

Assessment of inadvertent initiation of bridge wire electro-explosive devices by radio-frequency radiation — Guide

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/31/-/602, Radio-frequency radiation-induced ignition and detonation, which has the responsibility to:

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- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

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English version

**Assessment of inadvertent initiation of bridge wire
electro-explosive devices by radio-frequency radiation –
Guide**

Evaluation de la création
par inadvertance de dispositifs
électro-explosifs par pont métallique,
par rayonnement de radiofréquence –
Guide

Leitfaden zur Verhinderung
des unbeabsichtigten Auslösens
einer Zündeinrichtung mit Brückendraht
durch hochfrequente Strahlung

This Technical Report was approved by CENELEC on 2004-08-28.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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Foreword

This Technical Report was prepared by the Technical Committee CENELEC TC 31, Electrical apparatus for explosive atmospheres - General requirements.

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Introduction

Electromagnetic waves produced by radio-frequency (RF) transmitters (e.g. radio, television and radar) will induce electric currents and voltages in any firing circuit including leading wires of the electro-explosive device (EED) on which they impinge. The magnitude of the induced current and voltages depends upon the configuration of the firing circuit and leading wires relative to the wavelength of the transmitted signal and on the strength of the electromagnetic field. If the induced current which is transferred to the EED is in excess of the no fire current then the EED could initiate. This European Technical Report provides a systematic approach to assist transmitter operators, quarry managers and all others concerned with a logical method for the assessment and elimination of the initiation of EED by RF. The assessment procedures contained in this European Technical Report are based on measurements of the powers and current that can be extracted from typical firing circuits and leading wires and on the physical electrical parameters of various types of EED.

1 Scope

This European Technical Report provides guidance on assessing the possibility of inadvertent extraction of energy from an electromagnetic field propagated from radio frequency (RF), radar or other transmitter antennas and the coupling of this energy to an electro-explosive device (EED) in a manner capable of causing initiation. The frequency range covered by this European Technical Report is 9 kHz to 60 GHz. This European Technical Report only applies to bridge-wire devices which are directly initiated by radio frequency current and does not apply to special detonators, for example, electronic detonators. It does not cover the similar hazard arising from electromagnetic fields generated by other means, for example electric storms, electricity generating plant or power transmission lines.

This European Technical Report does not apply to the following equipment:

- air bag igniters for automotive applications (including the igniters before they are fitted);
- special pyrotechnic devices;
- pyromechanisms;
- igniters for fireworks;
- special military devices;
- special safety equipment.

NOTE The methods of assessment from 9 GHz to 60 GHz are based on extrapolation of data for frequencies below 9 GHz.

2 Normative references

No normative references are made in this standard.

3 Terms and definitions

For the purposes of this European Technical Report the following terms and definitions apply.

3.1

duty cycle

product of pulse duration (in seconds) and the pulse repetition frequency (in pulses per second)

3.2

electro-explosive device (EED)

one shot explosive or pyrotechnic device initiated by the application of electrical energy

NOTE EED is used to refer to either a single electro-explosive device or several devices, to comply with general practice within the industry.

3.3

hazard

potential source of danger to life, limb or health, or of discomfort to a person or persons, or of damage to property

3.4

safe distance

distance outside which it is considered that there is no potential hazard

3.5

no-fire energy/power/voltage/current

maximum energy or steady state power/voltage/current that will not cause initiation of the most sensitive EED of any particular design

NOTE The manufacturing tolerances permitted during the production of EED will cause normal statistical variation in their firing characteristics. The most sensitive EED permitted by this variation sets the appropriate no-fire level, which is generally accepted as a probability no greater than 0,01 %, with a confidence level of 95 %.

3.6

round of charges (shot)

one or more primed explosive charges or shots, for example main charge, primer (if used) and detonator

3.7

toe shot

shot designed to clear the foot of a face, for example a quarry face

3.8

hazard area

area, of any shape, containing the transmission source or sources and within which the radiation magnitude exceeds the designated hazard threshold

3.9

hazard threshold

mean power flux density or field strength that would permit only a negligible probability of EED initiation

3.10

exploder

means whereby a round of charges (shot) is fired electrically

3.11

equivalent isotropically radiated power (EIRP)

product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain)

3.12

effective field strength

value of electric field strength due to a single transmitter which is derived from the transmitter characteristics, modulation factors (see 6.5) and distance, and is used for the calculation of extractable power

3.13

antenna gain

gain produced by an antenna concentrating radiation in a particular direction

NOTE 1 The gain of an antenna is always related to a specified reference antenna.

NOTE 2 The gain, G , of an antenna in a particular direction is given by the equation:

$$G = \frac{R}{A}$$

where

R is the power in Watts, W , that should be radiated from the reference antenna;

A is the power in Watts, W , that should be radiated from the given antenna to give the same field strength at a fixed distance in that direction.

NOTE 3 The gain, which is often expressed in logarithmic form, is stated in decibels.

3.14

far field

region, distant from the transmitter, in which the field strength is inversely proportional to distance in the absence of ground reflection

NOTE The inner limit of the far field is generally regarded as the distance d from the transmitter defined as follows. For frequencies up to and including 30 MHz, $d = 8H^2/\lambda$ where H is the height of the top of the antenna above ground and λ is the wavelength. At frequencies above 30 MHz, $d = 2W^2/\lambda$ where W is the width of the antenna.

3.15

near field

region close to the transmitter, which lies within the far field region

NOTE In the near field region the dependence of the field strength on distance is complex and mutual coupling effects can also affect the value of extractable power.

