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Safety and Reliability in Initiation Systems with Electronic Detonators
Abstract

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Initiation systems use initiators to trigger the detonation of explosives. The different time delays needed are usually realised using pyrotechnics. A new development is to use electronics in the detonator to improve the accuracy of the time delays, and in some cases to facilitate a higher degree of flexibility through programmable delay times.

The use of electronics must not reduce the safety level. This report studies possible defects and causes of failure for detonators with electronic time delay. A market study is presented and conclusions are drawn.

Key words: initiation system, detonator, electronic detonator, safety, safety of electronics, software safety
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Preface

Initiation systems with electronic detonators are today introduced on the market by several manufacturers all over the world. Safety requirements and validation of safety must gain acceptance also for these systems. The research project described in this report aims to identify the possible causes of failure and to make a market survey. A continued work on the European level will be needed to harmonise the requirements.

The reference group supervising the project has had members from:
- National Board of Occupational Safety and Health (Arbetarskyddsstyrelsen), Sweden
- National Inspectorate of Explosives and Flammables(Springämnensinspektionen), Sweden
- Boliden Mineral AB, Sweden
- Nitro Nobel AB, Sweden
- Kimit AB, Sweden
- SP - Swedish National Testing and Research Institute

Thanks are directed to all members for their efforts and useful contribution to the project.

Manufacturers and testing institutes have supported the work by sending information and answering questions. Four of the companies have been visited. We are happy to have experienced good contacts also with companies outside Europe. Thanks are directed to:
- Asahi Chemical Industry Co., Ltd., Japan
- CSIR - Council for Scientific and Industrial Research, South Africa
- Davey Bickford SNC, France
- DCI - Delta Caps International, France
- Detonator Technologies (Altech), South Africa
- DMT - Gesellschaft für Forschung und Prüfung mbH, Germany
- Dynamit Nobel GmbH, Germany
- The Ensign-Bickford Company, USA
- Expert Explosives (Pty) Ltd, South Africa
- ICI Explosives Europe, United Kingdom
- Nitro Nobel AB, Sweden
- Thiokol Corporation, USA

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Summary

Detonators are used for initiating explosives used in mines, construction work, quarries etc. It is vital for the safety of the rock blaster that the detonation occurs in the expected way. Electronic initiation systems have been developed in recent years for use in civil blasting work. The main functions of the electronics are to improve the accuracy of the delay time, and in some cases to facilitate a higher degree of flexibility through programmable delay times.

Dangerous situations may be caused by failures of conventional as well as electronic initiation systems. Fault tree analysis has been used to describe the defects and the possible fault events. Unintended initiation at storage, transport and handling is classified as a critical defect for electronic initiation systems. Misfires or unintended detonations after the blasting field is cleared are classified as major defects. An incorrect delay time is classified as a minor defect.

Case studies have been made on 9 different systems. They use different operating principles and all have safety measures employed. However to some extent, there is always a risk remaining. In some aspects, the electronic systems may be considered to achieve a higher safety level than conventional detonators with pyrotechnic delay. On the other hand, new sources of possible faults in electronic hardware and software are introduced. It is not possible to give a general statement if the safety of the initiation system is enhanced or reduced by the introduction of electronics in the detonators.

Even if the electronics of the detonator are not fault tolerant, the safety level may be enhanced by the electronic circuits used. They may act as a barrier between the leading wire and the bridgewire of the detonator. The barrier can be both physical (to block high voltages and currents) and logical (to block interference from being interpreted as an initiation order).

Safety can be enhanced by design measures, proper operating procedures, safety functions and functions for self-checking in the system. The electronics make it possible to add safety functions to the system and make it possible to detect faults before they cause failures of the system. In general, higher demands of education and training of users must be stressed, due to the higher complexity of using most electronic initiation systems. A misuse which is very likely to happen, is to mix different electric or electronic detonator systems or parts of them e.g. to use a blasting machine for conventional detonators together with electronic detonators or vice versa.

Present standardised test methods for conventional detonators may be used also for electronic detonators. Some test methods are directly applicable. Other methods will require some modifications, while some methods will not be applicable. Future work is needed within the standardisation organisations to establish definitions, methods and requirements for electronic initiation systems. The work of the standardisation group will have to be proceeded by pre-normative research on European level.
1 Electronic Initiation Systems

1.1 Introduction

Detonators are used for initiating explosives used in mines, construction work, quarries etc. It is vital for the safety of the rock blaster that the detonation occurs in the expected way. Electronic initiation systems have been developed in recent years for use in civil blasting work. Detonators in these systems have delay times which are far more accurate than conventional detonators with pyrotechnic delay, which facilitates better blasting results, e.g. in terms of:

- better fragmentation - can reduce the total costs due to less investments and operational costs of crushing mills as well as less transportation and loading costs;
- reduced ground vibrations - are important when carrying out cautious blasting in sensitive areas;
- less damage on remaining rock- can reduce the reinforcement costs in tunnelling;
- larger blasting rounds possible;
- less flyrock - due to the possibility of decreasing the risk of overlapping of adjacent time steps;
- increased advance per round in tunnelling;
- increased potential for development of new blasting methods.

Disadvantages of electronic initiation systems could be:

- higher price than conventional detonator systems - mainly a problem related to the present small production volumes;
- the complexity of the systems increases the demands for education of the users.

The main factor determining if electronic initiation systems will increase their market share in the future is probably related to the question of obtaining total cost reduction by using these systems.

From a safety and reliability point of view electronic initiation systems are more complex than conventional electric and non-electric detonator systems, which results in a lot of new risk factors. As the area of electronic initiation systems is new, no harmonized standards or national standards exist.

About 10 manufacturers of electronic initiation systems have been identified world-wide of which four are European. All identified manufacturers have been contacted in this project.
1.2 Definitions

Detonators are devices intended to be used for initiating explosive charges. The following definitions can be used for different detonator types:

- An electric detonator can be defined as a detonator initiated by means of an electric current passing through a resistance wire imbedded in pyrotechnic composition.

- A non-electric detonator is a detonator initiated by means of a shock tube, gas tube or detonating cord with low explosive charge.

- An instantaneous detonator is a detonator with no delay element and with a firing time of virtually zero.

- A delay detonator can be defined as detonator in which a delay time is included: electric, non-electric or electronic.
• An electronic detonator is a detonator in which the time delay is electronically controlled.

• An electronic initiation system can be defined as an initiation system comprising blasting machine, measuring equipment, wire system and electronic detonators.

1.3 Product Categorisation

Different technical solutions and safety philosophies have been implemented by different manufacturers of electronic initiation systems. Detonators can have programmable or fixed delay times, communicate in one direction or two directions with a blasting machine/programming unit. Also electronic detonators initiated by non-electric signal conductors (shock tubes) exist.

Thus electronic initiation systems can be divided in the following three categories:
1. Programmable electronic detonators with electric wires
2. Non-programmable electronic detonators with electric wires
3. Non-programmable electronic detonators with non-electric signal conductors

To establish communication between a blasting machine and a programmable electronic detonator, it is necessary for the blasting machine to identify each detonator in a round. For this purpose some programmable electronic detonators can have an identity number set to each detonator at production. For other systems, all detonators are identical at production. The detonators are in these cases identified by:
• Programming an identity to each single detonator in the field before connecting the round using a special programming unit;
• Communication with one detonator at the time along the wire bus (daisy-chain principle). In this case the identification is depending on the connection order of the round.

Some manufacturers have advanced built in control functions for use in the field with two way communication while others emphasize on simple systems with similar handling as ordinary electric detonators. Manufacturers having systems with one way communication often provide some kind of simple measuring equipment checking the number of detonators connected in the blasting round. These manufacturers often also point out the need of complete function testing of the electronics in the detonator at production.

There are systems which are connected in series or in parallel having from two up to five wires in the wire bus. For most systems the detonators are designed with standard aluminium shells including both electronics and explosive charges. Some systems on the other hand are designed with a special electronic module which is attached to a standard instantaneous detonator.
Figure 1.2 - Example of connection principle of a blasting machine or measuring equipment to electronic detonators
2 Possible Defects and Causes of Failure

2.1 Fault Tree Analysis

Fault tree analysis (FTA) is concerned with the identification and analysis of conditions and factors which cause or contribute to the occurrence of a defined undesirable event. [IEC1025] FTA is a basically a deductive (top-down) method.

A fault tree is a graphical representation which specifies the "top event" (undesirable event, dangerous situation) and all possible events which may cause it. The events are described at an increasing level of detail until a reasonably detailed level is reached. The events at lowest level are sometimes called the "leaves" of the fault tree.

Fault trees are used in this report to give an overview of the causes of failure. The fault trees in this report are not claimed to be complete, but will give a reasonably good overview of the causes of failure. More detailed fault trees will be specific for different systems and designs. Causes which are mainly valid for conventional initiation systems are included but are not discussed in details.

The unintended initiation can be caused by failures in three parts of the system; the measuring equipment/blasting machine, the detonator or the leading wire. These three "branches" will be found in all four fault trees of clauses 2.3 to 2.6.

2.2 Causes of Failure

Several causes of failure are possible in initiation systems. A system based on detonators using pyrotechnic delay may be affected by environmental stress, hardware faults or user faults. When electronics are introduced for the time delay of the detonator, also electronic hardware faults and software faults must be considered for the detonator itself.

Electronic hardware faults can be either systematic or stochastic. Systematic faults are design faults introduced during the specification, design or maintenance of the electronic initiation system. Such faults should be avoided by proper development methods. Stochastic faults are the result of ageing and wear of the electronic hardware. These faults must be handled when the system is in operation.

Software faults are always systematic, i.e. they are introduced in some phase of the development life cycle. It will not be possible to guarantee error-free software, but much effort should be spent on fault avoidance during the development. State-of-the-art design normally includes measures to check the execution of the software. Monitoring of the execution time and plausibility checks of calculated results are examples of such measures.

Environmental stress can be separated in several different categories;
- electric environment (conducted interference, radiated interference)
- climatic stress (high and low temperature, moisture)
- mechanical stress (vibrations, shocks, impacts)
- chemical stress (corrosion etc.)
User faults are unintentionally caused by the operators of the initiation system. A good
design and training of the operators will help to reduce the risk of user faults. A complex
system is harder to handle and the risk to make a mistake increases. This calls for an
increased attention to the user interface when electronics are introduced in initiation
systems. Users who have handled conventional initiation systems may not always be able
to adopt easily to electronic initiation systems if too many new functions are offered.

A system which is capable of operation also at fault conditions, is called fault tolerant.
Examples of such systems can often be found in aviation applications. A system which
will not fail to danger is called fail-safe, i.e. the system is supposed to have the behaviour
that no dangerous failures can occur. Examples of such systems can be found in different
types of dangerous machinery which is not allowed to hurt the operator.

The blasting machine may be built around an embedded microcontroller. The functions
will be controlled by software. Possible faults in electronic hardware and software may
affect the operation of the blasting machine.

In the fault trees according to figure 2.1 - 2.4, all relevant causes of failure are listed
below each event. Causes of failure, which are earlier known, as they are common for
both conventional detonators and for electronic initiation systems have not been
discussed in detail. Repeatedly discussions on causes of failure, which might occur in
similar ways for many of the described events in the fault trees have also been avoided, if
they have not been found particularly interesting for certain events.

2.3 Critical Defect, Unintended Initiation

A critical defect is a defect that, according to judgement and experience, is likely to
result in hazardous or unsafe conditions for individuals using, maintaining or depending
upon the considered product; or that is likely to prevent performance of the function of a
major end item. [ISO3534]

The worst possible failure of an initiation system is when an unintended initiation is
causd during transport, storage and handling before the blasting field is cleared. This is
likely to cause severe or fatal injuries to the people in the blasting field. Such a failure is
classified as a critical defect. (See figure 2.1.)

