# Collection and Discrimination of AE Signals from Tank Ships using an intrinsically safe certified AE Sensor System

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**Abstract**. Equipment for use in potentially explosive atmosphere is subject to particular requirements on safety and quality as determined by a number of Standards. For use in Europe, such equipment needs to conform to the EC directive 94/9/EC, also called "ATEX Directive". The conformity must be certified by a so-called ATEX Certificate. In the frame of the EC-funded research project „Corrosion testing of tank ships", AE-field tests on board large tank ships were executed. Intrinsically safe certified AE sensors were temporarily immersed through a potentially explosive atmosphere from the tank top through manholes into the liquid contents. Ship owners and involved classification societies insisted on the availability of a system certificate confirming intrinsic safety for the used sensors and isolation barriers. This paper summarizes basics of explosion protection and the ATEX directive, the safety requirements on Acoustic Emission field test equipment for use in potentially explosive atmosphere, and shows a realization of certified equipment and data acquired from immersed sensors on board of a tank ship and used for the location of a natural artificial AE corrosion source.

## Important Terms and Basics of Explosion Protection

### *Explosion*

An explosion is a sudden chemical reaction of an ignitable material with oxygen releasing high energy. An explosion happens when the following three items come together:

- ignitable material,
- oxygen
- ignition source of sufficient ignition energy.

### *Integrated Explosion Protection*

Integrated explosion protection requires measures in the following sequence of priority:

*1. Primary Explosion Protection:*

This term comprises all measures preventing an atmosphere from becoming hazardous:

- Prevent the use of ignitable material
- Make the atmosphere inert by adding e.g. nitrogen or carbon dioxide.
- Limit the concentration of an ignitable atmosphere
- Ventilation

*2. Secondary Explosion Protection:*

This term means all measures preventing the ignition of an hazardous atmosphere.
This includes the development of intrinsically safe equipment.

*3. Limit the Effect of an Explosion to a Harmless Result.*

In some cases explosion can't be avoided but must then be limited to harmless results.

**Important Graduations of Explosion Protection**

***There are important graduations of explosion protection:***

*1. Graduation of Ignition-Prevention*

- Probability of danger (zones)
- Nature of the atmosphere (gas or dust)
- Intended location of the explosion proof apparatus (mines = group I, or others = group II)
- Minimum ignition energy of the atmosphere (high:IIA, middle:IIB, low:IIC)
- Kind of ignition protection (intrinsic safety and others)
- Ignition temperature (temperature class)

*2. Probability of Danger (Explosion Zones 0, 1, 2)*

Depending on the probability of danger occurrence, a gaseous hazardous area must be assigned to one of the following three zones:

**2.1 Explosion Zone 0:**
This is an area where a potentially explosive atmosphere may exist regularly, over a long period of time, or often. Example: The gaseous phase above a flammable liquid inside a tank. For tank ships, the area on deck, in a distance of up to 3 meters from a tank opening is classified to zone 0.

**2.2 Explosion Zone 1:**
This is an area where a potentially explosive atmosphere may sporadically exist. Example: An area on top of a tank of flammable content.

**2.3 Explosion Zone 2:**
This is an area where a potentially explosive atmosphere exists very rarely and for short time periods only. Example: An area at some distance from a tank of flammable content

*3. Category of an Electrical Apparatus*

According to the explosion zone, where an apparatus shall be used, the apparatus must be certified for one of three categories:

- Category 1 for use in zone 0 or 1 or 2,

- Category 2 for use in zone 1 or 2,
- Category 3 for use in zone 2.

*4. Nature of the Atmosphere (Gas or Dust)*

The hazardous atmosphere may be of the nature gas or dust.
For a dust atmosphere, a hazardous area must be assigned to one of the following zones: Zone 20 (like 0), 21 (like 1), or 22 (like 2).