3.16

leading wire resistance

total d.c. resistance of the leading wires excluding that of the EED itself

3.17

bridge wire resistance

internal d.c. resistance of the EED alone

3.18

safety resistor

resistor or resistors placed within the casing of an EED in order to desensitize it to the external electrical environment

4 Symbols and abbreviations

4.1 Modulation codes

AM	Amplitude-modulated speech or music transmission. Carrier power quoted
MCW	Amplitude-modulated tone transmission. Carrier power quoted
TV	Amplitude-modulated video transmission. Peak power quoted
R ()	Pulse-modulated radar transmission. Peak power quoted. The number in brackets indicates the pulse duration in s where known
FM	Frequency modulation
FSK	Frequency shift keying
GFSK	Gaussian frequency shift key modulation
SSB	Single sideband transmission. Peak envelope power quoted
CW	Continuous wave
MSK	Minimum shift keying
GMSK	Gaussian minimum shift keying

CDMA	Code division multiple access.
PCM	Pulse code modulation
PSK	Phase shift keying
PM	Phase modulation
DQPSK	Differential quadrature phase shift keying.

4.2 Polarization codes

V Vertical polarization.

H Horizontal polarization.

V/H Either vertical or horizontal polarization, or both simultaneously.

5 General considerations

5.1 Radio-frequency hazard

For radio-frequency hazard assessment detailed consideration should be taken of the conditions that have to be satisfied simultaneously for the hazard to exist. These are as follows:

- a) an electromagnetic field of sufficient intensity;

NOTE 1 An electromagnetic field of sufficient intensity may be generated by a fixed/mobile or portable transmitter, the magnitude of the field depending upon the transmitted power, the antenna gain and the proximity of the site under consideration.

NOTE 2 Intense electromagnetic fields are also generated by the intentional radio frequency sources in industrial, scientific and medical (ISM) equipment. Field strengths in the order of 10 V/m may be present in the near vicinity of the equipment.

Typical characteristics of industrial equipment are:

2,5 GHz to 10 kW	}	industrial microwaves
915 MHz to 100 kW		
27 MHz to (10 to 50) kW	}	welding or drying techniques
13,56 MHz to (10 to 50) kW		

- b) a means of extracting power from the electromagnetic field;
- c) an EED in a situation such that it can accept power or energy from the extracting device.

The procedures contained within this European Technical Report for assessing the presence of a potential hazard are based on a number of reasonable “worst-case” assumptions. They are based upon both experimental evidence and engineering judgement. Taken together these give a substantial margin of safety due to the extremely low probability of concurrence of all the worst-case factors. No extra, arbitrary, safety factors are included.

All conducting materials behave as receiving antennas, but the magnitude of the induced current and voltage depends upon the circuit configuration, that is, whether the EED is in a firing circuit or by itself. Experience gained indicates that for frequencies below 7 MHz it is the loop firing circuit which is the most sensitive whereas for higher frequencies it is the EED and its leading wires alone. The behaviour of these circuit configurations is described in Clause 7.

5.2 Philosophy of the systematic method of approach

A potential hazard only exists in relatively few locations, with only a small number of incidents reported that are possibly attributable to this cause.

This European Technical Report is based on a series of graded assessments, each requiring a progressively more detailed analysis.

The initial assessments are designed to eliminate from further consideration those locations where it is highly unlikely that a hazard exists. They are based on “realistic worst-case” estimates of the minimum distance of safe approach around different classes of transmitter within which a hazard might exist from the presence of a particular circuit configuration in this area.

For land based operations, if the initial assessments given in 9.3 indicate that a hazard might exist, the full assessment procedure given in 9.4 should be followed. For offshore operations the assessment in 9.7 should be followed. These provide a method of computing the field strength available from the transmitters, based on detailed information about the transmitters and their location relative to the site. The calculated field strength should then be compared to those that are required to initiate an EED in various circuit configurations, whether in a loop firing circuit or with the leading wires acting as a dipole.

When this systematic assessment procedure is followed, it will quickly become apparent whether the available information is adequate for an assessment to be made with a high degree of confidence or whether additional information is required from practical on-site measurements (see Clause 10 and Annex B). If doubt exists, then expert opinion should be sought (see Annex C).

The assessment procedures recommended in Clause 9 apply generally to most circumstances. For offshore and land based well-perforating operations the special considerations described in 7.3, 9.5.5 and 9.6.3 should be taken into account.

5.3 Responsibility for making the hazard assessment

The radio-frequency (RF) environment is becoming increasingly severe, with the proliferation of transmitting sources and increased transmitter powers and the exploitation of new techniques.

NOTE 1 Legislation, (for example in the UK see [1]) requires that employers safeguard both their employees and others who may be placed at risk by their activities. Hence, both operators of RF transmitters and users of EED have a responsibility to ensure safe operation.

NOTE 2 Particular locations such as mines and quarries may exist where additional responsibilities are placed on the owners and managers.

Operators of a proposed site in which EED are to be used should request details from the transmitter operators about relevant transmitters in the locality of the site. The transmitter operators should include details of transmitters for broadcast, commercial, military, air traffic and emergency services such as police, fire and ambulance. The site operator should then use the assessment procedures given in this European Technical Report, if necessary in consultation with the transmitter operators concerned.

Similarly, an operator of a proposed new (or altered) transmitter should contact all operators of sites where EED are used within the minimum distance of safe approach for the transmitter, and use the procedure given in this European Technical Report to assess the potential hazard at each location.

Where both the site and the transmitter already exist but an assessment is required, the site operator should be held responsible for ensuring that the assessment is made. If for some reason relevant information cannot be made available to the body responsible for the assessment, the responsibility for having the assessment carried out should be assumed by the body unable to release the necessary information.

NOTE 3 As an aid to those who need to make a hazard assessment but do not have the necessary technical resources, a list of sources of information and specialist organizations capable of providing consultation or test facilities is given in Annex C.