Checking or programming of the detonators is performed by using special equipment for
test and measurement. An unintended initiation order (see event 1, figure 2.1) from the
measuring equipment must not be possible. If the measuring equipment is capable of
sending a firing pulse (or the programming equipment is capable of sending an initiation
order), there is a risk of igniting the detonator unintentionally. Such events may be
causd by hardware or software faults. The risk may be eliminated by a design not
capable of generating higher voltage (or higher current) than necessary for igniting the
fusehead of the detonator. If the voltage (or current) still is high enough to initiate the
fusehead, the electronic hardware of the electronic detonator must be fail-safe, which
probably will be difficult to obtain e.g. single fault tolerance by redundant circuits. It is
also possible that repeating tests with the measuring equipment, each with safely low
voltage or current, in the end will cause energy high enough for initiation of the bridge-
wire to be built-up. Even if the electronics of the detonator are not fail-safe, the safety
level may be enhanced by the electronic circuits used.
In a similar way, risks may be eliminated by not making the measuring equipment capable of issuing an ignition pulse or ignition order. It will be a sound principle that the measuring equipment must not be capable of generating high voltage or high current, not even at faults in the equipment. Another sound principle is to exclude functions capable of issuing a blasting order in the software of the measuring equipment.

Special attention must also be drawn to the risk of unintended initiation caused by a test and measurement equipment for conventional electric detonators, which might be connected to an electronic detonator i.e. a user fault. To prevent this risk, the fusehead of the electronic detonators must not be more sensitive than fuseheads for conventional detonators, or there must be a safe barrier between the fusehead and the leading wire.

In a similar way an unintended initiation of a conventional electric detonator can be caused by the connection of test and measurement equipment for electronic detonators, with an output voltage (or current) capable of initiating the electric detonator.

The possibility of detonator failure must be observed especially after an interrupted firing sequence. Charging of the detonators may have been completed, but the initiation procedure is by some reason interrupted. It is then important that the capacitor storing the ignition energy is discharged and the detonator must be put in a safe state. (See event 2, figure 2.1.). The self-discharge process of the capacitor(s) in the detonator should work even if the detonator has been disconnected from the blasting machine.

There are of course also the usual risks of unintentionally igniting the fusehead or the primary charge e.g. by electric, climatic or mechanical environmental stress. (See events 3 & 4, figure 2.1.)

Environmental disturbances may affect the leading wires to generate an initiation pulse. Electromagnetic or electrostatic interference may generate a pulse in an electronic detonator system with electric wires; mechanical or climatic stress may generate a pulse in an electronic detonator system with non-electric signal conductors. (See event 5, figure 2.1.) The chip of an electronic detonator is the barrier between the leading wire and the explosive charge.

It is possible to include plausibility checks in the chip to check for a correct initiation pulse (initiation order). That may give the detonator the possibility to detect and ignore erroneous orders.

The choice of communication protocol (coding system and frequency) of the electronic initiation system might be of importance. If a unique protocol is chosen, i.e. a protocol which is not occurring in present radiofrequent systems, the risk of receiving an unintended initiation order to the detonator can be significantly reduced. On the other hand, if a protocol with high error detection possibilities is chosen, there is a risk that interference makes it hard to convey a valid firing order to all detonators at the same time. This may increase the risk of misfire. The conclusion is that an advanced protocol may give a very good protection against unintended initiation, but may also increase the risk of misfire due to communication interference (see chapter 2.5).

To cause an unintended initiation in an electronic detonator with electric wires, the interference must also generate enough energy for the detonator bridge wire to be initiated.
Detonator = all parts of the detonator itself including the sealing plug.

*Valid for non-electric systems
2.4 Major Defect, Unintended Initiation

A major defect is a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the considered product for its intended purpose. [ISO3534]

An unintended initiation during energy generation, set-up and firing sequence will occur when the blasting field is cleared. It will thus not cause direct harm to the people nearby. The risk of flyrock and ground vibration is increased at unintended initiation. The unintended initiation may also create extra work for the people performing the blasting, and also seriously reduce the efficiency of the blast. It may also lead to further risks later on due to possible remaining uninitiated explosives in the boreholes. It is classified as a major defect.

The fault tree for major defect, unintended initiation according to figure 2.2 is somewhat similar to the fault tree for critical defect, unintended initiation according to figure 2.1. The difference is that the left "branch" includes the testing/measuring equipment in the critical defect fault tree and includes the blasting machine in the major defect fault tree.

The blasting machine will store the energy needed for initiation and release it as an initiation pulse or initiation order. The initiation pulse must not be released to early even if the blasting field is cleared. Software and hardware measures must be taken to assure that no initiation pulse is released during set-up (programming), energy generation or at a too early stage in the firing sequence. (See events 1, 2 and 3, figure 2.2). Inadequate design of the blasting machine in respect of safety against environmental faults can cause an unintended initiation. The simplicity of blasting machine handling is also important for the user in this aspect.

The detonator will at some point of the firing sequence be charged with energy enough to initiate a detonation. The time when storing high energy in the detonator should be kept to a minimum. Risks of unintentional release of energy will thus be minimised. A fault in the logic of the detonator or a breakdown of a hardware component comprising the barrier between the energy storage and the fusehead may cause a detonation too early in the firing sequence. (See event 4, figure 2.2.)

The usual risks of unintentionally igniting the fusehead or the primary charge exist, e.g. by electric, climatic or mechanical environmental stress. (See events 5 & 6, figure 2.2. The events are common with events 3&4, figure 2.1.)

Environmental disturbances may affect the leading wires to generate an initiation pulse. (See event 7, figure 2.2. The event is common with event 5, figure 2.1.)
Figure 2.2: Fault tree analysis of major defect (unintended initiation).

- Hardware Design fault (HD)
- Hardware Stochastic fault (HS)
- Software fault (S)
- Electric environment fault (E)
- Climatic environment fault (C)
- Mechanical environment fault (M)
- Chemical environment fault (Ch)
- User fault (U)

Detonator = all parts of the detonator itself including the sealing plug.

*Valid for non-electric systems
2.5 Major Defect, Misfire

A misfire is a detonator which is supposed to detonate, but has failed to do so at the blasting order. This will create extra risks for the personnel responsible. Uninitiated explosives in the field are a great risk. The misfire is (together with the unintended initiation at cleared field) classified as a major defect.

Sufficient energy must be generated in the blasting machine to supply all connected detonators and make detonation possible. The most obvious fault is if the blasting machine fails to generate energy for the detonator (see event 1, figure 2.3). Another possible reason for misfire is if the supplied energy is not enough to trigger a detonation. (See event 2, figure 2.3.) Hardware or software faults in the blasting machine can be the cause. Depending on the connection principle of the system, i.e. parallel or series connection, the energy sent might not be enough for all detonators in the round. E.g. for a system using parallel bus connection, it is possible that the voltage is decreased along the bus due to wiring resistance, causing too low voltage to be sent to the detonator at the end of the bus. These problems can be handled by different solutions, e.g. voltage check at a feedback connection from the end of the bus or by 2-way communication between the blasting machine and the detonator.

Programmable systems require the programming to be made in a correct way to prevent misfires. If no set-up is sent from the blasting machine, or the set-up is not received by the detonator; the result may be a misfire e.g. caused by a hardware fault in the detonator electronics. (See events 3 and 7, figure 2.3.) Incorrect programming may occur if an incorrect set-up is sent by the blasting machine, or received by the detonator, e.g. due to signal distortion on the bus. (See events 4 and 8, figure 2.3.)

Triggering of the detonator requires an initiation pulse. There will be no detonation if no initiation pulse is sent, or no pulse can be received by the detonator. (See events 5 and 12, figure 2.3.) An incorrect pulse sent may be ignored by the detonator. (See event 6, figure 2.3.)

Normally electronic detonators include some kind of energy storage component e.g. a capacitor. Some systems are designed with separate capacitors for the electronics and the initiation of the bridgewire. If the blasting machine time-out between energy transfer and initiation command is too long, the energy of the capacitor(s) might be decreased due to leakage. The capacitor(s) might also have insufficient or no storing capacity. (See events 9, 10 and 11, figure 2.3.) The energy storing capacity of a capacitor might be dependent of temperature and by ageing effects.

The function of the delay timer is important to get initiation. Hardware faults in the electronic components may disable the operation of the delay timer. (See event 13, figure 2.3.) A test of the timer function is a good way to ensure functionality. This timer test cannot be performed after the detonation of the first detonator in a round. A detonation may well destroy the communication line between the blasting machine and the detonators.

The timer will have to continue counting also as shock waves from detonating explosives of other nearby holes cause mechanical stress (dynamic pressure) to the electronics. Depending on design of the electronics, housing of the detonator etc., this aspect might be more severe for electronic detonators than for conventional detonators. The internal
transfer from the energy storage to the bridge wire can also be interrupted by the influence of dynamic pressure. (See events 14 and 15, figure 2.3.)

There may also be problems to get the primary/base charge to ignite, but that may happen also with conventional detonators. (See event 16, figure 2.3.)

The initiation order (or initiation pulse) transferred on the leading wire may be blocked (e.g. open circuit or shortage) or interfered with. A serial communication order may be more sensitive for interference than an energy pulse. Signal distortion on the bus may seriously distort the blasting order, when a high-energy pulse will be only slightly distorted. Checking facilities of the detonator will reject the initiation order if the message is distorted. (See events 17 or 18, figure 2.3.)

The choice of communication protocol (coding system and frequency) of the electronic initiation system will be of importance. If a protocol with high error detection possibilities is chosen, there is a risk that interference makes it hard to convey a valid firing order to all detonators at the same time. This may increase the risk of misfire. As mentioned in chapter 2.3, a communication protocol will reduce the risk of unintended initiation. The conclusion is that a simple protocol will not increase the risk of misfires significantly, but it may not either significantly improve the protection against unintended initiation. An advanced protocol may give a very good protection against unintended initiation, but also increased risk of misfire due to communication interference.

Energy leakage might also occur due to water penetration in connection blocks, especially if inhole connections at the detonators are used. (See also the paragraph on event 2, figure 2.3 above regarding voltage loss along a parallel bus.)
Figure 2.3. Fault tree analysis of major defect (misfire).
2.6 Minor Defect, Incorrect Delay

A minor defect is a defect that is not likely to reduce materially the usability of the considered product for its intended purpose, or that is a departure from established specifications having little bearing on the effective use or operation of this product. [ISO3534]

An incorrect delay time of a detonator is of course not wanted, but the result is not likely to be fatal. Ground vibrations may be increased, fragmentation may be affected and there may be some flyrock. However, the field will have been cleared when proper blasting procedures have been observed and no one will get hurt. An incorrect delay time is classified as a minor defect.

There is a theoretical possibility of a very long incorrect delay time. If the delay timer has not expired before the supply energy detonator is discharged, the result will be a misfire. This report considers all such extremely prolonged delays as misfires.

Both the hardware and the software of the blasting machine must operate correctly to give the correct delay time. The blasting machine must order the correct delay time. (See event 1, figure 2.4.) Programmable systems might also introduce risks of incorrect delay times being programmed, especially if the software and the user interface is complicated.

The design may rely on either a correct timer in every detonator or a correct timer in the blasting machine. A calibration procedure will be needed in both cases. Timer calibration failures in the blasting machine or in the detonator will affect the delay. (See events 2 and 7, figure 2.4.)

A special case affecting the delay is when the energy sent to the detonator is enough to start the initiation, but small enough to increase the bridge-wire delay. (See event 3, figure 2.4.)

Programmable detonators may have set-up faults; either the delay time can be misinterpreted when received (see event 4, figure 2.4), or it can be stored in an incorrect way in the detonator (see event 5, figure 2.4). The information may be correct when it first was written into the memory, but can after some time be changed due to hardware faults in the memory cells.

Also the correct connection order between detonators can be important to "program" the delay times (see event 6, figure 2.4). Systems which relay on the sequential order of delays between detonators require a correct connection order. Detonators which are not programmed with identity (number and/or delay time) until before connecting the round in the field, introduces risks of confusion of detonators, especially if the identity of each detonator can not be confirmed by for example a manual marking procedure.

A good and stable timer is necessary to be able to execute a correct delay time. Depending on design, variations in temperature and supply voltage will more or less affect the electronic components of the timer. (See event 8, figure 2.4).

The information transferred on the leading wire may be interfered with and cause incorrect delay information. Checking facilities of the detonator will reject the delay time if the message is distorted. (See event 10, figure 2.4. The event is common with event 18, figure 2.3.)
- Hardware Design fault (HD)
- Hardware Stochastic fault (HS)
- Software fault (S)
- Electric environment fault (E)
- Climatic environment fault (C1)
- Mechanical environment fault (M)
- Chemical environment fault (Ch)
- User fault (U)

Detonator = all parts of the detonator itself including the sealing plug.