*5. Location of the Atmosphere (Mine: Group I, other: II)*

The hazardous area is either located in a mine or somewhere else. This decides the group the explosion proof apparatus must be assigned to. If the apparatus is for use in a mine, it belongs to group "I". If it is for other places, it belongs to group "II". An explosion proof apparatus can be certified to belong to either group. Onboard tankers, the certification must be for Gas atmosphere.

*6. Minimum Ignition Energy (IIA, IIB, IIC)*

Apparatus of group II must be furthermore graded by the minimum energy that may ignite the atmosphere:

- Group IIA is for an atmosphere of high ignition energy, e.g. Propane, Methane, Diesel, etc..
- Group IIB is for an atmosphere of medium ignition energy, e.g. Natural gas, Ethylene.
- Group IIC is for an atmosphere of lowest ignition energy, e.g. Hydrogen, Acetylene.

Apparatus for use on tank ships must be certified to IIB or IIC. Since IIC does niot allow for passing a pulse onto the intrinsically safe circuit, we decided for a certification for IIB

*7. Kind of Ignition Protection*

The following kinds of ignition protection are listed in the standards (in alphabetical order of the identifier):

| Id | Kind of ignition protection |
|---|---|
| d | Ignition source is enclosed in a pressure proof encapsulation that, in case of an inner explosion, protects the environment. For details see **EN50018** |
| e | Extended measures are taken for an enhanced level of safety. The potential explosive atmosphere is separated from high temperatures, sparks, lightning. For details see **EN50019** |
| p | Exclusion of potential explosive atmosphere within a apparatus by presence of a non flammable protection gas and an over-pressure encapsulation. For details see **EN50016** |
| ia | Intrinsically safe circuit. Limitation of maximum current, voltage and temperature by design. Certified to not be able to ignite an explosive atmosphere even with the presence of the worst combination of two failures. Needed for apparatus in zone 0. For details see **EN50020** |
| ib | Intrinsically safe circuit similar to ia, but certified to not be able to ignite an explosive atmosphere with the presence of one worst case failure. Needed for apparatus in zone 1. For details see **EN50020** |
| o, q, m | Encapsulation by oil (o), sand (q), or compound (m). For details see **EN50015, 50017, 50028** |
| n | For apparatus of category 3 (Zone 2). For details see **EN50021** |

Apparatus for measurement, control and surveillance, e.g. AE sensors and preamplifiers, need to comply with the standard for intrinsic safety, **EN50020,** (identifier ia or ib in above table) if they are used in, or if cables run through, zone 0 or 1. Since tank ships are classified to zone 0, a certification for ia was required. Ia means that two worst case failures may not cause the exceeding of power, current, voltage, pulse energy, surface temperatures, above defined limits.

*8. Ignition Temperature, Temperature Classes*

The surface temperature of an explosion proof apparatus must always remain below the ignition temperature of the potentially explosive atmosphere around it. This is ensured by a classification into temperature classes T1 to T6. Often encountered temperature classes are T4 (max 135°C) and T6 (max. 85°C). The design of the certified apparatus ensures that the maximum temperature will never be exceeded, even in the presence of the maximum specified ambient temperature and the worst case failure situation. For the sensors used on tank ships we decided for temperature class 6, that means, up to an ambient temperature of 60°C the sensor case cannot assume a temperature above 85°C even at the presence of the worst case combination of two failures.

## System Certification vs. Apparatus Certification

Over 100 European (CENELEC) and IEC-Standards deal with the subject "Electrical apparatus for explosive atmospheres" and their installation. For non-specialists in explosion protection, the many graduations explained above and the many cross references in these standards make it extremely difficult to find answers to simple practical questions, concerning the installation of a certified apparatus in a hazardous atmosphere.
The requirements on cabling, cable protection, earthing, over-voltage protection, electrostatic discharge, and other topics that must be considered for the installation vary with the above mentioned graduations, especially with the explosion zone. For example, special considerations need to be taken where a cable enters zone 0 in order to prevent over-voltages, e.g. from atmospheric electricity. Extremely difficult is the interpretation of the standards where a temporary installation must be made within a hazardous area.
On request of the authorities (ship owner and classification societies) we decided to obtain an ATEX **system certification** that covers not only the different kinds of needed apparatus, e.g. the sensor with preamplifier and a signal isolator, but the whole installation. The certification obtained covers sensor, signal isolator, cable sets, connectors, earthing points, lightning protection for the explosion zone 0, lighting protection for the signal isolator against over-voltage from atmospheric electricity, and the User Manual which contains a clear description in which sequence the installation must be done, and more.