5.4 Recommended practices for radio silence in offshore operations

The position adopted by many offshore operators has been to switch off all transmissions from the installation during the surface preparation of the explosive tool until its immersion in the well at 70 m below sea bed level. At this point services would be restored until the explosive tool was returned to a similar depth on the upward journey when all services would again be cut off. Following its removal from the well and inspection to ensure its safe condition, services would be restored provided no further explosive handling was to take place.

However, too great a reliance on all-embracing curtailment of services can itself present a potential hazard to structures which employ radio communication for safety reasons and as an integral part of product transportation systems (pipelines). The identification of these difficulties has highlighted the need for the hazard to be more accurately quantified in order to minimize the disruption of other necessary operations and to avoid the creation of further potential hazards.

6 Transmitters and transmitter output parameters

6.1 Types of transmitters

This clause provides information on various types of transmitter and transmitting systems. This information is necessarily rather brief for certain types of radar and other military equipment but basic details are given and further information may be sought from the specialist organizations listed in Annex C. Typical types of antenna installations are shown in Figure D.1.

6.2 Frequency range

The main frequency range covered is 9 kHz to 60 GHz. The types of transmitter considered include the following:

- a) radio and television broadcast transmitters in specific bands in the range 0,15 MHz to 1 000 MHz;
- b) fixed and mobile transmitters for communication purposes, private, commercial and amateur, in specific bands above 0,4 MHz and for military use above 0,15 MHz;
- c) radar, in specific bands at 220 MHz, 600 MHz and above 1 GHz;
- d) navigational equipment, non-directional beacons, etc., from 9 kHz upwards.

6.3 Transmitter output power

Transmitter output power from several watts up to megawatts may be encountered depending on the frequency range and the application. The method of specifying the power varies, which is significant for the hazard assessment when highly directional antennas are in use and when considering different modulation systems. In general, values are specified in the technical documentation for either the carrier or peak power output from the transmitter together with the antenna gain, although the product of the two is often quoted in the technical documentation to give the equivalent isotropically radiated power (EIRP).

6.4 Antenna gain

The reference antenna is often an isotropic antenna that radiates uniformly in all directions. Although this is a purely hypothetical concept it is nevertheless very useful for reference purposes. When the gain of an antenna relative to an isotropic reference antenna is stated in decibels it is denoted by dBi. In practice, the gain of an antenna is often expressed relative to a half-wave dipole which itself has a gain of 1,64 (or 2 dB) relative to an isotropic antenna. In special circumstances other reference antennas may be used, for example a short monopole. It is therefore important that the reference antenna is correctly specified. The maximum gains for typical antennas are included in Table D.1, Table D.2 and Table D.3.

6.5 Modulation factors

6.5.1 General

Most transmissions are modulated in order to convey information or to enable them to carry out specific tasks (for example, radar). The characteristics of the principal modulating systems are described in 6.5.2 to 6.5.5. A modulation factor, m , is necessary for calculating the effective field strength E (see 9.4.3). Modulation factors are listed in Table 4 for different types of modulation.

NOTE Radio-frequency transmissions may be unmodulated, in which case the radiated power is constant and the quoted power in the technical documentation should be used for assessment purposes. Such transmissions are sometimes referred to as continuous wave (CW).

6.5.2 Frequency modulation (FM)

The frequency of the transmission is varied to carry the information but the output power remains constant as with CW transmissions. Frequency shift keying (FSK) and gaussian frequency shift keying (GFSK), minimum shift keying (MSK) and gaussian minimum shift keying (GMSK), are forms of frequency modulation. Phase shift keying (PSK) and phase modulation (PM) are treated similarly in that no allowance for modulation is necessary since the output power is not affected by the modulation.

6.5.3 Amplitude modulation (AM)

6.5.3.1 General

The amplitude of the transmission is varied to carry the information. The latter may consist of speech or music or coded transmission or it may be a television picture waveform.

6.5.3.2 Speech and music

When speech and music are transmitted, the power quoted in the technical documentation is that of the unmodulated or carrier transmission but the mean power at the modulation peak may be up to 50 % greater when the speech or music is at its loudest volume. Since EED respond to mean power, it is necessary to make some allowance for the power increase when making an assessment; this may be done by assuming an effective field strength which is greater than that due to the unmodulated transmission. As a result of experience gained with amplitude modulated broadcast transmitters, a modulation factor, m , of 1,15 should be used for calculations of effective field strengths.

6.5.3.3 Coded transmissions

A version of amplitude modulation used for Morse and other coded transmissions is known as modulated continuous wave (MCW). For modulated continuous wave, whereby the carrier is fully modulated by a continuous tone, a modulation factor, m , of 1,22 should be used.

6.5.3.4 Television transmissions (TV)

For television transmissions the peak power is usually quoted in the technical documentation but in this case no allowance for modulation is necessary, because the mean power is approximately equal to the peak power.

6.5.4 Single sideband (SSB) operation

For single sideband (SSB) operation the peak envelope power is usually quoted in the technical documentation and a value of 0,71 for the modulation factor, m , should be used.

6.5.5 Pulsed radar

Pulsed radar consists of pulses transmitted at frequent intervals. The transmissions are characterized by a peak power, P_o , a mean power, P_m , a pulse duration t (in s) and a pulse repetition rate of n pulses per second. These are related by the equation:

$$P_o = \frac{P_m}{nt}$$

where

nt is the duty cycle.

Since the interval between pulses is less than the thermal time constant of bridge wire EED, the mean power, P_m , should be calculated and used for assessment purposes.

7 Circuits for blasting and well perforation

7.1 General

Voltage and current may be induced in a metal object or wire in an electromagnetic field. When sufficient voltage and current is transmitted to the initiating device of an EED such as the bridge wire, the EED might initiate. The source of RF power for the EED is in effect an antenna situated in the incident field. The antenna configuration may be formed by the leading wires of the EED itself or by the blasting circuit.

