using optical fibers with no compromise on performance for various civil engineering applications:

Application	*Structures*
Structural Health Monitoring	• *Distributed strain and temperature measurement in large critical infrastructures such as* ○ *Bridges,* ○ *Tunnels* ○ *Dams* ○ *Nuclear plants,* ○ *Storage tanks, ...*
Infrastructure management & design	• *In addition to an enhanced safety, SMH is looking at an extended service life through proper system management and preventive maintenance, eventually resulting in cost reduction by monitoring the structure load-bearing capacity instead over-designed structural elements*
Seismic areas	• *In seismic sensitive area, DITEST-SHM offers solutions that dramatically improve the safety assessment of infrastructure after earthquake occurrences.*

2.2.1 Fiber optic sensor selection is key

Various fiber optic sensor designs are available for strain monitoring combining reliability, excellent strain transfer from structure to fiber, strain range and mechanical strength. They are designed for deployment in large infrastructure and are compatible with bonding requirements, direct integration in concrete structures, discrete anchoring points.

2.2.2 Monitoring solution

Omnisens approach to develop monitoring solutions specifically to the requirements of each client ensures that the application monitoring requirements are met. Individual systems specifications are then developed and the system is engineered and installed based on the following approach.

Engineering of the project will include:

- Project scope analysis includes site survey, expected operational monitoring requirements, fiber optic cable selection, position and integration possibilities, need for additional cables and requirements, ...
- System configuration for targeted event detection and communication with third party' systems.
- Installation, specific configuration and commissioning.
- Service and customer support.

2.3 System Technology

2.3.1 Omnisens DITEST measurement technique

Distributed sensing is based on the analysis of backscattered light emitted when a light pulse is transmitted down an optical fiber. The DITEST interrogator system uses Stimulated Brillouin Scattering and brings a new dimension to distributed fiber monitoring by using the latest developments in fiber optic distributed sensing technique giving unrivalled monitoring performance and reliability.

The measurement setup relies on the use of a single laser source and an innovative modulation scheme for the generation of both optical signals. The DITEST unique optical signal processing technique brings the highest level of flexibility to the measurement system to cope with the most demanding monitoring conditions and offers outstanding performance characteristics.

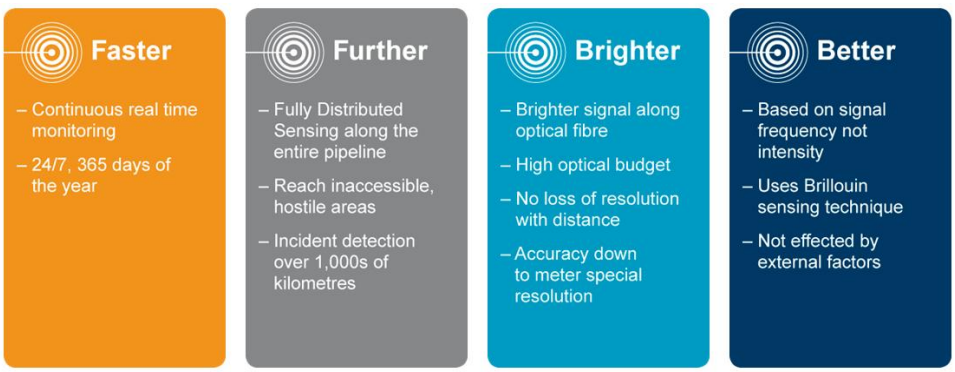
2.3.2 DITEST measurement technique advantage

The DITEST measurement technique is based on Brillouin scattering which is a physical phenomenon sensitive to **strain and temperature** variations along a sensing fiber. This is a unique feature that allows not only leakage detection but ground movement detection as well. Such application can be implemented provided that specific and dedicated cable is installed[1].

The DITEST measurement technique relies on the detection of the resonance **frequency** where the stimulated Brillouin interaction peaks. This technique a high flexibility in optical signal processing (active adaptation of signal levels with respect to fiber attenuation), is much more reliable and stable than intensity based detection methods (like Raman DTS) and demonstrates outstanding signal-to-noise ratio, optical budget as well as **insensitivity to fiber attenuation** change over time (cable repair, fiber aging, hydrogen darkening, rotary joints, …).

Distances over >40 km are measured, with no compromise on performance. Over this distance and using standard single-mode optical fiber, the system will detect events with 1 meter location resolution, even with an optical loss in excess of 10 dB budget along the fiber allowing extra margin for additional splices of the fiber optic cable during installation.