* Influence on bridge-wire delay
3 Market Survey

3.1 Introduction

This market survey aims to address parameters and functions specific for initiation systems using detonators with electronic time delay. The intention has not been to focus on issues which are known from conventional initiation systems. Several of the leading manufacturers are represented in the survey, but there are also other companies offering electronic initiation systems. The survey covers manufacturers from Europe, North America, Asia and Africa.

Case studies of different manufacturers have been made. The product information presented in this chapter is based on information, which has been provided by each manufacturer and is intended to give an overview of the state-of-the-art. Each manufacturer has been given the possibility of checking and correcting the information before publishing it in this report. No comparison between manufacturers has been made. Nor has any safety validation taken place.

Product data might be subject to change. Please contact the manufacturers for up-to-date information.
3.2 Asahi Chemical Industry Co, Ltd

Asahi Chemical Industry Co., Ltd is a Japanese company, which has developed an electronic initiation system: EDD® - Electronic Delay Detonators. This system has been on the market for about 4 years. The sales amount is about 100,000 detonator units (reported 1995).

The time delays of the detonators are fixed at production, i.e. the detonators are non-programmable. The delay times available are in the range from 10 ms up to 8190 ms in steps of 1 ms.

The detonator module consists of an electronic delay module and an instantaneous electric detonator, interconnected and housed in a plastic case with a maximum diameter of about 17 mm and a length of 110 mm.

The detonators are connected in series to a blasting machine, see figure 3.1. Up to 100 detonators can be connected to the blasting machine. A 600 detonator version is also available. The blasting machine is in principle designed as a conventional capacitor blasting machine. The output voltage of the blasting machine can be adjusted for the chosen number of detonators in the round. The connection and handling is therefore very similar to conventional electric detonators.

Testing of the blasting circuit can be carried out after connection of the round, using the resistance meter, which is built-in into the blasting machine or by using a conventional resistance meter for electric detonators, see figure 3.1. The resistance test is possible as the detonator has a resistor in parallel at the detonator input.

![Figure 3.1. Connection of blasting machine or resistance meter](image1)

A Detonator Checker is available for testing of the normal function of a single detonator on site, see figure 3.2. The Detonator Checker is capable of checking connection, bridgewire and energy. Furthermore another checker to be used at production is available for checking of connection, delay time, bridgewire and energy (capacity of the power supply capacitor).

![Figure 3.2. Connection of the Detonator Checker](image2)
The main functional components of the electronic delay module are:
- An input circuit consisting of a resistor in parallel on the input, a diode bridge, a power supply capacitor and a constant voltage circuit;
- Timer circuits including a reset circuit and an oscillator/counter circuit;
- An ignition current firing circuit.

The operation of the system is described in figure 3.3 starting from the point when the complete round has been connected to the blasting machine. First the correct number of detonators is chosen. The circuit resistance as well as the output voltage from the blasting machine are automatically calculated when the correct number is given to the blasting machine. Secondly, the circuit resistance is measured. If the measured circuit resistance corresponds with the calculated resistance, the charging command turns operable. The capacitor is then charged to the chosen voltage level. At the fire command the capacitor is discharged through the series of detonators.

When the initiation voltage pulse is received by the detonator from the blasting machine the capacitor of the detonator is charged. At this moment the quartz oscillator and counter are powered up in a short time. During the power-up-time the counter is held in a reset state. After 5 ms, controlled by a RC-timing circuit, the reset-state is released and the counter starts counting. After a predetermined number of clock pulses the thyristor in the ignition current firing circuit is triggered, causing the energy stored in the main detonator capacitor to discharge through the electric detonator bridge-wire.

Thus the delay time of the detonator consists of two times:
- A reset time of 5 ms controlled by a resistor/capacitor circuit and a comparator.
- A predetermined delay time controlled by the quartz oscillator and the counter.

The used instantaneous electric detonator has a no-fire-current of 0.4 A. It is claimed that the electronic detonator assembly is safe against unintended initiation caused by electrostatic discharge with 2000 pF up to 40 kV on either legwire and 9 kV between legwires.

The electronic delay circuit is patented according to US patent number 5,363,765, dated November 15, 1994.
Figure 3.3. Flow chart of EDD® operation
<table>
<thead>
<tr>
<th>EDD® - Electronic Delay Detonators summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>Delay principle</td>
</tr>
<tr>
<td>Delay times available</td>
</tr>
<tr>
<td>Delay accuracy</td>
</tr>
<tr>
<td>Housing of detonator</td>
</tr>
<tr>
<td>Connection</td>
</tr>
<tr>
<td>Max number of detonators</td>
</tr>
<tr>
<td>2-way communication</td>
</tr>
<tr>
<td>Working voltage</td>
</tr>
<tr>
<td>Over-voltage protection</td>
</tr>
<tr>
<td>Energy stored in detonator</td>
</tr>
<tr>
<td>Self discharge</td>
</tr>
<tr>
<td>Checking possibilities</td>
</tr>
<tr>
<td>- connection check</td>
</tr>
<tr>
<td>- delay check</td>
</tr>
<tr>
<td>- bridgewire check</td>
</tr>
<tr>
<td>- energy/voltage check</td>
</tr>
</tbody>
</table>

* Single detonator checker

** Possibility of checking the connections in the round using the resistance meter, which is built in the blasting machine or using a conventional resistance meter for electric detonators
3.3 Davey Bickford SNC

Davey Bickford SNC is a French company with head office in Rouen and production facilities at Hery. The development of the electronic delay blasting cap started in 1993. The design is now being tested in France.

The time delay of each detonator is programmable in steps of 1 ms. A single type of detonator can be programmed by the user to any delay in the interval 0 to 3000 ms. The delay can also be modified later if changes in the blasting pattern are decided. Modifications of the delay time can be made remotely without entering the blasting field. The delay is executed by an electronic circuit in each detonator after receipt of the order for detonation.

Each detonator must be assigned an identity (address) and a delay time. This programming is made by a separate programming unit which must be connected to every detonator before the detonators are connected together. (See figure 3.4.)

![Diagram](image)

Figure 3.4. Programming the identity (address) into a detonator.

The detonators and the blasting machine are then connected to a two-wire parallel bus. The programming unit is connected to the blasting machine. (See figure 3.5.)

![Diagram](image)

Figure 3.5. Connection of blasting machine and programming unit

The programming unit starts the programming of the identity into a detonator by first checking that the connection is correct. Then the functions of the detonator are tested, and after that the identity is programmed into the detonator. Any faults detected in the tests will be indicated by an error message on the display of the programming unit. (See figure 3.6.)
Figure 3.6. Flow-chart of programming the identity into a detonator (Davey Bickford).

An identity must always be given to the detonator by the programming unit. The detonator may also be programmed with a delay time manually from the programming unit. As an option, it can instead be given a delay time first when it has been connected to the blasting machine.

The charging and firing sequences are handled by the blasting machine. (See figure 3.7.) Blasting plan and delay numbers are transferred from the programming unit to the blasting machine. Each detonator contains two capacitors; one for electric supply of the electronics and one for the firing. Initially the blasting machine charges the capacitors for supply of electronics. Checks are performed by the blasting machine before orders for charging and firing can be transmitted.
Figure 3.7. Flow-chart of charging and firing (Davey Bickford)
The blasting plan may also be edited in a separate personal computer and then transferred to the blasting machine (computerised firing pattern). Delay times are then transferred to the detonators. It is also possible to modify the delay times using the blasting machine.

There is a 30 second time-out limit after charging the firing capacitor. Fire command has to be given within 30 seconds and the completion of the charge command. Otherwise the blasting machine will order discharging of the firing capacitor. The discharge is executed by the detonator in less than 2 seconds.

The blasting area should be cleared before the blasting machine is connected to the detonators. The potentially most dangerous state is entered when the firing capacitor has been charged.

The communication is two-way, i.e. the detonator can actively reply to messages sent from the blasting machine or the programming device.

The functionality of the detonator can be divided into 6 parts:
- Reception, interpretation and execution of commands from the blasting machine and from the programming unit.
- Storing the identity parameters in non-volatile memory.
- Generate a delay corresponding to the stored value.
- Storing of the energy necessary to operate during the delay phase.
- Storing of energy necessary to initiate a detonation.
- Generation of an electrical impulse to trigger the base charge.

The architecture of the detonator can be described in 4 sub-systems; power module, communication interface, logic unit and driver module. (See figure 3.8.)

![Diagram of detonator architecture](image)

**Figure 3.8.** Architecture of the detonator
Recognition and execution of 8 different commands are possible in the detonator;
- Read: read blast pattern no., address and delay time from the memory of the detonator.
- Program: program parameters into the memory of the detonator.
- Pulse: verify the frequency of the internal clock.
- Test: test the firing circuit by feeding a small current through the bridgewire.
- Test result: report the result of the test of the firing circuit.
- Charge: charge the firing capacitor and the capacitor for energy supply to the electronics.
- Discharge: discharge the firing capacitor.
- Fire: start detonation by discharging the firing capacitor through the bridgewire.

<table>
<thead>
<tr>
<th>Davey Bickford summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>Davey Bickford SNC, France</td>
</tr>
<tr>
<td>Delay principle</td>
</tr>
<tr>
<td>Programmable optional intervals</td>
</tr>
<tr>
<td>Delay times available</td>
</tr>
<tr>
<td>0 - 3000 ms in steps of 1 ms</td>
</tr>
<tr>
<td>Delay accuracy</td>
</tr>
<tr>
<td>± 0.5 ms</td>
</tr>
<tr>
<td>Housing of detonator</td>
</tr>
<tr>
<td>Standard aluminium shell</td>
</tr>
<tr>
<td>Connection</td>
</tr>
<tr>
<td>Electrical, 2-wire parallel bus</td>
</tr>
<tr>
<td>Max number of detonators</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>2-way communication</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Working voltage</td>
</tr>
<tr>
<td>&lt;4 V at programming, &lt;20 V at charging</td>
</tr>
<tr>
<td>Over-voltage protection</td>
</tr>
<tr>
<td>Yes, spark gap, fuses</td>
</tr>
<tr>
<td>Energy stored in detonator</td>
</tr>
<tr>
<td>Yes, capacitor for electronics, (capacitor for fusehead just before firing)</td>
</tr>
<tr>
<td>Self discharge</td>
</tr>
<tr>
<td>Yes (1-2 s), interrupted communication 30s</td>
</tr>
<tr>
<td>Checking possibilities</td>
</tr>
<tr>
<td>- connection check</td>
</tr>
<tr>
<td>at production</td>
</tr>
<tr>
<td>at test on-site</td>
</tr>
<tr>
<td>at run-time</td>
</tr>
<tr>
<td>- (Not applicable)</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes (bus shortage)</td>
</tr>
<tr>
<td>- delay check</td>
</tr>
<tr>
<td>No (function: yes)</td>
</tr>
<tr>
<td>No (computed firing pattern);</td>
</tr>
<tr>
<td>Yes (manual pattern)</td>
</tr>
<tr>
<td>- bridgewire check</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>- energy/voltage check</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
</tr>
</tbody>
</table>
3.4 DCI - Delta Caps International

Delta Caps International, Nice, France has developed systems for electronic detonators claiming both accurate and fully programmable delay times. The system described in this report is the DSL2 system.

The older DSL1 system is no longer in use. DSL1 required every delay time to be set manually by mechanical switches on every detonator. There is also the DSL3 system which incorporates the possibility to monitor and control the blasting process in real time. The DSL3 is not yet introduced on the market.

The electronic detonator is designed as an electronic delay unit attached to a conventional electric detonator with zero delay. It is possible to adapt the system for application with different detonator types in respect of electric sensitivity.

An electronic delay circuit generates an accurate delay time before the detonator is fired. The detonator and the electronic circuit are integrated and handled as a single unit by the user.

According to figure 3.9, the detonators are connected in series to the blasting machine on a two-wire bus (four wires to each detonator). After the holes are loaded, the blasting machine is connected and the delay times are programmed into the detonators. Identification of the detonator is made through its position on the bus. The communication is handled according to the "daisy-chain" principle (communication with one detonator at the time).