## Realisation of an Intrinsically Safe Certified EQUIPMENT: Product Family Vallen "ISAFE"

The term "acoustic emission system" usually means a specialized data acquisition and analysis system with a number of AE channels and a computer. Each channel comprises at least a sensor, a sensor-internal or external preamplifier and the data acquisition and signal processor module. The product family ISAFE comprises those parts of the AE system that must be intrinsically safe and those that isolate intrinsically safe circuits from the rest of the AE system. Meeting all relevant standards may cause degradation of the signal to noise ratio, for example when earthing of the signal cables is required.

We decided on an electrical isolation of each intrinsically safe circuit from all other circuits. This ensures non-degraded signal quality independent of whether or not and where the shield of the cables must be earthed. In addition, the electrical isolation of the AE signal avoids disturbances, such as crosstalk between channels, and ensures an optimum signal-to-noise ratio.
The intrinsically safe cables run from the control room, a non-hazardous area where the AE system is located, into the hazardous areas of perhaps different zones, and it can be several hundreds meters long.

*Block Diagram of ISAFE*

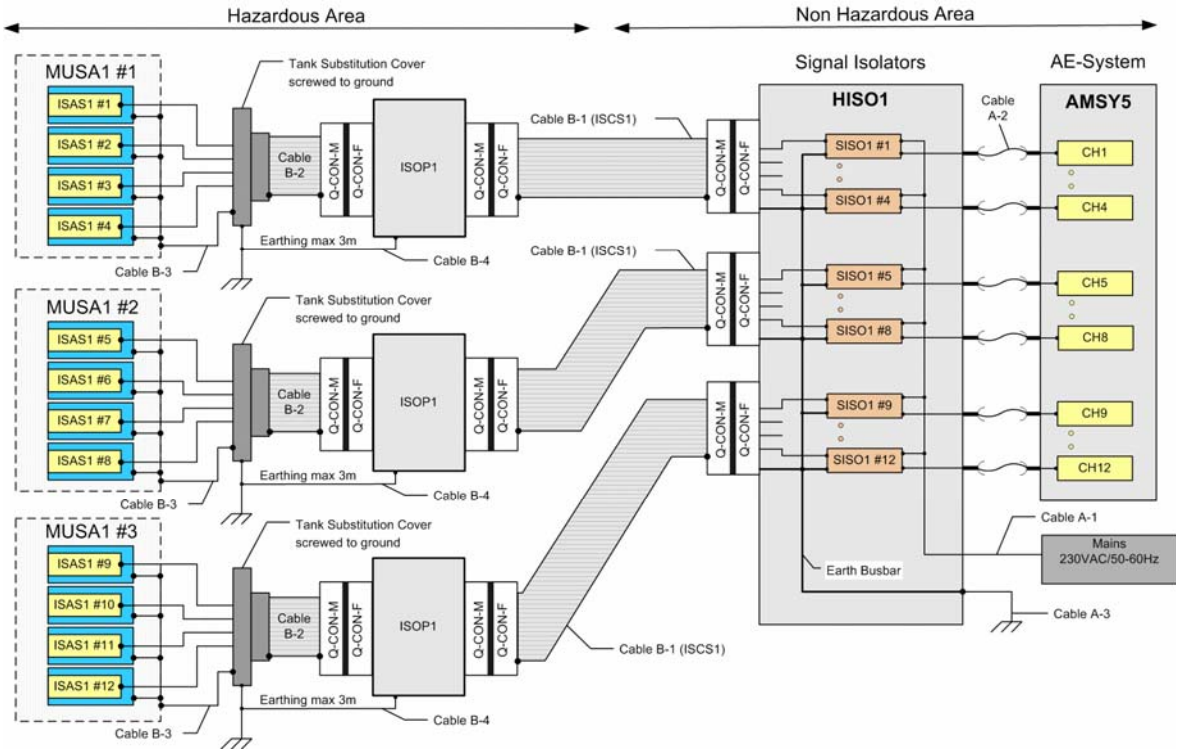


**Fig 1:** Block diagram of product family ISAFE with connection to the AE-system (AMSY-5)

ISAFE comprises (from left to right in Fig. 1)

- The intrinsically safe sensors model **ISAS1**, for use in the hazardous area of zone 0 or 1;
- The 4-channel multi-sensor-assemblies model **MUSA1**, which holds 4 sensors at certain positions in order to allow source location in the 3-dimensional space on the bottom or one of the vertical tank walls. MUSA is mounted and earthed at the ship over a substitution cover;
- The 4-channel over-voltage protection box **ISOP1**, that prevents over voltage, e.g. from a lightning strike, reaching zone 0;
- The 4-channel cable set **ISCS1**, that connects 4 signal isolators located in the non-hazardous area with 4 sensors in the hazardous area, with or without using an ISOP1;
- The single-channel signal isolator **SISO1**, that isolates the intrinsically safe cable set from the AE system;
- The 12-channel signal isolator box **HISO1**, that houses up to 12 SISO1;

- Plus all relevant accessories for installation and use; all instructions that normally cover earthing, lightning protection, avoidance of electrostatic discharge during installation, and more.

The AE system itself needs not be intrinsically safe, since the signal isolators (SISO1 and HISO1) ensure safety of all intrinsically safe circuits to the sensors; even for the worst case that on the non-hazardous side, an AE signal is connected to a voltage up to 250V.

The following shows some relevant information about the items of ISAFE.

*ISAS1 Intrinsically Safe AE Sensor*


**Fig. 2:** Left: ISAS1 in delivery status. Right: cables to be installed in the field

Fig. 2 shows an ISAS1 in delivery status. The cable can be installed in the field. Fig. 3 shows the frequency response curve of ISAS1 at 40dB gain.