The DITEST measurement technique uses proven optoelectronic telecommunication components with long lifetime expectancy and it has been developed with the emphasis on providing faster, further, brighter and better measurement reliability, accuracy and system robustness than any other system in its class today.



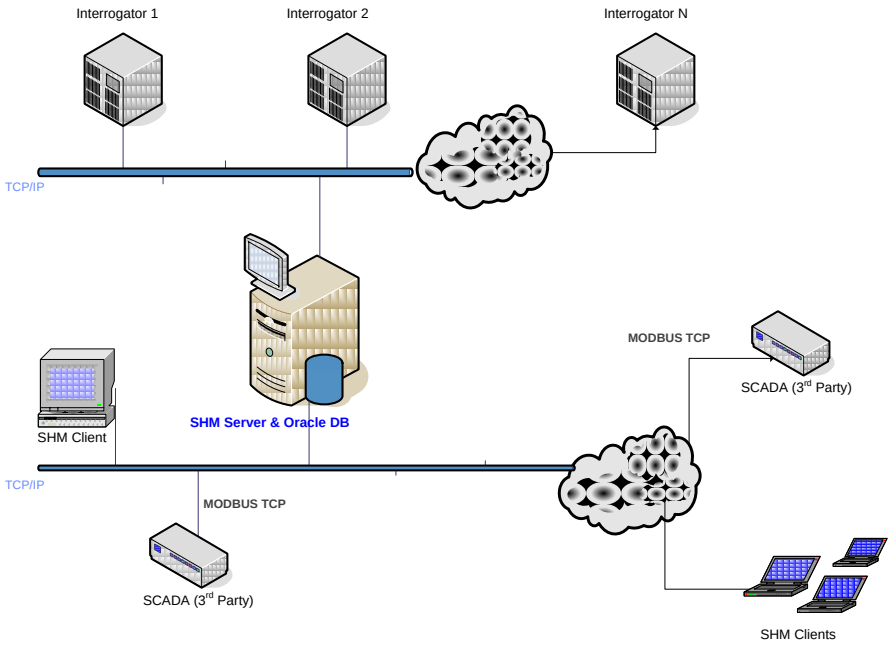
[1] *see cables datasheets for more details on temperature and strain measurements*

2.4 DITEST monitoring system configuration

In order to guarantee long term stability and highest possible reliable operation, Omnisens has developed an innovative configuration and control system concept which splits measurement control from configuration, data storage and visualization.

- On the one hand the DITEST interrogator unit is fully controlled by dedicated acquisition software called the Engine which performs the measurement.
- On the other hand the DITEST-SHM™ software provides centralization of measurements generated by single or multiple DITEST interrogators, storing to database, data processing, analysis (to identify and classify target events) and visualization, as well as the configuration of the monitoring structure with zone, alarms and related events. The software is connected to a database containing the entire infrastructure information (configuration & measurements). Events and instrument status are generated, logged and can be transferred through MODBUS TCP communication protocol to third parties' systems (SCADA).

The system architecture is presented in the figure below.



For standalone configuration, the measuring unit and the DITEST-SHM™ software may be collocated on the DITEST interrogator unit. For complex installation, the interrogator unit is connected to a dedicated DITEST server (via gigabit Ethernet) where the DITEST-SHM™ software is installed and connected to all other DITEST interrogator units.