For analogy with simple antenna types, the leading wires of an EED may be considered as a dipole antenna when these wires are separated to form a blasting or well-perforating circuit. After connection the circuit may be considered as a loop antenna.

For the optimum transfer of voltage and current it is essential for the antenna to be tuned. However, even for large loop circuits, untuned loops can carry voltage and current.

Experience gained indicates that below 7 MHz it is the loop which is the most sensitive circuit, whilst at higher frequencies it is the EED and its leading wires alone.

7.2 Typical blasting circuit layouts

7.2.1 General

Whilst in theory an infinite number of blasting circuit layouts are possible, in practice they may be divided into five broad types:

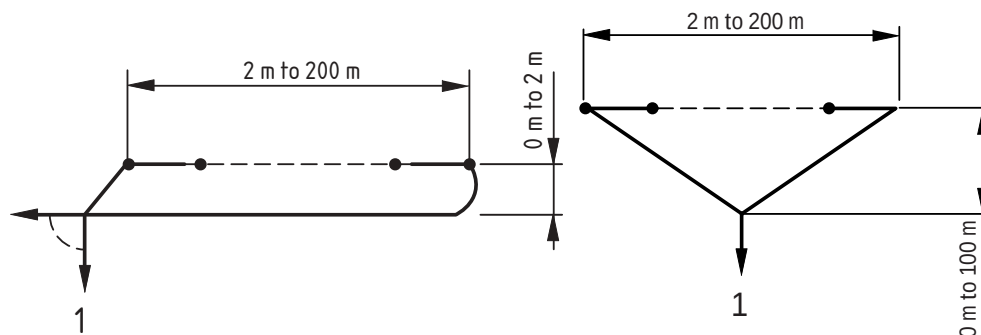
- a) extended line blasts;
- b) benching or 3-dimensional blasts;
- c) multipattern blasts;
- d) shaft sinking;
- e) demolition.

These layouts are briefly considered in terms of methods of connecting up the shotholes one to another, of connecting up the whole blast to the shotfiring cable, and of overall dimensional variations that might reasonably be expected to occur in the field.

Figure 1, Figure 2, Figure 3 and Figure 4 show the extremes of circuitry that are known to occur, although the vast majority of practical circuits lie between the two extremes.

7.2.2 Extended line blasts

The simplest version of this blast pattern is a row of single holes along a quarry face. For example, between two shotholes and 100 shotholes the layout would be as in Figure 1.



Key

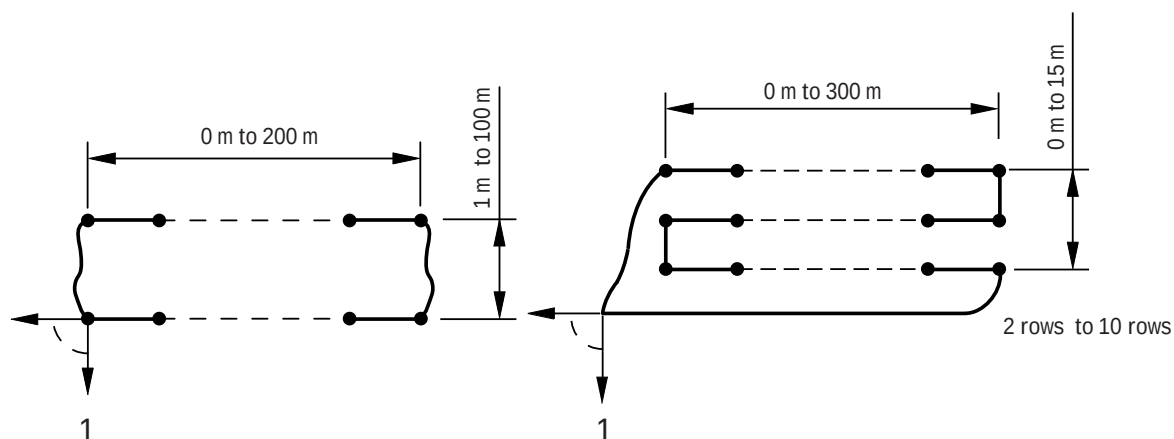
1 Shot firing cable to exploder (30 m to 100 m)

a) Shotfiring cable connected at end of a row

b) Shotfiring cable connected anywhere along the row

Figure 1 — Typical single extended line blasting circuits (plan view)

In Figure 1 the holes, from 0,5 m to 60 m deep, may be either top or bottom primed, with essentially one or two detonators on the surface or from one to 10 detonators down the holes. In the case of Figure 1b) the connection to the shotfiring cable may be made anywhere along the line of holes. Other situations might arise where more than one row of holes might be connected up to form a single blasting circuit, giving rise to patterns such as those shown in Figure 2.



Key

1 Shot firing cable to exploder (30 m to 300 m)

a) Quarry-face blasting

b) Trench blasting

Figure 2 — Typical multiple extended line blasting circuits (plan view)

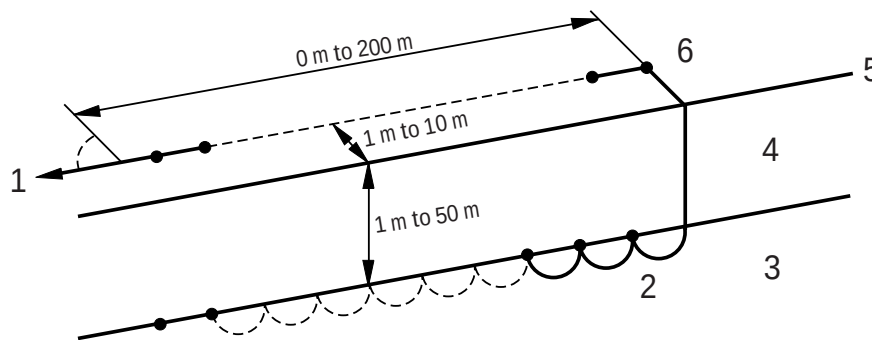
NOTE 1 Figure 2a) corresponds to a situation where retreating faces are being blasted, and Figure 2b) to trench blasting.