![Diagram](image)

Figure 3.9. Connection to blasting machine

The delay time can be specified from 0 to 30 seconds in steps of 1 ms. The delays are entered through the blasting machine, and can be modified at any time before the blast. An absolute accuracy of 1.5 ms is claimed for a 30000 ms delay. The relative accuracy between 2 consecutive delays is claimed to be at 0.2 ms for a 30000 ms delay.

At power-up, the blasting machine checks its internal battery. Also the line is tested regarding leakage or short-circuit. If the result is unsatisfactory, the blasting machine will not allow continued operation.

The flow chart of figure 3.10 displays how the programming, charging and firing is performed. Each detonator contains two capacitors; one for electric supply of the electronics and one for the firing. The blasting machine starts by charging each of the capacitors for supply of electronics. Then a delay time is transferred to every detonator.
An acknowledge is sent from each detonator to the blasting machine that a delay time has been received.

Then the large capacitors used for firing the bridgewires are charged. Each detonator will have to confirm that sufficient energy has been received. Then the system is ready to blast and prompts the operator to order detonation. If there is not any order for detonation within 20 seconds, the process is interrupted.

When the operator presses the FIRE button, a FIRE command is sent to all detonators. Each detonator then starts its internal timer and uses the energy stored in one of its two capacitors to operate during the delay time. As the delay timer runs out, the bridge wire is ignited by using the energy stored in the firing capacitor.

<table>
<thead>
<tr>
<th>DSL2 summary</th>
<th>Delta Caps International, France</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Delta Caps International, France</td>
</tr>
<tr>
<td><strong>Delay principle</strong></td>
<td>Programmable delay times</td>
</tr>
<tr>
<td><strong>Delay times available</strong></td>
<td>0 - 30 s in steps of 1 ms (up to 60 s option)</td>
</tr>
<tr>
<td><strong>Delay accuracy</strong></td>
<td>0.005 % (relative)</td>
</tr>
<tr>
<td><strong>Housing of detonator</strong></td>
<td>Detonator in standard aluminium shell attached to an electronic module in steel (tube length 100 mm, diameter 20 mm).</td>
</tr>
<tr>
<td><strong>Connection</strong></td>
<td>Daisy chain, 2-wire serial bus (2 wires in, 2 wires out), 4-pin connector on the electronic module (water proof).</td>
</tr>
<tr>
<td><strong>Max number of detonators</strong></td>
<td>200 standard, (up to 2000 as option)</td>
</tr>
<tr>
<td><strong>2-way communication</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Working voltage</strong></td>
<td>48 V line voltage</td>
</tr>
<tr>
<td><strong>Over-voltage protection</strong></td>
<td>Yes, regulator acting as a fuse, no spark gap</td>
</tr>
<tr>
<td><strong>Energy stored in detonator</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Self discharge</strong></td>
<td>Yes (150 seconds)</td>
</tr>
<tr>
<td><strong>Checking possibilities</strong></td>
<td>at production at test on-site at run-time</td>
</tr>
<tr>
<td>- connection check</td>
<td>- (Not applicable)</td>
</tr>
<tr>
<td>- delay check</td>
<td>No No Yes</td>
</tr>
<tr>
<td>- bridgewire check</td>
<td>Yes No No</td>
</tr>
<tr>
<td>- energy/voltage check</td>
<td>No No Yes</td>
</tr>
</tbody>
</table>
Figure 3.10. Flow chart of DSL2 operation.
3.5 **Detonator Technologies (Altech)**

Detonator Technologies is a South African company developing electronic delay detonators called Electrodet™. The development project has been going on for more than 10 years, and now a factory with large production capacity has been established.

Detonator Technologies is a daughter company of Altech, one of the largest electronics companies in South Africa. Altech's primary products are professional telecommunications equipment.

The detonators are factory programmed with four different intervals; 0, 32, 64 and 128 ms. By connecting them in daisy-chain, longer delay times will be achieved by adding the delay times of the previous detonators in the chain. The overall delay timing is controlled by the connection sequence of the individual units in the harness.

The chain of detonators is connected to a panel (face box) which is capable of handling 250 detonators. The panel is then connected to the blasting machine (charge control unit) which may control up to 6 panels. (See figure 3.11.)

A five-wire connection harness is used. The voltage generated for initiation (32 V) is fed to the detonators on one of those wires. The use of a separate wire makes a hardware interlock in the charge control unit possible. A key switch for each panel must be turned at the charge control unit before the initiation voltage can be fed to the detonators.

![Connection diagram](image)

**Figure 3.11. Connection to blasting machine and panel**

The delay sequence is achieved by two delay timers, both within the on-board microchip. An incoming signal from the panel starts the first timer of the first detonator of the chain. When the first timer is completed, the signal is passed to the next timer in the chain, at the same time as the second timer of the first detonator is started. All detonators have a second delay timer of 32 seconds. The sum of the delay times of the both timers gives the total delay from sending out the fire order from the panel to detonation. (See figure 3.13 for example.)
Figure 3.12. Flow chart of Electrodet® operation.
Figure 3.13. Example of timing in daisy chain

It is possible to have multiple zero delay detonators consecutively, this results in instantaneous blasts. All delay times can be used and mixed in any combination.

An instant shut-down will be made if a safety-critical defect is detected. Minor defects (such as one defect detonator) can be chosen to be ignored. The man in charge of the blasting can decide to go on with the rest of the blast.

<table>
<thead>
<tr>
<th>Electrodet® summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>Delay principle</td>
</tr>
<tr>
<td>Delay times available</td>
</tr>
<tr>
<td>Delay accuracy</td>
</tr>
<tr>
<td>Housing of detonator</td>
</tr>
<tr>
<td>Connection</td>
</tr>
<tr>
<td>Max number of detonators</td>
</tr>
<tr>
<td>2-way communication</td>
</tr>
<tr>
<td>Working voltage</td>
</tr>
<tr>
<td>Over-voltage protection</td>
</tr>
<tr>
<td>Energy stored in detonator</td>
</tr>
<tr>
<td>Self discharge</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Checking possibilities</td>
</tr>
<tr>
<td>- connection check</td>
</tr>
<tr>
<td>- delay check</td>
</tr>
<tr>
<td>- bridgewire check</td>
</tr>
<tr>
<td>- energy/voltage check</td>
</tr>
</tbody>
</table>
3.6 Dynamit Nobel GmbH

Dynamit-Nobel GmbH is based in Troisdorf, Germany. The DYNATRONIC detonator system has been approved for general use in Germany. A special training is required by the German authorities to be allowed to use the system for blasting.

The time delay of the detonator is controlled by an electronic circuit in each detonator. 61 different delay numbers may be used at delay times up to 6.1 seconds. The detonators are connected to the blasting machine (or to the test instrument) on a parallel two-wire bus.

![Figure 3.14. Connection of blasting machine](image)

The test instrument, Dynatest, is separated from the blasting machine. This is done to prevent accidental unintended transfer of energy to the detonator during the test procedure. It is regarded as physically impossible that the test equipment would cause the initiation of a detonator (electrical or electronic). Furthermore it is claimed that a conventional ohm-meter could not cause an unintended initiation of an electronic DYNATRONIC detonator.

The test instrument indicates the number of detonators connected in parallel with an accuracy of ±1 unit (electrical resistance principle).

There are 61 different delay numbers, and the interval between numbers can be chosen from 1 ms to 100 ms. The delay time of each detonator can be calculated as delay number multiplied by the time interval. An absolute accuracy of 0.1 % can be reached. Detonators with the same delay interval will detonate simultaneously at less than 1 ms time difference.
<table>
<thead>
<tr>
<th>Delay number</th>
<th>Delay time [ms]</th>
<th>Delay time [ms]</th>
<th>Delay time [ms]</th>
<th>Delay time [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>10</td>
<td>20</td>
<td>...</td>
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<td>...</td>
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<td>...</td>
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<tr>
<td>20</td>
<td>0</td>
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<td>40</td>
<td>...</td>
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<td>...</td>
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</tr>
<tr>
<td>50</td>
<td>0</td>
<td>50</td>
<td>100</td>
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</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>100</td>
<td>200</td>
<td>...</td>
</tr>
</tbody>
</table>

Figure 3.16. Table of delay times

DYNATRONIC is used by first selecting detonators with proper delay numbers and then connecting them to the blasting machine. The blasting machine and the detonators will then operate as indicated in the flow-chart of figure 3.17.

Firstly, the blasting machine will make an internal check. If this check is approved, the blasting machine will prompt the operator to select the time interval. After that it will be possible to press the "FIRE" button. "FIRE" will cause the blasting machine to give supply power to the detonator, send a security code, send timing information and to order detonation.

DYNATRONIC requires both energy and information to start a detonation. (A conventional electric detonator requires only energy.) To prevent unintended detonation, a security code is required by the detonator. The blasting machine has to transmit a correct security code to the detonators. Any detonator receiving an incorrect security code will go into a blocked state. That detonator will require a power-down before it may operate again.
Figure 3.17. Flow-chart of DYNATRONIC operation
<table>
<thead>
<tr>
<th><strong>DYNATRONIC summary</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manufacturer</strong></td>
<td>Dynamit Nobel GmbH, Germany</td>
</tr>
<tr>
<td><strong>Delay principle</strong></td>
<td>Programmable (fixed delay numbers, 0 to 60)</td>
</tr>
<tr>
<td><strong>Delay times available</strong></td>
<td>0 - 6 seconds, intervals 1-100 ms</td>
</tr>
<tr>
<td><strong>Delay accuracy</strong></td>
<td>0.1 % (for the longest delay)</td>
</tr>
<tr>
<td><strong>Housing of detonator</strong></td>
<td>Standard aluminium shell</td>
</tr>
<tr>
<td><strong>Connection</strong></td>
<td>Electrical, 2-wire parallel bus</td>
</tr>
<tr>
<td><strong>Max number of detonators</strong></td>
<td>200</td>
</tr>
<tr>
<td><strong>2-way communication</strong></td>
<td>No</td>
</tr>
<tr>
<td><strong>Working voltage</strong></td>
<td>15 V</td>
</tr>
<tr>
<td><strong>Over-voltage protection</strong></td>
<td>Yes, spark gap, fuses</td>
</tr>
<tr>
<td><strong>Energy stored in detonator</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Self discharge</strong></td>
<td>Yes (60 seconds)</td>
</tr>
<tr>
<td><strong>Checking possibilities</strong></td>
<td>at production</td>
</tr>
<tr>
<td></td>
<td>at test on-site</td>
</tr>
<tr>
<td></td>
<td>at run-time</td>
</tr>
<tr>
<td></td>
<td>(Not applicable)</td>
</tr>
<tr>
<td><strong>- connection check</strong></td>
<td>Yes (number of detonators, resistance)</td>
</tr>
<tr>
<td></td>
<td>Yes (load check, open circuit, short circuit)</td>
</tr>
<tr>
<td><strong>- delay check</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>- bridgewire check</strong></td>
<td>Yes</td>
</tr>
<tr>
<td><strong>- energy/voltage check</strong></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
3.7 The Ensign-Bickford Company

The Ensign-Bickford Company is an American company, which has developed an electronic initiation system called DIGIDET™. The system has been field tested in several blasts around United States to date (reported 1996). A second generation product is planned to be field tested in 1997.

The DIGIDET™ system is non-electrically initiated using standard shock tube or low energy detonating cord. The time delays of the detonators are fixed at production, i.e. the detonators are non-programmable. The delay times available are in the range from 0 ms up to 10000 ms.

The detonator is designed as a standard detonator with an aluminium shell. The system is used and connected in the same way as conventional non-electric initiation systems using existing non-electric components, see example in figure 3.18. No special blasting machines or measuring devices are necessary.

![Diagram of a detonator](example-diagram)

Figure 3.18. Connection example for DIGIDET™

The main functional components of the detonator are:
- Input transmission line (shock tube or detonating cord);
- An energy conversion part including a small explosive charge, a piezo ceramic device, a steering diode and a storage capacitor;
- An electronic delay timing module including a voltage regulator, an oscillator/counter circuit, a power on reset circuit, an igniter switch and an igniter,
- An explosive output charge.