2.5 DITEST-SHM™ software

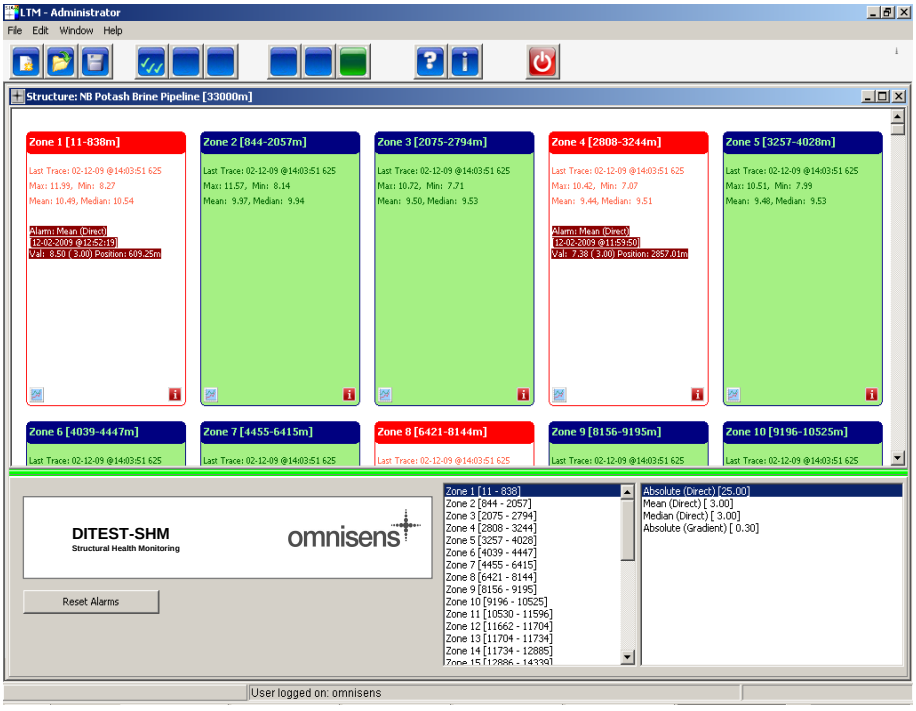
This is the actual Graphical User Interface (GUI) of the complete system. It runs on the DITEST server or on the DITEST interrogator unit and communicates with the Engine via TCP/IP.

It features:

- Password protected access
- Configuration of monitored Structure (zones, alarms, …)
- Visualization of events and alarms based on
  - Distributed strain
  - Distributed temperature
  - Cracks (optional module)
- Possibilities to compensate strain profiles with temperature profiles by zone.
- Compensation of concrete thermal expansion on the strain measurements
- Visualization real-time temperature/strain profiles
- Event logger
- Database storage
- Data communication with third party systems (e.g. SCADA).

The DITEST-SHM™ software ensures a user-friendly and simple configuration of the system; it enables non-technical people to get the maximum out of the instrument performances.

Example of the DITEST-SHM™ Graphical User Interface with the different active zones and their respective status (red when in alarming conditions have been detected in the zone, green when no alarm conditions have been detected).



2.5.1 Optional module: Crack detection

Omnisens DITEST-SHM distributed strain monitoring system features enhanced signal processing algorithms in order to detect highly localized strain contributions along fiber optic sensors associated to the development of cracks in structures.

Cracks in the millimeter range can be detected within the spatial resolution of the instrument (0.5m).

Cracks can be efficiently detected provided that specific strain sensitive fiber optic sensors and specialized sensor integration are combined.

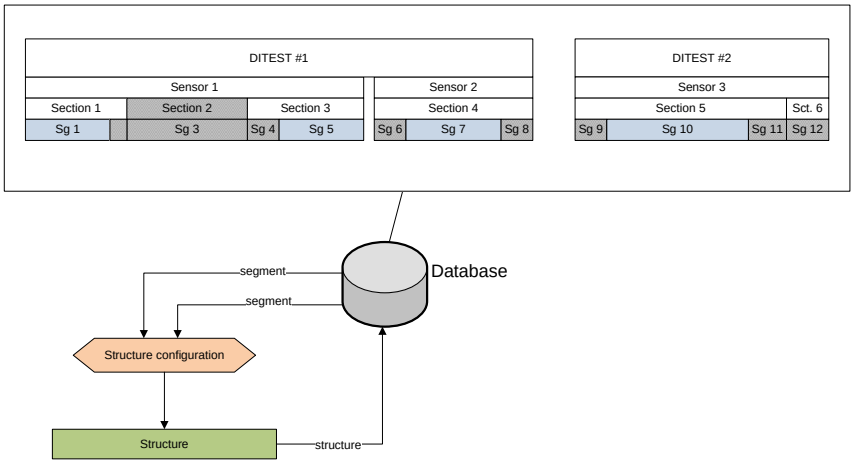
2.5.2 DITEST Communication Interface

The DITEST-SHM™ software are designed for remote control operation, configuration and maintenance via TCP/IP connection.

The DITEST-SHM™ software includes a MODBUS TCP communication protocol used for transferring event alarms and status to third party systems.