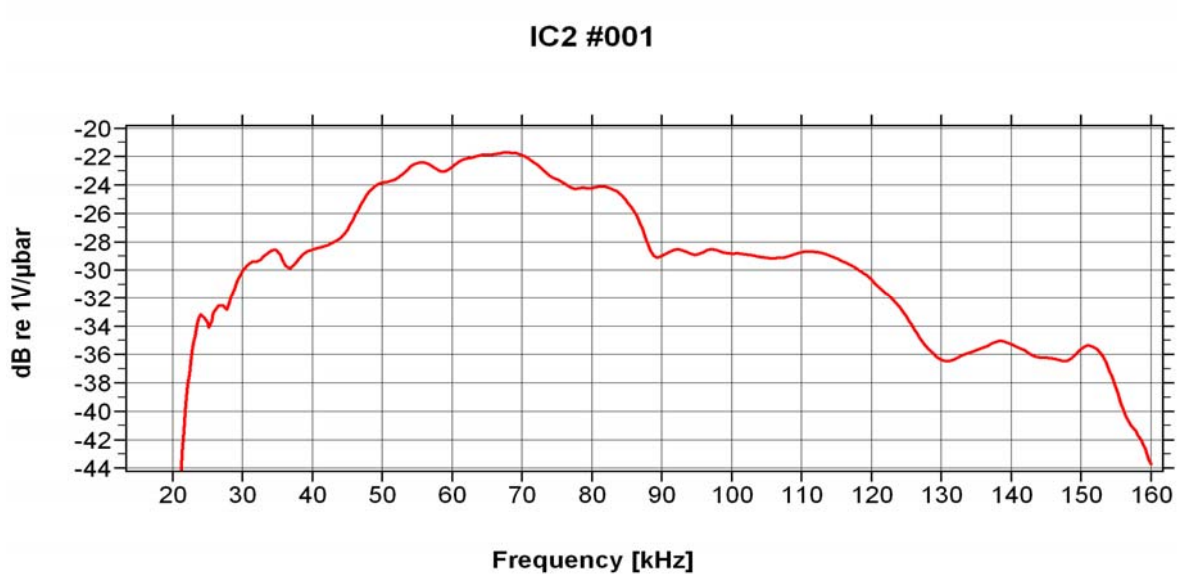


**Fig. 3:** Frequency response of ISAS1 at 40dB gain

ISAS1 is certified for tightness up to 12 bar (e.g. caused by sloshing forces) in a depth up to 30m.

ISAS1 is labeled according to the ATEX directive and the CENELEC standards. The labels have the following meaning (left to right):

| Label: | Meaning: |
|---|---|
|  | labeled object is conform to ATEX directive 94/9/EG. |
| II: | Group II: electrical apparatus for areas other than mines. |
| 1: | Apparatus category 1: „very high measure of safety" for use in zone 0, 1 or 2) |
| G: | For gas atmosphere |
| E: | Certified according to CENELEC Norms (EN50… respectively EN60…) |
| EX: | Explosion protection |
| ia: | Type of protection: intrinsic safety for use in zone 0, 1 or 2. |
| IIB: | For gas atmospheres with medium ignition energy |
| T6: | Temperature class T6: Surface will in worst case failure not exceed 85°C |

Meaning of the other labels:

| | |
|---|---|
| TÜV A: | Notified body for the Type examination and certification: TUEV Austria, Division for Electrical Engineering |
| 05: | Type Certification obtained in 2005 |
| ATEX: | Type Certification complies to ATEX directive |
| 0001: | First Type Certification of notified body in 2005 |
| X: | Documentation must be consulted for instructions for use |
| CE0123: | Notified body for the certification and surveillance of the manufacturer's quality management system: TUEV Sued, Munich |
| Tamb: | Ambient temperature range -20°C to +60°C |
| IP68: | Degree of protection by enclosure: "permanent immersion" (up to a depth of 30m). |

The low noise of the sensor and the signal isolator allows to use a threshold of 30dB at 40dB gain..