NOTE 2 All the configurations shown in Figure 1 and Figure 2 may be on horizontal ground or on ground inclined at angles up to about 30°.

In blasts of the type shown in Figure 2a) the number of rows can vary from two to 30. The circuits will be series connected but different connecting configurations may be adopted. The detonators may be on the surface (one or two per hole) or down holes from 0,5 m to 60 m deep (one to 10 detonators per hole).

7.2.3 Benching or 3-dimensional blasts

Possible situations in which a benching or 3-dimensional blast pattern may be used are those in which a single line quarry blast is coupled with one or more toe shots on the quarry floor, or those in which two single line blasts are being done on “benches” at different levels. A composite pattern is shown in Figure 3.



Key

1 Shot firing cable to exploder	4 Face
2 Toe shots	5 Crest
3 Floor	6 Top

Figure 3 — Quarry blast including toe shots

As shown in Figure 3 the floor and top may be in the horizontal plane, the face in the vertical plane, or the whole system may be set on an inclined plane, for example on a hillside. Again, top or bottom priming may be used in the quarry face part of the blast with one or two detonators per hole for top priming and from one to 10 for bottom priming.

7.2.4 Multipattern blasts

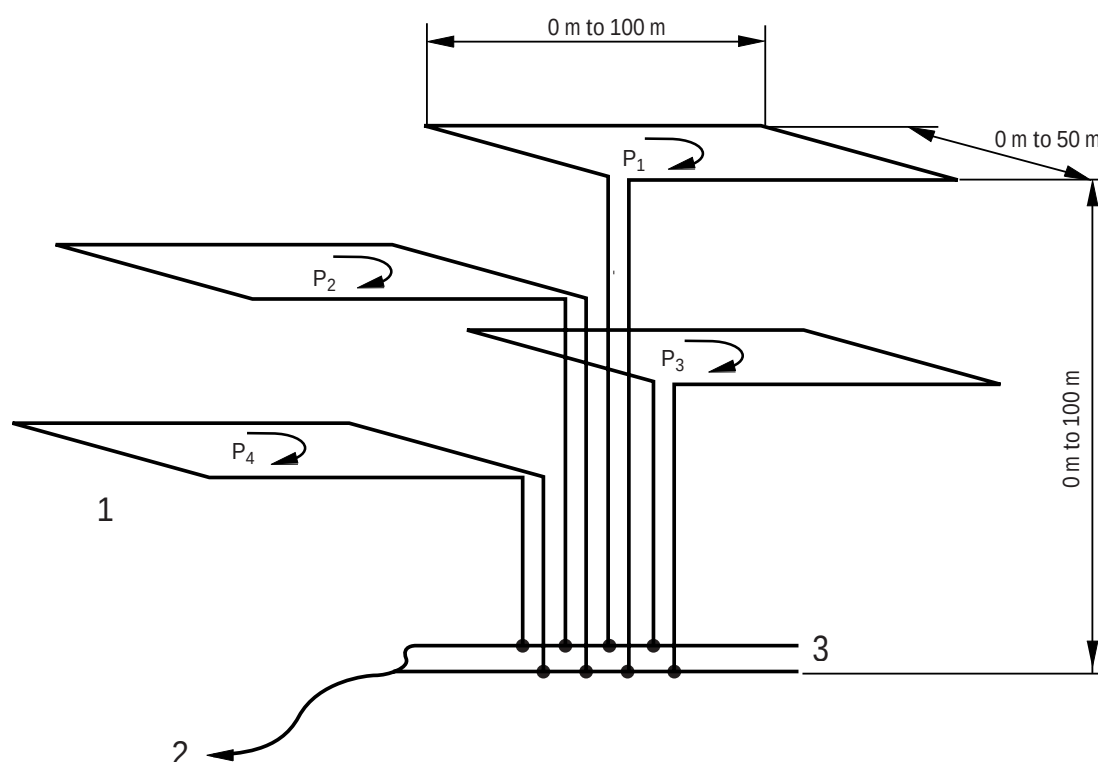
This situation might arise when more than one of the previously described blast patterns are set up in close proximity to each other and so may conveniently be connected together and fired as a single round. A typical case might be where two faces at right angles to each other are being blasted. Where separate blast patterns are being connected together to form one circuit, the overall distances of wiring involved might correspond to roughly a square or rectangle with sides up to about 400 m in length. Again the terrain may be level or inclined.

7.2.5 Shaft sinking

Blasting does not begin in shaft sinking operations until the soil has been removed and the bedrock exposed, normally about 10 m below the surface. The shaft diameter can vary from 1 m to 10 m and the depth can be down to 1 200 m. The blasting system commonly used is one in which the detonators are connected in parallel to busbars which form concentric circles. Up to five such circuits might be formed, each within the other in the form of pairs of decreasing diameter circles. The busbars are connected together to form one parallel circuit which is then connected to two hanging cables. These hanging cables in turn are connected to two cables on the surface which lead to the firing point, between 50 m and 200 m from the shaft. Both the surface cables and the hanging cable may be some distance apart, the only constraint on their relative positioning being the connections at the ends.