2.5.3 Monitoring data and database storage

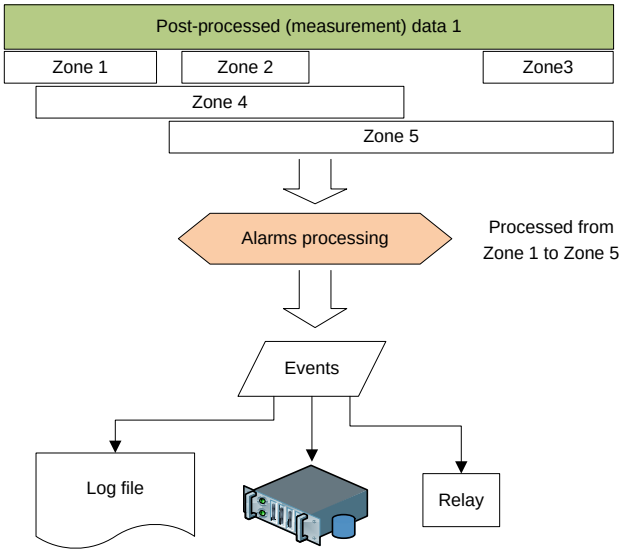
When multiple DITEST interrogator units are used, the DITEST-SHM™ software gathers the relevant configuration and measurement information from all DITEST interrogator units connected to the DITEST server and performing the actual monitoring in a main database.



2.5.4 Measurements and zones configurations

The presentation of the monitoring data is designed for quick display and unambiguous interpretation of the measurement results. Problem detection and identification is facilitated by dividing the structure in zones with specific alarm threshold. Alarm events are available through TCP/IP on the DITEST-SHM™ server viewer and made available to the third party system via MODBUS TCP.

Relay may also be implemented as an option for local alarms or actions (sound alarm, flash light, discrete input to SCADA system).



2.6 Alarm management

2.6.1 Assessment of Alarms or Events

In a large scale distributed system such as DITEST-SHM™ given the overall extent of the system which may stretch many 10's if not 100's of kilometres, the accurate assessment of alarms and events is crucial to focus the attention of operators to true events and to reduce the number of false alarms.

Omnisens has developed algorithms for a precise events detection and classification.

2.6.1 Alarm definitions

Several types of alarms can be associated to each zones of the sensing cable and can be used to detect specific events.

The available alarm options are defined by set of parameters that allows generating events based on measurement gathered by the DITEST interrogator (Distributed strain and/or temperature). Events are computed based absolute or relative values or on rate of change or a combination of those:

- The alarm threshold detection type can be based on:
  - Absolute temperature/strain
  - Relative to average zone temperature/strain
  - Relative to median zone temperature/strain
- Detection of hot spot (measured temperature is higher than the threshold) or cold spot (measured temperature is lower than the threshold)
- The events generated by the alarm have 2 types:
  - Pre-warning
  - Warning

2.6.2 Alarm confirmation

The alarm goes off only when the alarming conditions are met repeatedly a given number of times. Moreover the alarm is only triggered when consecutive alarming conditions are identified in same zone (consecutive measurements confirm the occurrence of an alarm at the same location).

2.7 System/Components specifications

The DITEST-SHM™ monitoring system is a set of components mounted in a 19'' EMC rack cabinet and which is composed of:

- 19'' ventilated EMC rack cabinet,
- DITEST interrogator unit (6U)
- Multiple channel switch module SO-N (3U)
- DITEST server with screen display (1U),
  keyboard and mouse (1U drawer),
  plus a (1U) drawer for tools and documents
- UPS (uninterrupted power supplies) - Optional
- Cooling system - Optional

For best performance, the rack cabinet may be equipped with extra active cooling (optional) or active temperature control (optional). If the ambient temperature is expected to exceed 30°C in the station, it is recommended to install built-in cabinet extra active cooling (available as option).

2.7.1 Operating conditions

The DITEST characteristics are listed in the table below:

Operating temperature	*0 C to 30 °C*
Storage temperature	*-10°C to 60°C*
Relative humidity	*Max 95% non condensing*
Altitude	*< 3000 m (10000 ft)*
Protection	*IP20 (indoor use)* *Pollution degree 2*

2.7.2 DITEST Interrogator unit

Omnisens DITEST interrogator unit comprises high MTBF Commercial-off-the-Shelf based components, in a 6U height, 19” rack mountable unit. The DITEST interrogator unit includes two built-in measurement channels, allowing the measuring unit to measure temperature profiles over 40 km in each direction for a total coverage of 80 km.

Installation is straightforward requiring connections to:

- mains power supply [standard IEC connector]
- the sensing fibers [standard E2000-APC fiber connector]
- network connection [standard RJ45 connector].