*MUSA1 Multi-Sensor-Assembly*

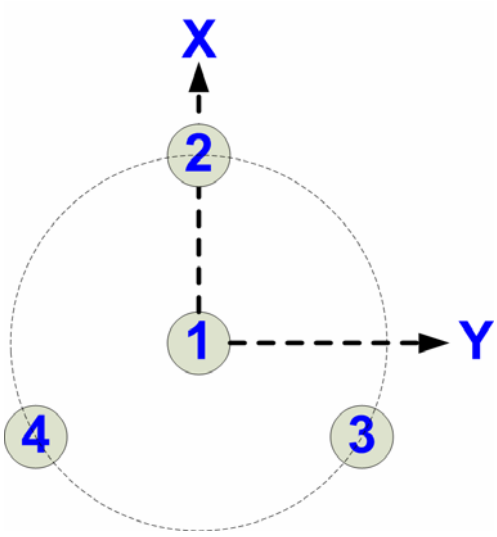


**Fig. 4:** MUSA sensor pos. top view
(X looks forward, Y to the right)

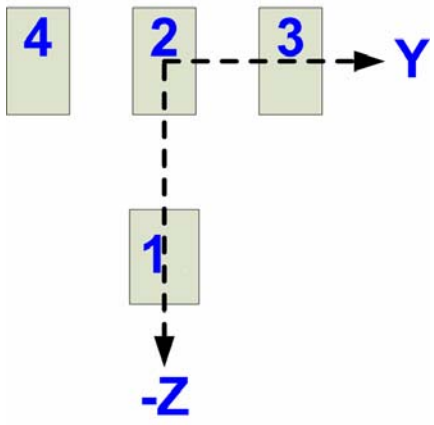


**Fig. 5:** MUSA positioning, side view
(+Z looks upward, Y to the right)

**Fig. 6:** MUSA1, before immersion into a tank

**Fig. 7:** Substitution cover carrying MUSA1 and tightening the tank

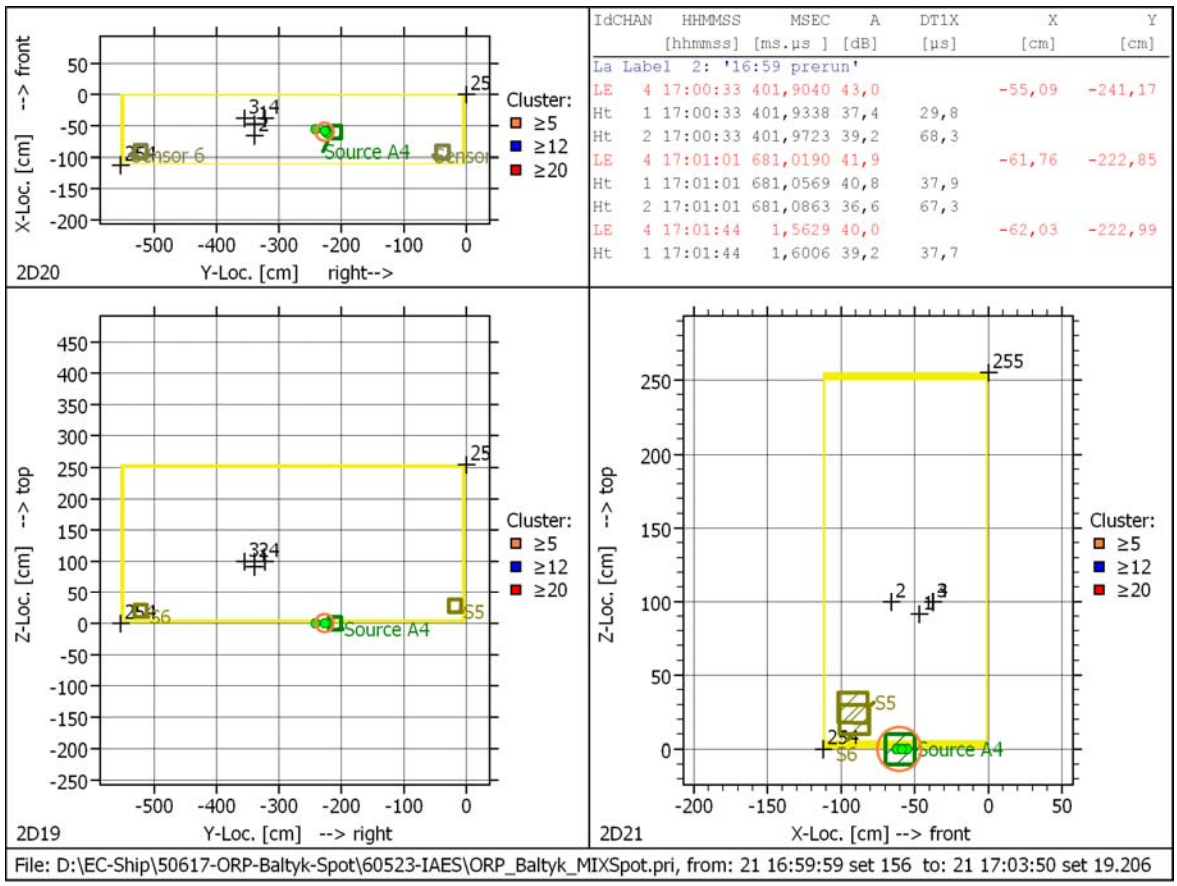


**Fig. 8: "**Cuboid" Location algorithm determines location on the bottom or on a surrounding wall.

MUSA1 is a mechanical assembly that holds 4 sensors in a defined position (Fig.4-7). Fig 6 shows a MUSA1 prior to immersion into a tank. Three sensors are mounted on levers that can be opened, like an umbrella, by turning the handle shown on Fig. 7. In that way the distance between the sensors can be widened when MUSA1 has passed the narrow tank opening. Fig. 7 shows the closed and fastened substitution cover that holds the MUSA1 in a defined fixed place and direction. The cables running through the cover are protected by an isolating flexible metallic tube.