7.2.6 Demolition work

The pattern of the blasting circuit to be used in demolition will depend on the structure being demolished. Any circuit is likely to contain both vertical and horizontal components. Where large buildings are to be demolished, it is probable that horizontal series connected circuits will be laid on more than one level and then connected to vertical wires leading to the shot firing cable. The sub-circuits may be connected using series or parallel connections. The vertical heights involved may range from 0 m to 100 m and the dimensions of the horizontal loops may range from 0 m to 50 m by 0 m to 100 m, treated as being rectangular. An example of a multilevel blast in which the series connected loops on the various levels are connected in parallel to the vertical wires is shown in Figure 4. The horizontal loops may be at risk from horizontally-polarized transmissions, especially as field strength usually increases with increasing height above ground. The vertical wires leading to the shot-firing cable may be susceptible to vertically-polarized transmissions, but the risk can be minimized by spacing them close together as shown in Figure 4. Expert advice should always be sought when demolition blasting.



Key

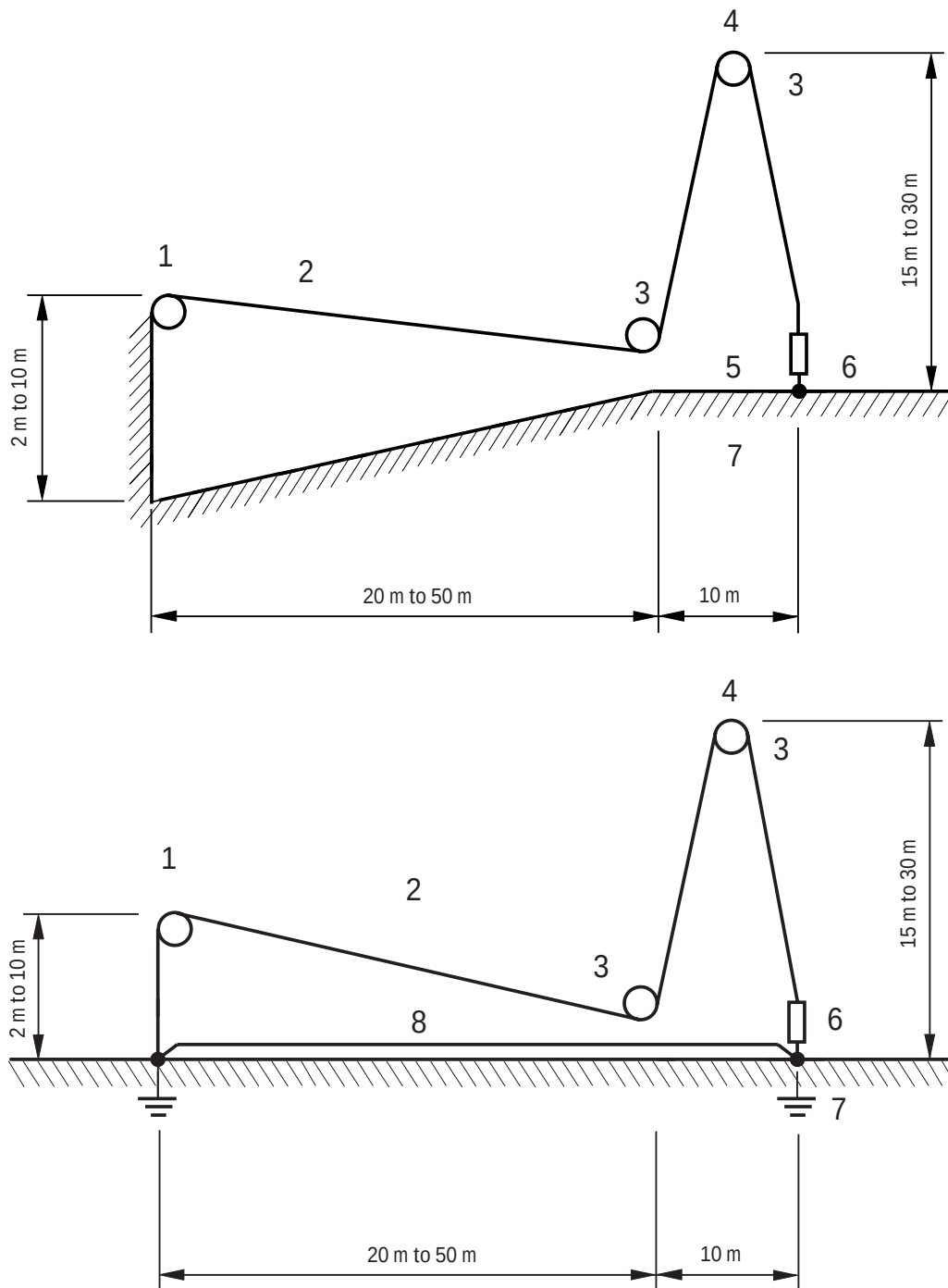
- 1 P₁, P₂, P₃ and P₄ are the perimeters of the loop circuits
- 2 Shot firing cable to exploder
- 3 busbar

Figure 4 — Multilevel series-in-parallel demolition blast

7.3 Circuits formed during well-perforating using wireline

Explosives initiated by EED are used for well perforation in both offshore and land based operations. The EED are initiated by electric current transmitted through the wireline which connects the explosive downhole tool to the controlling logging cabin. The method is well tried and convenient. However, a potentially hazardous situation exists since there is a risk of premature detonation caused by stray currents induced from sources other than the intended means of providing the firing current impulse. Currents may be induced by RF radiation which may emanate from local radio equipment (on board or within the site) or from external sources such as transmitters based on land, ship or aircraft. It should be noted that the number of potential hazard sources is much greater with land based operations.

Figure 5 shows the layout of the wireline cable when it is connected to the explosive tool and about to be lowered into the well. It runs from the cable drum up to a sheave in the derrick and down to the well head. Under fault conditions the EED could be connected in series with the cable as shown in Figure 5. It will be seen that the arrangement of a land-based drilling rig is similar to an offshore platform, the main difference being that the site is level, with the metal deck replaced by ordinary ground. The size of the loop formed by the wireline cable is not very different from that of an offshore platform but the loop is completed by an earth wire between the derrick and the cable drum. The presence of a single wire rather than a metal platform tends to increase the RF resistance of the loop. This in turn introduces a margin of safety if the methods used for offshore rigs are applied as they stand.