When the detonator receives the signal from the transmission line (shock tube or cord), the small explosive charge fires. This activates the piezo ceramic device, see figure 3.19 and 3.20, which causes a current to flow through the steering diode to the storage capacitor. The capacitor is charged. A voltage regulator provides constant voltage to the oscillator to control the frequency of the oscillator. A "power-on reset" circuit preloads the counter upon initial application of the input voltage. When the voltage of the storage capacitor has increased above a certain value, the counter begins decrementing upon each pulse from the oscillator. When the counter reaches zero, the firing switch is activated causing the remaining energy in the capacitor to be discharged through the igniter, which ignites the explosive charge.
Figure 3.19. Schematic circuit of the detonator

Figure 3.20. Flow chart of DIGIDET™ operation
Due to the non-electric shock tube/cord system and the fact that the metallic shell creates a Faraday cage around the electronics in the detonator, it is claimed that the system has a very high resistance to electromagnetic and electrostatic sources as well as spurious electric sources. The detonators and shock tubes have been tested in respect of radiofrequency resistance at 200 V/m from 14 kHz to 18 GHz and electrostatic resistance at 30000 V from 2000 pF.

As the transmission line (shock tube or cord) has a certain detonation velocity, the delay interval time between detonators can be slightly affected by the transmission time, especially if different lengths of line is used to different detonators (see figure 3.18).

The energy generation and storage mechanism is patented according to US patent number 5,173,569.

<table>
<thead>
<tr>
<th>DIGIDET™ summary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>The Ensign-Bickford Company, U.S.A.</td>
</tr>
<tr>
<td>Delay principle</td>
<td>Fixed delays (non-programmable)</td>
</tr>
<tr>
<td>Delay times available</td>
<td>0 - 10000 ms (standard and non-standard periods)</td>
</tr>
<tr>
<td>Delay accuracy</td>
<td>1 ms</td>
</tr>
<tr>
<td>Housing of detonator</td>
<td>Standard aluminium shell</td>
</tr>
<tr>
<td>Connection</td>
<td>Non-electric, shock tube or low energy detonating cord</td>
</tr>
<tr>
<td>Max number of detonators</td>
<td>Not limited</td>
</tr>
<tr>
<td>2-way communication</td>
<td>No</td>
</tr>
<tr>
<td>Working voltage</td>
<td>Information not available</td>
</tr>
<tr>
<td>Over-voltage protection</td>
<td>Yes, communication is non-electric</td>
</tr>
<tr>
<td>Energy stored in detonator</td>
<td>Yes, only after the shock tube or detonating cord has been initiated to the detonator.</td>
</tr>
<tr>
<td>Self discharge</td>
<td>Information not available</td>
</tr>
<tr>
<td>Checking possibilities</td>
<td>at production at test on-site at run-time</td>
</tr>
<tr>
<td>- connection check</td>
<td>- (Not applicable) No Yes, visual</td>
</tr>
<tr>
<td>- delay check</td>
<td>Yes No No</td>
</tr>
<tr>
<td>- bridgewire check</td>
<td>Yes No No</td>
</tr>
<tr>
<td>- energy/voltage check</td>
<td>Yes No No</td>
</tr>
</tbody>
</table>
3.8 Expert Explosives (Pty) Ltd

Expert Explosives (Pty), Ltd is a South African company, which has developed an electronic initiation system: Expert Explosives 1000 System (ExEx® 1000). Expert Explosives is a division of ICI Explosives. The ExEx® 1000 has been used in the field for four years of production blasting (reported 1996).

The system is programmable with delay times from 0 -15000 ms in steps of 1 ms. The detonators are designed as a standard detonator with an copper shell. A 6-wire cable with a special connector at the end of the cable is used to the detonators. On the rock surface a 5 wire bus is used.

Identification of the detonator is made through its position on the bus. The communication is handled according to the "daisy-chain" principle (communication with one detonator at the time).

According to figure 3.21, four harnesses can be connected each with a maximum of 255 detonators to the blast programmer. Two or more blast programmers can be joined together for larger blasts.

![Diagram of blast programmer connection](image)

Figure 3.21 - Connection of blast programmer(s) to the detonators.

The blast programmer performs the following main functions:
- Testing of detonators before and during the blasting cycle;
- Programming of individual delays;
- Providing power to charge detonator capacitor;
- Sending the digital codes to arm and fire the detonators.

Using a personal computer with a special Microsoft Windows application called Winblast, it is possible to program the delay times of the blast pattern and load it into the blast programmer. With this software it is also possible to e.g:
- Make timing calculations;
- Simulate blasts;
- Generate blast layout;
- Use database functions.
Special testing devices are provided for connection check during hook-up:

- Leakage and downline testers for testing the wiring of all detonators
- System tester for testing the functionality of detonators and rows (ExEx® 1000B only, described below).

The testing devices are claimed to be inherently safe defined as 'equipment unable to generate signals required to initiate the electronic detonator. Signals may be a combination of voltages, currents and coded sequences, which are required to initiate the electronic detonator'.

Two different versions of ExEx® 1000 exist:

- ExEx® 1000 detonators can only be tested for continuity at a voltage below 3 V after deployment.
- ExEx® 1000B detonators are tested not to fire at 9 V during manufacture. Using the principle of ‘inherent safety’, full functional testing in the field may be carried out using a separately licensed ‘inherently safe tester’ operating at 7 V maximum.

As the system uses two-way communication it is possible to use both the testing devices and the blast programmer to check connections, programmed delay times, voltages) and bridgeworks of each detonator.

Due to special sets of messages it is claimed that it is impossible to electronically fire a detonator without the use of the dedicated blast programmer.

The main functional components of the detonator electronics are:
- Digital timing chip with integral hotspot;
- Printed circuit board;
- An energy storage capacitor.

The operation of the system is described in figure 3.22 starting from the point when the complete round has been connected to the blasting machine and after the blasting program has been transferred from the computer to the blast programmer.

The blast programmer (BP) is first initialised. An initialise/reset command is sent to the detonators. The BP establishes that each detonator is fully functional. The BP sends a calibration command in order to calibrate the oscillators of each detonator. The timing information is transferred from the BP to the detonators. Each detonator confirms that it has received the correct delay time.

The capacitors of the detonators are charged. The detonators confirm that they have been charged correctly. When “fire” is pressed on the BP, the detonators start countdown from their programmed time to zero (detonation). If a misfire occurs at that stage, the capacitor of the detonator is discharged i.e. the detonator is reset to a safe state.
Figure 3.22. Flow-chart of ExEx® 1000 operation
Furthermore it is possible to return to the initialise/reset state from any point (software controlled). The last exit point may be changed to an earlier state if required.

It is claimed that the electronic detonator assembly is immune against electrostatic discharge at 2500 pF, 30 kV. The systems has been tested in respect of electromagnetic resistance over the range of 10 kHz to 1.8 GHz at a field strength of 80 V/m, resulting in no detonations and detonators remaining functional after testing.

<table>
<thead>
<tr>
<th>ExEx® 1000 System</th>
<th>Manufacturer</th>
<th>Expert Explosives (Pty), Ltd.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay principle</td>
<td>Programmable</td>
<td></td>
</tr>
<tr>
<td>Delay times available</td>
<td>0 - 15000 ms in 1 ms increments (ExEx® 1000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 - 10000 ms in 1 ms increments (ExEx® 1000B)</td>
<td></td>
</tr>
<tr>
<td>Delay accuracy</td>
<td>± 0.2 %</td>
<td></td>
</tr>
<tr>
<td>Housing of detonator</td>
<td>Copper shell, diameter 9.5 - 10 mm</td>
<td></td>
</tr>
<tr>
<td>Connection</td>
<td>Electrical 5/6 wire bus</td>
<td></td>
</tr>
<tr>
<td>Max number of detonators</td>
<td>255 per harness, 4 harnesses per blast programmer, programmers stacked</td>
<td></td>
</tr>
<tr>
<td>2-way communication</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Working voltage</td>
<td>18 V</td>
<td></td>
</tr>
<tr>
<td>Over-voltage protection</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Energy stored in detonator</td>
<td>Capacitor in detonator</td>
<td></td>
</tr>
<tr>
<td>Self discharge</td>
<td>Yes, multiple paths, re-entry after 5 minutes</td>
<td></td>
</tr>
<tr>
<td>Checking possibilities</td>
<td>at production</td>
<td>at test on-site</td>
</tr>
<tr>
<td>- connection check</td>
<td>- (Not applicable)</td>
<td>Yes</td>
</tr>
<tr>
<td>- delay check</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>- bridgewire check</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>- energy/voltage check</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
3.9 Nitro Nobel AB

Nitro Nobel AB of Gyttorp, Sweden has developed an electronic initiation system, which has been used in field tests and production blasts since 1990. The system is designed to handle maximum 250 detonators per blasting machine with time delays up to 6.25 seconds. An electronic circuit in the detonator controls the delay between the command "Fire" and the detonation. The detonators are connected to the blasting machine on a parallel two-wire bus (see figure 3.23, where "5" indicates the firing cable, and "2" the bus wire).

![Figure 3.23. Connection of blasting machine](image)

Timing information is normally fed into a personal computer (PC) and then transferred to the blasting machine during a preparation phase of the work.

![Figure 3.24. Connection of the test instrument](image)

The test instrument is separated from the blasting machine. This is done to prevent accidental unintended transfer of energy to the detonator during the test procedure. The test instrument is designed to be operative during connection of the detonators to the bus wire (see figure 3.24). It uses the principle of measuring and analysing relative changes in the total resistance of the round. The display will show the total number of connected detonators. Certain errors will also be detected and indicated.

Each detonator has an identity (address = sequence number) between 1 and 126 (optionally up to 254). There may be several detonators with the same identity. Delay times are individually programmed for each identity at a minimum interval of 1 ms. The maximum possible delay time is 6.25 seconds. The time base of a detonator is automatically calibrated at use. An interval time accuracy of 0.02 - 0.03 % (relative accuracy) is claimed. This corresponds to a standard deviation of approximately 1 ms at a delay time of 6 seconds.
Example:

A round of 6 detonators (2 with the same identity) will be fired to get detonation at 25, 40, 600, 4510 and 5115 ms delay. This can as an example be programmed with the following detonators identities (while many other combinations are also possible):

<table>
<thead>
<tr>
<th>Detonator</th>
<th>Identity</th>
<th>Delay time [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;a&quot;</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>&quot;b&quot;</td>
<td>2</td>
<td>40</td>
</tr>
<tr>
<td>&quot;c&quot;</td>
<td>4</td>
<td>600</td>
</tr>
<tr>
<td>&quot;d&quot;</td>
<td>(4)</td>
<td>*)</td>
</tr>
<tr>
<td>&quot;e&quot;</td>
<td>5</td>
<td>4510</td>
</tr>
<tr>
<td>&quot;f&quot;</td>
<td>10</td>
<td>5115</td>
</tr>
</tbody>
</table>

*) Detonator "d" will automatically get the same delay time as detonator "c".

Figure 3.25. Table of delay times

A built-in safety feature will also guarantee that a detonator which has not been programmed will anyhow fire in the correct sequence.

The operation of the system is described in figure 3.26. A self check is conducted by the blasting machine at start-up. Timing data integrity is also checked. Any detected faults will be indicated and operation will be stopped when required from a safety aspect. If no errors are detected, the blasting machine waits for the operator to press the CHARGING button. All detonators will then be charged, and the voltage on the bus will continuously be checked.

Timing information will be transferred to every detonator. Transmission quality is monitored to try to detect signal distortion. A READY light will light on the blasting machine when the charging of energy and transfer of timing information is successfully completed. The operator may then order detonation by pressing the FIRING button.

The communication is one-way, i.e. the blasting machine does not receive confirmation from the detonators if messages have been correctly received. Instead the signal quality is monitored at the end of the bus line. If the blasting machine detects its own message to be distorted at the end of the bus, then there is a risk that the message has been misinterpreted by some detonator. Certain degrees of distortion may be corrected by the blasting machine, while other degrees are regarded as "fatal" and will cause operation to be stopped.
Figure 3.26. Flow-chart of operation (Nitro Nobel)
The blasting machine also measures the supplied current to check if the number of connected detonators in within the expected interval.