DITEST interrogator unit

2.7.3 DITEST Server

Measurement data generated by the DITEST interrogator units are transferred to a DITEST server for storing, display and analysis.

The typical characteristics of the server are:

- 19’’ Rack mountable industrial computer, 1U high, 2 Ethernet connector, 2 x USB in front panel, redundant 450W power supplies,
- Operating system: MS Windows™ Server (English)
- 19’’ Rack mountable drawer (1U high) with 15” LCD Monitor/ Keyboard/ Mouse;

2.7.4 Communication – network

A standard, customer supplied 10/100 Megabit T-Ethernet network (not only dedicated to the monitoring system) is required to connect the DITEST interrogator units to the DITEST-SHM™ server. It is assumed in the present proposal that this communication network is available at every monitoring location and no communication equipment is therefore included in this proposal.

2.7.5 Power supplies

It is assumed that suitable power supplies will be provided at the location of each Omnisens DITEST Interrogator Unit and at the user terminal.

2.7.6 Applicable Standards are

- Environmental requirements (operating temperature and relative humidity ranges) according to EN60068-1:1995
- Index of protection (IP rating) according to EN60529 and IEC529
- Pollution degree according to EN60664-1 and DIN VDE 0110
- Electrical Safety and EMC: see here below “CE Marking”
- Laser classification: Class 1M Laser Product according to EN 60825-1 (2001) and EN 60825-2 (2005)

2.7.7 CE Marking

Instruments proposed by OMNISENS are CE marking compliant, based on the Council Directive 2006/95/EC, Low Voltage Directive (safety) and on the Council Directive 2004/108/EC, Electro-Magnetic Compatibility Directive (EMC).

The DITEST interrogator units are designed to meet the requirements of “electrical equipment for measurement, control and laboratory use” based on the following standards:

Electrical Safety: EN61010-1: 2001,

Electromagnetic compatibility: EN61326-1: 2005

Immunity: EN55011 Emission, Class A

Emission: Industrial Environment

EN 61000-4-2: 2008	Electrostatic discharge ESD
EN 61000-4-3: 2006	Radiated RF fields immunity
EN 61000-4-4: 2004-07	Electrical Fast Transient/Burst immunity
EN 61000-4-5: 2005	Surge immunity
EN 61000-4-6: 2008	Immunity to Conducted Disturbance
EN 61000-4-8: 2009	Power Frequency Magnetic fields immunity
EN 61000-4-11: 2003	Voltage Dips and Short Interruption

3 Delivery, Installation & Acceptance

3.1 Conformance Testing – Components / Small Systems

All DITEST™ interrogator units are subject to rigorous testing and quality control at all stages of production.

Prior to being issued with a conformance certificate each unit undergoes final tests as follows:

- To demonstrate that all components of the deliverable system have been manufactured in accordance with their specifications and successfully tested at component and assembly level
- To prove the operation and performance of the completed unit prior to delivery

The presence of the Conformance Certificate demonstrates that the system conforms to the qualified build schedule and operates in accordance with the system design specification.

Any delivery of 3rd party equipment (e.g. PC systems) will only be selected from reputable manufacturers able to provide appropriate levels of quality certification. All certification will be delivered together with the equipment at time of delivery.

3.2 Conformance Testing - System Verification Testing

In the circumstances where clients are procuring a complete system from Omnisens (multiple DITEST Interrogator units, server, displays etc) a representative subset comprising multiple systems will be rigorously tested at Omnisens premises on a simulated deployment.

The output of this test will provide (in addition to component conformance certification) a scaled verification of the overall system capability – demonstrating the integrated, networked performance.

The conduct of such a test is clearly bespoke to individual program and is addressed in appropriate program documentation on a case by case basis.

3.3 Packaging and Delivery

The DITEST-SHM™ system is freighted in good standard commercial, cardboard packaging.

As standard, systems are delivered Ex-works, Omnisens, Morges-CH. Optionally; clients may wish to procure delivery via agreed INCOTERM 2000 terms to a specific global destination. Such arrangements are made by prior quotation.

3.4 Installation and Commissioning

Installation and configuration of the system must only be carried out by an Omnisens certified installation engineer – this may be a client appointed engineer.

Omnisens will provide as part of a deliverable project a test document which will detail the full installation process and commissioning tests to be utilized and provide these in advance to the client. The document will detail both Omnisens and client responsibilities for the installation and commissioning phase as well as timescales.