Key

- 1 Cable drum
- 2 Wireline cable
- 3 Sheave
- 4 Derrick

- 5 Deck
- 6 EED
- 7 Wellhead
- 8 Earth connection

Figure 5 — Layout of wireline cable for offshore and land based operations

It has long been recognized that a hazard may occur during such operations and two stages have been identified during the operations when such a hazard may exist. The first is when an EED is removed from its package and is prepared for connection to the firing circuit. During this time, the lead wires are splayed out and may form a dipole receiving antenna which can accept sufficient RF energy from incident radiation to initiate the EED. The second is when the EED is connected to the firing circuit. Under fault conditions, the wireline itself, which forms a loop or monopole receiving antenna, may similarly deliver sufficient RF energy to the EED to cause premature initiation. The various stages of a typical explosives operation and the extent of the hazard presented are as follows.

Stage 1: Preparation of the explosive

The assembly of the explosive material into its carrier may take place at the well site.

No hazard exists due to RF radiation during this operation nor during subsequent storage prior to installation of the EED.

Stage 2: Electric arming (EED connected electrically to the firing circuit)

This step involves attaching the EED to the explosive tool ballistically and electrically.

If the EED in use has leading wires a potential hazard exists from RF radiation during this operation because the leading wires may form an effective receiving antenna. Other forms of EED without leading wires do not present such a hazard.

Stage 3: Ballistic arming (EED connected mechanically to the explosive charge)

Mechanical interconnection of the explosive tool to the wireline and arming of the explosive tool takes place immediately prior to running the explosive tool into the well.

A hazard may exist during this operation due to the possibility under fault conditions that the wireline cable forms an effective receiving antenna, as shown in Figure 5, and may deliver energy to the EED.

Without this fault condition no significant energy can be delivered to the EED and there is no hazard. However, if a faulty electrical circuit is present or occurs during explosive tool handling, a potential hazard can arise until the explosive tool and cable are sufficiently deep in the well to provide an alternative electrical path for dissipation of the RF energy.

Stage 4: Explosive tool run to depths greater than 70 m below ground

The current practice of relaxing radio silence when the explosive tool is at depths greater than 70 m is supported since regardless of the existence of a fault condition, no potential hazard is presented in the practical circumstances considered in this European Technical Report. However, if explosives operations are carried out close to high power (for example broadcast) stations it is recommended that positive steps be taken to ensure continuous electrical contact between the armour of the wireline cable and the metallic structure of the well.

Stage 5: Explosive tool returned to surface for removal

At this time there is no absolute certainty that the EED has initiated or the explosive tool has operated fully satisfactorily and that no part of it remains live and armed. Visual inspection following its removal confirms successful firing or that a misfire occurred.

While the explosive tool remains attached to the cable the possibility of forming an effective receiving antenna continues to exist and a hazard may be presented which is similar to that of stage 3.

Stage 6: Disassembly of a misfired explosive tool

If a misfire is suspected or confirmed a possibility exists that a faulty EED could be initiated by RF radiation. A hazard, therefore, may exist until the explosive tool is disassembled which is comparable to that of stage 2.

Thus operations conducted using EED may present hazards during stages 2, 3, 5 and, if it occurs, 6. The operations using these stages are:

- well-perforating;
- explosive backoff;
- explosive cutter applications;
- cased hole formation testing.

Because the EED used for sidewall sampling and bridge plug setting do not have leading wires, no hazards arise during stages 2 and 6 of these wireline operations.

8 Electro-explosive devices

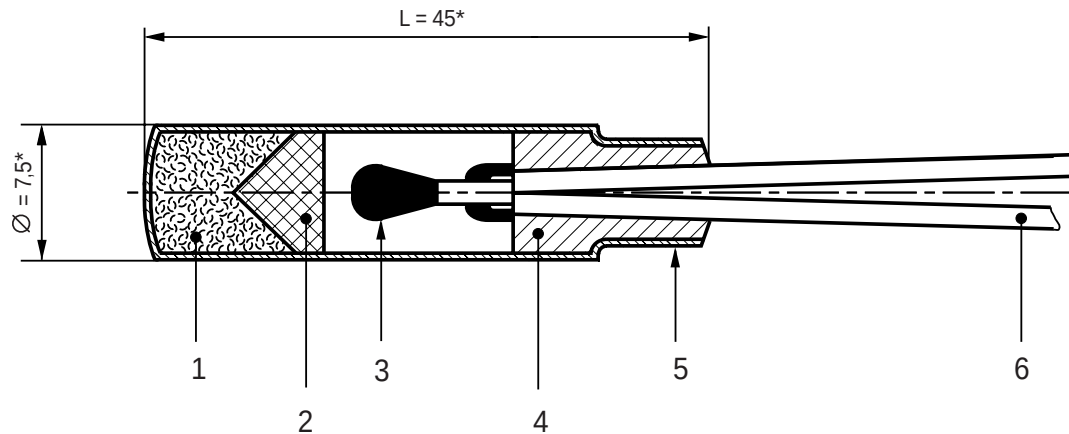
8.1 General

The EED considered in this European Technical Report are of the bridge wire type. Other EED, such as the conducting composition device or CC cap, have very limited commercial application and their use requires specialist advice which should be sought from an appropriate body (see Annex C).

Bridge-wire EED fire as the result of some part of the device being heated to a critical temperature by an electric current. Any EED will have a characteristic no-fire current and no-fire power (see 3.5). The significance of this is that while the no-fire current dictates the safety level when considering EED with extended leading wires (see Figure 13) and in loop circuits (see Figure 14 and Figure 15), the no-fire power dictates the safety level in considering single EED (see Figure 12).