<table>
<thead>
<tr>
<th>Nitro Nobel summary</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Nitro Nobel AB, Gyttorp, Sweden</td>
</tr>
<tr>
<td>Delay principle</td>
<td>Individually programmable delay times</td>
</tr>
<tr>
<td>Delay times available</td>
<td>0 - 6.25 seconds</td>
</tr>
<tr>
<td>Delay accuracy</td>
<td>0.1 % absolute accuracy (for the longest delay) Optional trimming towards nominal delay time possible.</td>
</tr>
<tr>
<td>Housing of detonator</td>
<td>Standard aluminium shell</td>
</tr>
<tr>
<td>Connection</td>
<td>Electrical, 2-wire parallel bus</td>
</tr>
<tr>
<td>Max number of detonators</td>
<td>250 (per blasting machine)</td>
</tr>
<tr>
<td>2-way communication</td>
<td>No</td>
</tr>
<tr>
<td>Working voltage</td>
<td>&lt; 25 V</td>
</tr>
<tr>
<td>Over-voltage protection</td>
<td>Yes (spark gaps, fuses, thyristor)</td>
</tr>
<tr>
<td>Energy stored in detonator</td>
<td>Yes (Internal capacitor, charged from blasting machine during firing sequence.)</td>
</tr>
<tr>
<td>Self discharge</td>
<td>Yes (Approx. 1 - 1.5 minutes, 20 seconds down to 3 V level, recommended waiting time 5 min)</td>
</tr>
<tr>
<td>Checking possibilities</td>
<td></td>
</tr>
<tr>
<td>- connection check</td>
<td></td>
</tr>
<tr>
<td>- delay check</td>
<td>Yes</td>
</tr>
<tr>
<td>- bridgewire check</td>
<td>Yes</td>
</tr>
<tr>
<td>- energy/voltage check</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*) The blasting machine checks delay time integrity before signalling and continuously checks transmitted delay time information during signalling.
3.10 Other Manufacturers

Three additional manufacturers of electronic initiation systems have been identified and contacted in the project:
- Thiokol Corporation, U.S.A (patent property of The Ensign-Bickford Company)
- CSIR - Council for Scientific and Industrial Research: Mikomtek, South Africa
- SMI - Sasol Mining Initiators, South Africa

Since limited product information has been available from these manufacturers, they have not been included in this market survey. A brief description of the ACCUBLAST™ system developed by Thiokol Corporation is given below.

Thiokol Corporation is a US company based in Elkton, Maryland. The electronic detonator ACCUBLAST™ has been developed. The patent is now acquired by The Ensign-Bickford Company.

The device is programmed to provide blast delays in one millisecond increments ranging from 1 to 500 milliseconds. The detonators come preprogrammed with delay times, but the delay times may also be programmed and reprogrammed in the field. The programming of detonator delay times are accomplished on a separate machine.

The detonators are connected to a terminal board by a two-wire parallel bus. The terminal board is connected to the blasting machine. (See figure 3.27.) The terminal board has got 10 output channels, each capable of initiating up to 150 detonators. A total of 1500 detonators can be fired at the same time.

![Figure 3.27. Connections between blasting machine, terminal board and detonators.](image)

The commands sent to the detonator for programming, arming and firing are coded. Coded commands were incorporated to provide enhanced safety in comparison to conventional detonators and blasting machines. ACCUBLAST™ uses a semiconductor bridge (SCB) initiator instead of a bridgewire to initiate the charge. The SCB is claimed to have better precision than conventional hot-wire devices, and also to have better immunity against electromagnetic interference. The time-delay circuitry consists of a semi-custom applications specific integrated circuit (ASIC).
4 Relevant Present Test Methods

4.1 Introduction

As far as what has been evident in this project, no country in the world has developed standards for electronic initiation systems. Still safety evaluation and testing of electronic initiation systems have been carried out using different own developed methods and testing memorandums in some countries. Present relevant methods have in these cases been considered as far as they are applicable. National approvals have been issued in some cases, often with restrictions for use only with specially trained staff and in certain blasting fields. One of the reasons for introducing restrictions is the uncertainty from national authorities and testing institutes of the new risks introduced by these systems.

The directive 93/15/EEC on Explosives for civil uses established by the European Commission describes the Essential Safety Requirements (ESR) which all explosives shall meet in order to be allowed to be placed on the common European market. The Commission has mandated to the European Committee for Standardization, CEN, to establish harmonized standards, which shall comply with the ESR in the directive. A technical committee CEN/TC 321 and five working groups have been established to carry out this task. Working group 4 (WG 4) of CEN/TC 321 is dealing with standards for detonators and relays. The work programme of WG 4 includes 15 standards of which one is addressed for electronic initiation systems. This standard will possibly define both new test and evaluation methods as well as references to the other standards where applicable.

In this project a review of the work programme of WG 4 has been included, in order to identify standards and test methods for conventional electric and non-electric detonators (including accessories), which might be valid also for electronic initiation systems to some extent. It needs to be pointed out that the analysis and views in chapter 4.2, are not adopted by WG 4, as the discussion on electronic initiation systems in WG 4 has not started at the time of publishing this report.

4.2 Methods according to Work Programme of CEN/TC 321/WG 4

In table 4.1 below, the work programme of CEN/TC 321/WG 4 is listed. Most of the 15 standards includes different methods/substandards (column 2). For each method the relevance of applying the method also for electronic initiation systems have been indicated with the following categories (column 3):

A. Directly applicable. The method can be adopted for electronic initiation systems without any changes.

B. Applicable after some modifications. The method is relevant for electronic initiation systems, but needs to be modified in one or more aspects.

C. Not applicable. The method is not relevant for electronic initiation systems.
<table>
<thead>
<tr>
<th>Standards' title (Work Item = WI)</th>
<th>Method(s)/Substandard(s)</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI 32. Requirements</td>
<td>- To be specified -</td>
<td>B</td>
</tr>
<tr>
<td>WI 33. Method(s) for the</td>
<td>a) High temperature stability of detonator, relay and shock tube</td>
<td>A</td>
</tr>
<tr>
<td>determination of thermal stability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 34. Method(s) for the</td>
<td>a) Sensitiveness to impact of detonator, relay and shock tube</td>
<td>A</td>
</tr>
<tr>
<td>determination of sensitiveness to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>impact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 35. Method(s) for the</td>
<td>a) Drop resistance of detonator and relay</td>
<td>A</td>
</tr>
<tr>
<td>determination of resistance to</td>
<td>b) Sensitiveness to electrostatic energy of detonator and relay (electric and non-</td>
<td>B</td>
</tr>
<tr>
<td>accidental initiation</td>
<td>electric)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Electromagnetic resistance of detonator</td>
<td>B</td>
</tr>
<tr>
<td>WI 36. Method(s) for the</td>
<td>a) Initiating energy output of detonator</td>
<td>A</td>
</tr>
<tr>
<td>determination of initiating power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>output</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 37. Method(s) for the</td>
<td>a) Delay time accuracy of detonator and relay (incl. pyrotechnic delay)</td>
<td>B</td>
</tr>
<tr>
<td>determination of delay accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(to apply to pyrotechnic delays</td>
<td></td>
<td></td>
</tr>
<tr>
<td>only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 38. Method(s) for the</td>
<td>a) Resistance to water and hydrostatic pressure of detonator and relay</td>
<td>A</td>
</tr>
<tr>
<td>determination of resistance to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>water and hydrostatic pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 40. Method(s) for the</td>
<td>a) Resistance to abrasion of leading wire and shock tube</td>
<td>A</td>
</tr>
<tr>
<td>determination of mechanical</td>
<td>b) Resistance to cutting damage of leading wire and shock tube</td>
<td>A</td>
</tr>
<tr>
<td>integrity</td>
<td>c) Resistance to cracking in low temperatures of leading wire</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>d) Mechanical strength of leading wire, shock tube, connection, crimp and closure</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>e) Resistance to vibration of plain detonator</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>f) Resistance to bending of detonator</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>g) Resistance to torsion of sealing plug</td>
<td>A</td>
</tr>
<tr>
<td>WI 41. Method(s) for the</td>
<td>a) Extreme temperatures, pressures and other conditions (according to</td>
<td>A</td>
</tr>
<tr>
<td>determination of safety under</td>
<td>manufacturer's specification)</td>
<td></td>
</tr>
<tr>
<td>extreme conditions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WI 42. Detonators for use in coal</td>
<td>- To be specified -</td>
<td>B</td>
</tr>
<tr>
<td>mines or other underground works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>where flammable gas may be a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>hazard - Method(s) for the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>assessment of suitability for use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>in flammable gases</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4.1 (Continued on next page)
<table>
<thead>
<tr>
<th>Standards' title (Work Item = WI)</th>
<th>Method(s)/Substandard(s)</th>
<th>Relevance</th>
</tr>
</thead>
</table>
| WI 43. Electric detonators - Method(s) for the determination of electrical characteristics     | a) No/all firing current of electric detonator  
  b) Series firing current of electric detonator  
  c) Firing pulse of electric detonator  
  d) Total resistance of electric detonator  
  e) Flash-over voltage of electric detonator  
  f) Sensitiveness to stray currents of electric detonator  
  g) Insulation resistance of leading wire  
  h) Capacitance of leading wire  
  i) End insulation of leading wire | B (or A*), no-fire  
  C (or A*), all fire  
  C (or A*)  
  B (or A*), no-fire  
  C (or A*), all-fire  
  C (or A**) | B  
  B  
  B  
  A | |
| WI 44. Non-electric detonators - Method(s) for the determination of shock tube characteristics   | a) Shock wave velocity of shock tube  
  b) Non-conductivity of shock tube | A  
  A | |
| WI 45. Definitions and requirements for devices and accessories for reliable and safe function of detonators and relays | a) Extra requirements for use in coal mines or other underground works where flammable gas may be a hazard  
  b) Blasting machines, test apparatus, resistance meters, warning apparatus, ignition cables  
  c) Transfer capacity of relay and coupling accessory | B  
  B  
  A | |
| WI 57. Definitions, methods and requirements for electronic initiation systems                  | - To be specified -                                                                        | A                                  |

* Only if the electronic detonators are connected in series and fired with a blasting machine of conventional principle without any coded firing pulses.

** Depending on connection and design principle, relevant if this is a parameter related to the use of a specific system.

Table 4.1 Relevant test methods for electronic initiation systems with reference to work programme of CEN/TC 321/WG 4 - Detonators and relays

In the following discussion some comments to each standard according to table 4.1 are indicated:

**Work Item 32, Requirements.** In this standard all requirements from the other 14 standards are compiled. If it is considered to be necessary to modify requirements for electronic initiation systems compared to requirements for conventional electric and non-electric detonators, it is discussed separately under each standard below.

**Work Item 33, Method(s) for the determination of thermal stability.** This is a safety test standard (i.e. safety against unintended initiation) for all detonators, relays and shock tubes in respect of high temperature. The applied temperature levels are based on relevant levels of detonators subjected to normal transport, storage and use. Electronic
detonators are used in the same environment and must withstand the same stresses. The method is therefore directly applicable on electronic initiation systems.

Work Item 34, Method(s) for the determination of sensitiveness to impact. This is a safety test standard (i.e. safety against unintended initiation) for all detonators, relays and shock tubes in respect of impact stress. The applied impact levels (weight and height) differs between products used on the rock surface (relays and shock tubes) and detonators only to be used in the boreholes. Product which are used on the rock surface must withstand significantly higher impact stresses as they are exposed to falling stones from e.g. tunnel ceilings, than borehole detonators. For borehole detonators impact tests are carried out separately for the two most sensitive parts: the fusehead and the primary charge.

Electronic detonators are used in the same environment and must withstand the same impact stresses. The method is therefore directly applicable on electronic initiation systems. However, for certain electronic detonator designs, there might be new sensitive parts introduced, which also must be tested, e.g. a piezoelectric transducer of an electronic detonator using non-electric shock tubes.

Work Item 35, Method(s) for the determination of resistance to accidental initiation. This standard includes 3 different substandards:

- **Work Item 35 a. Drop resistance of detonator and relay.** The method is directly applicable on electronic detonators as they must withstand the same stress in respect of free fall as conventional detonators.