For most installations, Omnisens will take care of:

- The routing and the termination of the fiber optic cable in the termination panel;
- The installation of the DITEST interrogator unit in the existing equipment rack;
- The connection of the DITEST interrogator to the fiber optic cable and to the communications system;
- The connection of the DITEST interrogator units and server to the station power supply;
- The on-site tests and the verification of all the components.

The validation of the DITEST-SHM™ system will be carried out by Omnisens.

3.5 System Test & Client Acceptance Test

After the system has been installed, configured, tested and commissioned for use in the specific environment, the purchasing client will witness a field demonstration of the system operating in accordance with the system specification.

The client tests will be tailored to the needs of specific installation requirements and the software modules selected by the client in the form of an “On-Site Functional Test – Test Specifications” – the SAT.

As well as detailing the test environment, the SAT will specify the individual tests to be performed for final site acceptance test and detail client responsibilities in support of the tests.

The tests are concluded by a formal Test Record Sheet where the success of the individual tests is noted and signed off.

The full verification of system performance in terms of probabilities of detections and false alarm rates is a time consuming and protracted affair involving a commitment that is well beyond the needs of on-site customer acceptance.

In order to perform a suitable and convincing test, full system test and evaluation can be conducted after installation but this will require a bespoke, prolonged period of evaluation – similar to the commitment required for a full scale Reliability Demonstration programme for example.

4 Maintenance & Support Services

4.1 Operator Training

Omnisens systems are delivered complete with a detailed set of installation and operational manuals which provide the user with sufficient resources to both install the system and operate it to an expert level.

In addition to the comprehensive installation and operation manuals, Omnisens also operates a support service to ensure that effective operations are maintained with the highest availability.

4.2 Preventative Maintenance

Beyond periodic visual inspections, no preventative maintenance activities for the system are required.

4.3 Corrective Maintenance

Omnisens systems have been designed with minimal corrective maintenance in mind – from the reliability oriented design of the interrogator to the ability to incorporate client IT management, Omnisens installations will present a maximal availability to the end user ensuring the greatest possible cost effectiveness of the system.

Significant levels of remote diagnosis are built into the DITEST-SHM™ software and the DITEST interrogator unit allowing the devices to be remotely diagnosed and operating clients advised accordingly.

Defective items will be dealt with in accordance with Omnisens warranty policy provided in the sales and supply conditions.

No operator maintenance is possible within the system. Intermediate levels of maintenance are confined to replacement of major sub systems such as the measurement unit or the server. All further level of maintenances and all repairs of defective Interrogator Units are classified as depot level maintenance.

Clients often wish to manage their own IT infrastructure and thus manage the maintenance aspects of the computer network in-house. This is recognized by Omnisens and thus in many cases the majority of expected maintenance activities (on IT infrastructure) can be conducted at an Intermediate level without recourse to support from Omnisens.

4.4 Omnisens Support Mechanisms

Omnisens systems are normally sold through our extensive network of system integrators and in general, support agreements are effected directly.

When sales are concluded directly with Omnisens, the following level of support is provided:

The basic level of support that is included in the initial 12 months warranty comprises CH Working Hours Telephone Support.

Two levels of support are also available as follows:

- Standard Support CH Working Hours, 24 max turnaround
- Enhanced Support 24 / 7 Engineering Response

CH working hours are defined as GMT+1, 09:00 to 17:00.

Whilst the majority of system support enquiries are answered immediately by Omnisens support staff, where the level of enquiry demands an engineering response, if not immediately available, client requests are logged and answered within 24 hours.

If client systems are internet connected this will afford an extra dimension in fault diagnosis that is provided free of charge – minimising needless costly equipment returns.

The procedure for warranty repairs is described in the standard sales and supply conditions. Repairs on systems that are out of warranty and not included in support plan are conducted at standard Omnisens labour rates, exclusive of replacement costs.

In addition to the telephone support, Omnisens also offers extended levels of engineering support:

- On Site engineering support – procured as an extension to the equipment installation – utilizing the services of an Omnisens engineer to assist with familiarization and equipment inspection. Equally if required this can be booked and utilized for out of warranty equipment installation post repair.
- Corrective maintenance rapid response – for critical operations where system spares are not held locally, Omnisens provides a rapid response capability to enable equipment replacement and installation within 100 hours[2]. This facility is available as an annual facility charge together with specific call out rates, billed on a pro-rata basis for both diagnosis and repair activities.

[2] *From Omnisens acknowledgement of defective status and subject to transport and import limitations and subscription of the customer to a service program.*