A location algorithm has been developed and implemented into VisualAE to determine the location of an AE source on the bottom or on one of the walls surrounding MUSA1. As the listing in Fig. 8 shows, the location can be calculated from only 3 hits of an event.
Fig. 8 shows three location diagrams for three views. Diagram on top left (Id: 2D20) is the top view that shows the bottom of the tank. The vertical axis points to the tanker's front, the horizontal axis to the right (control board). The axis legends indicate the directions in all three diagrams. The listing gives an indication of the arrival time distance between the sensors and the amplitudes (see column "DT1X"). The total gain (integrated preamplifier plus gain on signal isolator) was 40dB, the threshold 31dB. "Source A4" labels a polygon indicating the position of an artificial, natural corrosion source. This source was built of a small steel tube, closed at both ends, filled with an acid solution that caused corrosion inside the tube. As the location cluster in the diagram proves, this source of AE from corrosion was well detected, located and distinguished from noise.

"S5" and "S6" indicate the positions of two additional sensors that were placed in two corners of the tank for the purpose of pulsing (also well locatable, but no data from pulsing shown in Fig. 8).

*ISCS1 Cable Set*

The cable set (see Fig. 9) is usually up to 100 m long, and additional cables can be used to cover any required length. Based on requirements of the standards, all coaxial cables that run through the hazardous area must be protected by an isolated, flexible metallic tube which also feeds the earth connection from the non hazardous area into the hazardous area.


**Fig. 9:** Cable set ISCS1 (2m) with quadruple coaxial connectors Q-CON-F and –M


**Fig. 10:** Signal isolator SISO1

*SISO1 Signal Isolator*

SISO1 (see Fig. 10) is an electronic board that provides electrical isolation between AE system and sensor. During testing, it transfers the AE signal to the AE system. For sensor coupling test, it can be reversed to transfer a pulse from the AE system to the sensor. Of course, to ensure safety, the signal isolator must limit the pulse with respect to its energy and repetition rate.

*HISO1 12-channel housing for signal isolator*

HISO1 (See Figs. 11 and 12) houses up to 12 SISO1 modules. The BNC connectors at the front are to be connected to the AE system, the 4-channel Q-CON-F connectors on the rear are to connect the intrinsically safe cables to the sensors.

**Fig. 11:** HISO1 Front view with BNC connectors power input and EX label

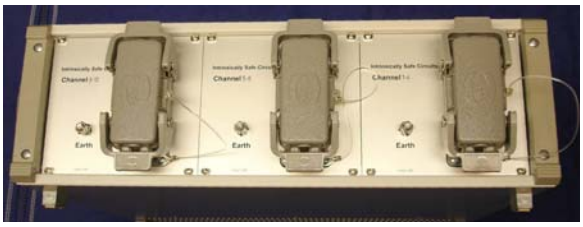

**Fig. 12:** HISO1 rear view with 3 Q-CON-F quadruple coaxial-connectors and earthing points

## Applications

ISAFE hardware and a new location algorithm has been developed for applications where sensors or cables are used in a potentially explosive atmosphere and where the sensor shall pick up liquid borne acoustic emission waves, e.g. for corrosion testing in all kinds of tanks.

## Thanks

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## References

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[4] DIN EN 60079-11:2004-12 Electrical apparatus for explosive gas atmospheres – Part 11: Intrinsic safety “i”
[5] EN 60079-25:2004-01 Electrical apparatus for explosive gas atmospheres – Part 25:Intrinsically safe systems