- **Work Item 35 b. Sensitiveness to electrostatic energy of detonator and relay (electric and non-electric).** Detonators must not be initiated when they are subjected to an electrostatic stress. Electronic detonators are used in the same environment as conventional detonators. However, for electric detonators it is assumed that the safe function of the fusehead is not essentially affected by the electrostatic stress. It is likely that a detonator, which has been subjected to electrostatic stress during transport, storage or connection, will be used afterwards, as it is not possible to identify an electrostatically stressed detonator by visual inspection.

For electronic detonators, the same safety aspects can be adopted, i.e. they must not be initiated when they are subjected to an electrostatic stress. In contrast to electric detonators, it can not be assumed that they will have remained performance after the test, as the electronic chip might be damaged in one way or another. Therefore a function criteria for electronic detonators after the electrostatic stress test needs to be discussed.

- **Work Item 35 c. Electromagnetic resistance of detonator.** Detonators must not be initiated when subjected to an electromagnetic stress. Referring to Work Item 35 b above, the same principles apply for electronic initiation systems in respect of the need of a function test after electromagnetic stress.

Work Item 36. Method(s) for the determination of initiating power output. Detonators must have sufficient output strength in order to be able to initiate the explosives, which they are intended to be used with. The method is directly applicable on electronic detonators as they must meet the same requirements as conventional detonators in this respect.
Work Item 37. Method(s) for the determination of delay accuracy (to apply to pyrotechnic delays only). The main advantage of choosing electronic detonators instead of conventional detonators is the improved accuracy of the delay times.

The deviation of delay times of conventional detonators are related to the burning time of a pyrotechnic charge. The deviation for electronic detonators are caused by lots of more factors depending on the design principle, e.g. reset time of the counter, calibration of the oscillator, temperature influence on the oscillator, correct recognition of the programmed delay time (described further in chapter 2).

The objective of the standard with reference to the demand of the directive is "to ensure that the probability of overlapping of the delay times of adjacent time steps is insignificant". Electronic detonators will presumably meet the requirements in respect of overlapping if they have received the timing information correctly from the blasting machine and if the hardware is working correctly.

Requirements for delay times can be indicated with reference to the fulfilling of the manufacturer’s specification. However a minimum requirement in respect of probability of overlapping needs to be included as for pyrotechnic delays. For certain applications, e.g. cut blasting in tunnelling, the overlapping criteria might not be relevant to consider.

The principle of taking samples for electronic detonators can also be discussed. Electronic detonator are presently far more expensive than conventional detonators. In case of using programmable detonators, testing of complete assemblies of electronic detonators in respect of all delay intervals can be replaced by non destructive testing of the electronics. The bridgewire can in this case be replaced by a dummy load. The same items can be used for testing different interval times.

Work Item 38. Method(s) for the determination of resistance to water and hydrostatic pressure. The applied water and pressure levels are based on relevant levels of detonators subjected to normal use. Electronic detonators are used in the same environment and must withstand the same stresses. The method is therefore directly applicable on electronic initiation systems.

Work Item 40. Method(s) for the determination of mechanical integrity. This standard includes 7 different substandards covering mechanical aspects for detonators, shock tubes, leading wires, connections, crimps and closures. Electronic detonators and their leading wires are used in the same environment and must withstand the same stresses. The methods are therefore directly applicable on electronic initiation systems except for testing according to Work Item 40-e), Resistance to vibration of plain detonator, which is not applicable. The need of testing vibration on plain detonators are related to the risk of explosive charges coming loose from the unsealed plain detonator.

Work Item 41. Method(s) for the determination of safety under extreme conditions. This standard applies to detonators intended to be used at conditions of temperature and pressure, which are outside the range of which the apparatus of the other standards can be used. Special methods and apparatus must be used in this case. If electronic detonators are intended to be used at extreme temperatures and pressures, the method is directly applicable.
Work Item 42. Detonators for use in coal mines or other underground works where flammable gas may be a hazard - Method(s) for the assessment of suitability for use in flammable gases. It is not likely that electronic detonators for use merely in coal mines will be developed. Still if electronic detonators are intended to be used in such environments, the method is applicable, possibly after some modifications.

Work Item 43. Electric detonators - Method(s) for the determination of electrical characteristics. This standard includes 9 different substandards:

- **Work Item 43 a. No/all firing current of electric detonator.** No-fire current of electric detonator is a safety related test defined as the lowest current which will initiate an electric detonator. All-fire current is defined as the electric firing current required to reliably initiate an electric detonator.

The applicability of no-fire current on electronic detonators is depending on the design and connection principle. No-fire current and all-fire current is directly applicable only if the electronic detonators are connected in series and fired with a blasting machine of conventional principle without any coded firing pulses. All-fire current is not applicable in other cases.

For systems using coded pulses for firing command, the electronic chip is a barrier between the blasting machine and the detonator. Assuming that the chip is not fault-tolerant, it is still relevant for safety reasons to discuss the no-fire current (or voltage where applicable) for the bridgewire inside the electronic detonator. The no-fire current/voltage of the bridgewire is therefore of general safety interest and also necessary for comparison with the maximum allowed current/voltage of a measuring device.

- **Work Item 43 b. Series firing current of electric detonator.** Series firing current is a reliability test defined as the lowest constant direct electric current, which will reliably initiate all electric detonators in a series connected round. Same applicability is valid for series firing current as for all firing current described above.

- **Work Item 43 c. Firing pulse of electric detonator.** No-fire pulse is defined as the lowest electrical pulse which will ignite an electric detonator. The applicability of no-fire pulse is the same as for no-fire current described above.

All-fire pulse is defined as the electric firing pulse required to reliably initiate an electric detonator. The applicability of no-fire pulse is the same as for all-fire current described above.

- **Work Item 43 d. Total resistance of electric detonator.** It is only relevant to define the electric resistance of an electronic detonator measured between both ends of the leading wires if this is a parameter related to the use of a specific system. E.g. if a measuring device presents the number of connected detonators in a round based on the total resistance value, this parameter needs to be tested.

- **Work Item 43 e. Flash-over voltage of electric detonator.** Flash-over voltage is defined as the minimum direct voltage, which will give electrical breakdown between the electric detonator’s conductor system and the metal casing. The requirement level is related to the voltage level delivered from the blasting machine to the detonators. The highest voltage of the blasting machine must be lower than the minimum flash-over voltage of the detonator with a certain safety margin. As electronic detonators might use
lower system voltages than conventional detonators, the requirement of the minimum flash-over voltage needs to be adjusted to a relevant level in such cases.

It is also relevant to discuss an upper level of the flash-over voltage, i.e. a level where flash-over reliably occurs, for preventing high electrostatic voltages to be charged in the fire system during loading of boreholes. The relevance for electronic detonators in this respect is the same as for Work Item 35 h, Sensitiveness to electrostatic energy of detonator and relay (electric and non-electric) described above. It must be demanded that a detonator which has been subjected to a flash-over will have remained function afterwards. A function test will have to be included to cover this demand.

- **Work Item 43 f. Sensitiveness to stray currents of electric detonator.** Stray currents can be induced in the leading wires of a detonator from adjacent power lines and ground currents. It is normally considered as a safety related test, e.g. no detonation must occur. However it must be demanded that a detonator which has been subjected to stray currents will have remained function afterwards. A function test will have to be included to cover this demand.

- **Work Item 43 g. Insulation resistance of leading wire.** The insulation of leading wires need to be sufficient in order to minimize the leakage current. The demand for this parameter is related to the actual system voltage of the electronic initiation system. Requirements therefore needs to be modified with reference to the applied system voltage.

- **Work Item 43 h. Capacitance of leading wire.** The capacitance of the leading wires must be limited in order to prevent high energy from being charged in the wire system during loading of boreholes (see also Work Item 43 e above). The method, related to a safety demand for prevention of unintended initiation, is applicable on leading wires for electronic detonators, possibly after some modifications.

- **Work Item 43 i. End insulation of leading wire.** Demands for end insulation is needed for the purpose of preventing the wires from being directly touched, which might cause an electrostatic discharge. Furthermore, depending on safety philosophy, shorted or open wires and the end of the wires are preferred in different countries. The method, related to a safety demand for prevention of unintended initiation, is directly applicable on leading wires for electronic detonators.

**Work Item 44. Non-electric detonators - Method(s) for the determination of shock tube characteristics.** This standard includes 2 different substandards both directly applicable only for electronic detonators supplied with non-electric shock tube system:

- **Work Item 44 a. Shock wave velocity of shock tube.** The velocity of the shock tube is verified against the nominal value stated by the manufacturer.

- **Work Item 44 b. Non-conductivity of shock tube.** Non-conductivity of shock tube is safety related, i.e. it is intended to ensure that shock tubes which are claimed to be non-electric really are non-electric.
Work Item 45. Definitions and requirements for devices and accessories for reliable and safe function of detonators and relays. This standard includes 3 different substandards:

- **Work Item 45 a.** Extra requirements for use in coal mines or other underground works where flammable gas may be a hazard. It is not likely that electronic initiation systems for use merely in coal mines will be developed. Still if electronic initiation systems are intended to be used in such environments, the method is applicable, possibly after some modifications.

- **Work Item 45 b.** Blasting machines, test apparatus, resistance meters, warning apparatus, ignition cables. Demands for blasting machines in respect of environmental stresses, can be adopted also for electronic detonator devices (i.e. climatic, mechanical and electrical), mainly due to the fact that they are used in the same environment as devices for conventional detonators. (However because of the complexity of electronic initiation systems, other tests and evaluation methods need to be developed.)

- **Work Item 45 c.** Transfer capacity of relay and coupling accessory. This method defines function tests of the safe transfer between different components of a non-electric initiation system. It is therefore directly applicable only for electronic detonators supplied with non-electric shock tube system.

**Work Item 57. Definitions, methods and requirements for electronic initiation systems.** In this standard all necessary tests for electronic initiation systems will be specified. References will as far as possible be given to other applicable standards of the work programme of CEN/TC 321/WG 4. Furthermore new test and evaluation methods need to be included in this standard.
5 Conclusions and Recommendations

5.1 Conclusions

The initiation systems with electronic time delay which are available on the market today fall into two categories:
- systems where the main function of the electronics is to improve the accuracy of the delay time;
- systems where the electronics facilitate both accuracy in delay time and a higher degree of flexibility through programmable delay times.

Programmable delay times offer advantages to the rock blaster. An exact and free choice of delay times makes it possible to design well-adopted blasting patterns. It also reduces the need to keep a large stock of detonators for every delay time in use. However, the technique of programmable delays must be user-friendly and easy to learn for a rock blaster who is used to working with conventional detonators.

Failures of electronic systems may be the result of faults in hardware or software; user faults and environmental stress may also cause failures. Good design and proper development methods will help to reduce the risk of failures in complex electronic systems.

Very dangerous situations may be caused by failures of electronic detonator systems as well as conventional detonator systems. The systems available today have all safety measures employed. However, there is always a slight risk remaining. In some aspects, the electronic systems may be considered to achieve a higher safety level than conventional detonators with pyrotechnic delays. On the other hand, new sources of possible faults in electronic software and hardware are introduced.

It is not possible to give a general statement if the safety of the initiation system is enhanced or reduced by the introduction of electronics in the detonators. The general advice is that electronic detonator systems must be treated with the same caution as all blasting equipment.

The possibility of failures of the electronics shall be considered when assessing an electronic detonator system; a fault must not cause a dangerous situation.

Fault-tolerance requires some kind of redundancy to be employed. The efforts for fault-tolerance may include microprocessors working in parallel, redundant software or other redundancy in electronic hardware. Such measures are not always affordable to achieve a product attractive on the market.

Even if the electronics of the detonator are not fault tolerant, the safety level may be enhanced by the electronic circuits used. They may act as a barrier between the leading wire and the bridgewire of the detonator. The barrier can be both physical (to block high voltages and currents) and logical (to block interference from being interpreted as an initiation order).

If fault tolerance is not affordable in practise, safety must be enhanced by other design measures, proper operating procedures, safety functions and functions for self-checking in the electronic initiation system.
A misuse which is very likely to happen, is to mix different electric or electronic detonator systems or parts of them e.g. to use a blasting machine for conventional detonators together with electronic detonators or vice versa. It may also happen that a blasting machine from one manufacturer of electronic detonators is connected to detonators from another manufacturer. The result is not always easy to foresee. It is more complex than calculating all-fire current and no-fire current of a conventional initiation system. The mixing of different systems will have to be studied further.

5.2 Evaluation and Testing Principles

The electronic initiation systems introduce a high level of complexity and possibilities to add functions which are impossible to implement in conventional initiation systems. Testing only will not be enough to cover all possible aspects and fault modes. The traditional tests for initiation systems based on pyrotechnic delays will have to be supplemented. Functional tests and evaluation of the design details will have to be introduced. It is important that the established level of safety is not reduced by the use of new technology.

Before an evaluation of safety can be conducted, the evaluators must know the design and the functions of the system. This requires a considerably higher effort than for a conventional system. The safety principles must be known to the evaluator, and the safety-related parts of the control system will have to be identified.

Functional tests will be important for initiation systems with electronic detonators. The electronics will facilitate much more functionality than in the conventional initiation systems.

Any claims for inherent safety or fail-safe behaviour will have to be assessed. This can be done by a Fault Mode and Effects Analysis (FMEA) of the electronic hardware components.

Software is an important component for the safety of many systems. The safety-related software will have to be evaluated by analysis and test. However, software can never be regarded as fault-free. A possible logical fault in the software must not cause a critical defect of the initiation system. One way to reduce the risk of software failure is to employ redundant software (i.e. two different pieces of software) performing the same control task.

The environmental stress tests can to a large extent be the same as for conventional initiation systems. (See chapter 4.) The requirements to withstand environmental stress are the same independent of the technology used for the design.

The blasting machine and the measuring equipment contain electronic hardware of low complexity as well as high complexity, microcomputer hardware and software. They will certainly be the most complex devices of the initiation system. An evaluation should include such issues as
- the risks of unintended initiation by the blasting machine.
- the risks of unintended initiation by the measuring equipment.
- user-friendly software for programming of detonators should reduce the risk of incorrect programming.
5.3 Recommendations for Future Work

A harmonised approach on safety of initiation systems using electronic detonators is needed. Several manufacturers present systems on the market today, but the design principles are not the same. A free movement of explosives within the European Union requires a member country to accept approvals of initiation systems made by a notified body in another member country. That will be hard if there is not a common approach on safety requirements and how to validate safety.

As described earlier in chapter 4, working group 4 (WG 4) of CEN/TC 321 is dealing with standards for detonators and relays. The work programme of WG 4 includes 15 standards of which one is addressed for electronic initiation systems. In order to prepare a draft European standard for electronic initiation systems, fulfilling the Essential Safety Requirements (ESR) of the EC-commission directive 93/15/EEC on Explosives for civil uses, pre-normative research is necessary. Relevant test and evaluation methods in the field have to be established.

The pre-normative research should focus on the following objectives and considerations:

- Relevant risk factors and causes of failure including safety and reliability aspects related to risks of unintended initiation, misfire and incorrect function.

- Possibility of coordination with reference to other methods for detonators within the work programme of CEN/TC 321/WG 4 with modified criteria in some cases

- To aim at uniform minimum safety level compared to conventional electric and non-electric detonators in other standards.

- To cover different present technical system solutions either with general demands or special demands for different systems.

- Possibilities for non-destructive testing due to high costs of electronic detonators.

- The possible need for evaluation of safety-critical electronic hardware and software both in detonators and in blasting machines/programming units.

To fulfil the objectives and considerations above the following work needs to be carried out:

a) Establishment of general requirements fulfilling the ESR of the directive 93/15/EEC and based on possible causes of failure in current risk analysis. Possible supplementary risk analysis might be needed. The relevance of the requirements has to be checked for different technical system principles. Some systems might introduce new risk factors, which need to be considered.

To quantify the requirement levels, the principles of defects described in chapter 2 (critical, major and minor defect) can be used. The causes of failure described in chapter 2 need to be considered (e.g. hardware design fault, electric environmental fault).
Requirements need to be considered for all parts of the initiation system, i.e. electronic detonators, blasting machines, programming units, test apparatus, accessories and wire systems.

b) Establishment of definitions considering different present technical system solutions.

c) Establishment of test methods, evaluation methods and design demands, which are related to the defined requirements in clause a) above.

- Identification of test method standards according to the work programme of CEN/TC 321/WG 4, which are directly applicable also for electronic initiation systems as described in chapter 4 (e.g. thermal stability, initiating energy output of detonator).

- Identification of test method standards according to the work programme of CEN/TC 321/WG 4 which are applicable after some modifications as described in chapter 4 (e.g. delay time accuracy, electrostatic energy test including a new function criteria, no-fire current/voltage). The modification details shall in this case be defined.

- Establishment of relevant new test methods (e.g. energy storage capacity in the detonator, self discharge time, dynamic pressure test of the electronics, function tests possibly related to the maximum specified system capacity).

- Establishment of evaluation methods and design demands will be an important part of the standard mainly due to the complexity of the systems (e.g. safety demands on the software in the programming unit/blasting machine, safety margins of voltage/current from measuring equipment compared to no-fire voltage/current of the bridge wire, fault durability, possibility of checking the blasting round connection). Methods for theoretical safety analysis of the software and the electronic hardware therefore have to be considered.

d) Establishment of information to be supplied by the manufacturer to the customer will be necessary especially related to the function and specified capacity limits of the system, e.g. maximum number of detonators in a round, maximum length of a bus wire, restrictions for use with other systems (electric detonators), discharge times etc.
5.4 Recommendations for Authorities, Manufacturers and Users

As stated above (see chapter 5.1), safety must be enhanced by design measures, proper operating procedures, safety functions of the initiation system and functions for self-checking in the initiation system.

5.4.1 Design Measures

Design measures are measures implemented in the design to increase the level of safety. Examples of such measures are:

- Fault tolerance.
  Faults in hardware or software must not lead to a dangerous situation. This may be achieved by redundancy (e.g. two separate hardware channels).

- Voltage and current levels for testing.
  The voltage and current levels used at testing are chosen to be sufficiently low. The test current must be lower than the no-fire current of the fusehead.

- Operation at reduced voltage level.
  The normal operating voltage supplied to the detonators from the blasting machine should be considerably smaller than the voltage level needed for detonation. The detonators will then during all the time up to charging of the main capacitor operate at a voltage which is very unlikely to cause an accidental detonation.

- Initiation order.
  The measurement equipment must not be capable of issuing a blasting order on the communication line to the detonators. The software must not contain any such function.

- Mechanical strength.
  The detonator (especially the capacitor, the electronics and the fusehead) must have sufficient mechanical strength in order to maintain reliable function after dynamic pressure stress from the detonation of an explosive in an adjacent borehole.

5.4.2 Operating Procedures

Good operating procedures will increase safety and should be planned for - storing
- programming
- loading
- connection
- charging
- blasting
- exception handling (such as interruptions or misfires)
In general, higher demands of education and training of users must be stressed, due to the higher complexity of using most electronic initiation systems.

Many procedures are the same as when using detonators with pyrotechnic delay, but need to be stressed also for electronic detonators. Examples of operating procedures are:

If the delay is programmed into the detonator before loading, it shall be possible to read the delay time on the detonator. (E.g. by markings on a label.)

If the delay times are depending on the correct connection order of the detonators, higher demands for blasting plans and connection procedures are introduced.

Never to let people be present in the blasting field when the detonators are connected to the blasting machine.

Never to enter a blasting field to look for misfires before all electrical energy stored in the electronic detonators is discharged.

Never to use electronic detonators from one manufacturer together with a blasting machine from another manufacturer.

Never to mix electronic detonators from different manufacturers in the same round.

Never to use electronic detonators together with a blasting machine intended for use with conventional detonators.

5.4.3 Safety Functions

Electronic initiation systems are far more complex than conventional initiation systems. The electronics make it possible to add new functions to the system. Safety functions will provide additional safety to the system, and make it possible to detect faults before they cause failures of the system.

Examples of such safety functions are:

Discharging of detonator energy.
If a charged detonator is disconnected and left idle for a certain period of time, the stored electrical energy must be discharged. It is not advisable to handle armed detonators which accidentally may be triggered to detonate.

Self-contained detonator.
Each detonator must be capable to operate in a self-contained way after the first detonator of the round has detonated. The first detonation can destroy the communication line between the blasting machine and the detonators. The delay timer shall continue to run, and the energy supply in the detonator must be sufficient for operation until the delay time has expired. The discharge time must therefore be properly set in relation to the longest delay time.
Time-out in blasting machine.
If a charge order from the operator is not followed by a firing order within a
certain period of time, the blasting sequence should be interrupted.

Time-out in detonator.
The blasting machine maintains communication with the detonators at a certain
interval of time. If a detonator loses communication with the blasting machine for
a time period longer than the time-out interval, the detonator sends out an alarm
and disables (i.e. discharges) itself.

Interrupted blasting sequence
The initiation system should include possibilities of interrupting the blasting
sequence after the firing order has been sent, especially if the system uses long
delay times between firing order and detonation. If this possibility is not included,
the risk of getting people inside the danger zone increases. This problem is
previously known from use of detonators with safety fuses.

Confirmation of connected detonator.
The blasting machine may verify that all detonators are operational and connected
to the blasting machine. Two-way communication or load check by resistance
measurement are examples of how to confirm the number of connected detonators.

Confirmation of programmed delays.
The delay time of a certain detonator may be verified by the blasting machine. The
firing programme is possible to verify before charging and blasting are
commenced.

Monitoring of communication.
The signals sent to the detonators may be fed back into the blasting machine to
monitor the signal quality. If the returned message is not identical to the
transmitted message, there is a risk that some detonators have not received it.

Calibration of timer.
The timer is calibrated to make sure that correct delays are generated. The
important time-base to calibrate may be in the detonator or in the blasting machine
depending on how the time delay is controlled.

Coded initiation order.
The initiation order from the blasting machine to the detonators may be coded.
This is to avoid any interference to be interpreted as an initiation order.

5.4.4 Functions for Self-Checking

One of the advantages of an electronic system is the possibility to introduce functions
which check the functionality of the system itself. This may be more powerful than only
a visual inspection or an instrument check. Two-way communication facilitates each
connected detonator
- to be identified by the blasting machine.
- to read and report its delay time to the blasting machine.
- to check its functions and report the result to the blasting machine.
Faults in an electronic initiation system may be detected before a failure is caused, and
the system can be shut down. The blasting sequence must continue only after proper
action and manual reset by the operator. A state-diagram of possible self-checking
procedures is given in figure 5.1.

![State-diagram](image)

Figure 5.1. Self-checking of a component used in an electronic initiation system.

Examples of self-checking functions are:

Start-up check of the blasting machine.
The blasting machine may check the operation of its microprocessor, its memory
and other electronic hardware. Checks of the instruction set of the microprocessor
and checksumming of memory are examples of such checks. Checking is
performed at start-up and operation is not allowed to start before the check has
been passed.

Run-time check of the blasting machine.
Similar as the start-up check but performed as a background task during the
operation. An alarm is given when a fault is detected, and the operation is stopped.
(A safe state is entered.)

Start-up check of the electronic detonator.
The detonator may check the operation of its electronic hardware (microprocessor
etc.). Checks of memory, microprocessor instruction set and voltage regulation are
examples of such checks. Checking is performed at start-up and operation is not
allowed to start before the check has been passed.

Run-time check of the electronic detonator.
Similar as the start-up check but performed as a background task during the
operation. An alarm is given when a fault is detected, and the operation is stopped.

Checked storing of delay information.
The delay information stored in the detonator is protected against accidental
changes. This can be achieved by checksum, parity bit, double storing in memory
etc.
Coding of transmitted messages.
All messages sent from the blasting machine are coded, i.e. the information is arranged in a special format. If this format is not followed, the message will be ignored.

Checking of transmitted messages.
All messages sent between the blasting machine and the detonators may include checking facilities to detect distorted messages. Such a check may be implemented by a checksum in the message.

Checking of timer operation.
The operation of the delay timer is checked to make sure it is possible to operate.

Checking of bridge-wire
The resistance of the bridgewire is measured to check for an interruption which would cause a misfire.

Voltage-level checking.
All detonators may check that the level of the supplied voltage is high enough to assure a proper ignition.

Checking of capacitors.
All detonators may check that the capacitances of capacitors used for storing energy in the detonators are high enough to ensure enough energy being stored.
Appendix A. References

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