8.2 Commercial EED

The bridge wire type is the device commonly used commercially as the “electric detonator”. It is available in both standard and “special purpose” varieties. It is essentially a low-voltage device constructed as shown in Figure 6.



* typical dimensions in mm

Key

- | | |
|-------------------|---------------------------------|
| 1 Base charge | 4 Sealing plug |
| 2 Priming charge | 5 Metallic tube |
| 3 Fusehead charge | 6 Plastic covered leading wires |

Figure 6 — Section through a typical commercial instantaneous EED

The characteristics of an EED can vary according to country of origin and type. The EED are divided into Types as follows:

- | | |
|----------|---|
| Type I | Type A EED or Typical French BI EED |
| Type II | Standard UK EED |
| Type III | Typical French MI EED |
| Type IV | Typical German Type U |
| Type V | Swedish VA |
| Type VI | Typical French HI and German HU |
| Type VII | Typical EED used in well-perforating operations |

Typical d.c. values for EED used in Europe are shown in Table 1.

Table 1 — Typical d.c. data on EED

	Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII
No-fire current in mA	180	300	450	450	1 200	4 000	200
Bridge-wire d.c. resistance in Ω	1	0,9	0,45	0,5	0,15	0,05	1
Value of safety resistance in Ω	0	0	0	0	0	0	50
Leading wire resistance/unit length in Ωm^{-1}	0,062	0,062	0,047	0,35	—	0,062	—
Leading wire (5m + 5m) resistance in Ω	0,62	0,62	0,47	3,5	3,15	0,62	—
Total EED resistance in Ω	1,62	1,52	0,92	4,0	3,3 ^a	0,67	10 ^b
NOTE In the case of all EED except for Type VII EED where it is taken into account, a multiplying factor should be used to calculate the worst-case RF effective resistance of the leading wire from the leading wire resistance in this table. Unless otherwise calculated from Annex E the value should be taken as 0,31. ^a For the Swedish VA detonator the total EED resistance is constant irrespective of the length of the leading wire. ^b For Type VII EED the lowest effective radio frequency impedance of 10 Ω for the device should be used.							

If other types of EED are to be considered, their characteristics should be obtained from the manufacturer with a statement of the statistical probability of initiation at the stated no-fire levels. A user may apply a further safety factor to these values if considered desirable. Given this information for any type of device, minimum distances of safe approach from various transmitters should be assessed as recommended in Clause 9.

8.3 EED hazard threshold

The hazard threshold in terms of input to any particular device should be expressed in terms of both no-fire energy and no-fire current. The latter can alternatively (assuming a purely resistive load) be:

- a) no-fire power,
since power = (current)² × resistance;
- b) no-fire voltage,
since voltage = current × resistance.

These no-fire characteristics are determined statistically by experiment and relate to a stated probability of firing. They should be stated by the manufacturer of any particular device.

8.4 Common mode operation

Radio-frequency voltages may be induced between the EED leading wires and earth, and RF currents may flow from the leading wires to earth through the EED. This is known as common mode operation.

Two possible, but unlikely, common mode firing mechanisms should be considered when using metal-cased EED. These are:

- a) RF bulk heating of dielectric components within the metal case;
- b) RF voltage breakdown between the bridgewire and the metal case.

The first mechanism is less sensitive than the circulating mode no-fire power threshold. The second mechanism is unlikely to prove a hazard in practice due to the presence of built-in protective measures against inadvertent initiation by electrostatic charges in most commercial EED. These protective measures limit the potential difference that might be built up between the leading wires and the case and, where necessary, protect the explosive composition of the fusehead from any spark produced by discharge between them.

9 Methods of assessment for determining potential RF ignition hazards on a site where EED are used

9.1 General

This clause describes the methods of assessment that can be used to ascertain whether or not a potential RF detonation hazard exists on a site where EED are used.

Subclauses 9.2 to 9.7 describe the theoretical assessments that should be performed in order to determine whether it is necessary to carry out the practical on-site tests that are described in Clause 10. For land based operations, 9.3.2 gives a initial assessment method for a particular site using EED and 9.3.1 is the initial assessment of the risk from a particular transmitter site. Offshore operations are covered in 9.7.

Flow charts are given in Figure 7 and Figure 8 in order to clarify the assessment methods. These “assessment flow charts” list the steps in both the theoretical assessment methods and outline the procedures that are recommended for practical on-site tests. The flow charts have been designed so that safe situations become apparent as soon as possible and the initial assessments involve the minimum effort. Figure 7 applies to the use of EED in land based operations whilst Figure 8 applies to offshore drilling operations.

The flow charts are designed to provide a step by step guide to the assessment procedure of this clause, the actions required at each stage being clearly indicated in the blocks. The number(s) in the blocks refer to the subclause(s) in this clause which are relevant to the action or decision required. Figure 7 shows the procedures for land based operations for assessment of the risk to a particular land site or for the assessment of the risk from a particular transmitter. These procedures are followed until either no hazard is indicated or the full assessment is reached, at which point they merge into a single procedure. If a hazard is indicated by the full assessment, Figure 7 indicates the sequential procedure to be followed for the following cases:

- 1) for existing sites and transmitters;
- 2) for existing sites and a proposed transmitter;
- 3) for existing transmitter modifications.

Even when an assessment indicates that there is no RF detonation hazard at the time the assessment is undertaken, it is important that the assessment be revised whenever a modification to the sites or transmitters is considered.

Figure 8 is a simplified flow chart which applies to offshore drilling operations, where most, if not all, of the transmitters which might cause a hazard are on or near the platform and under the control of the operator.

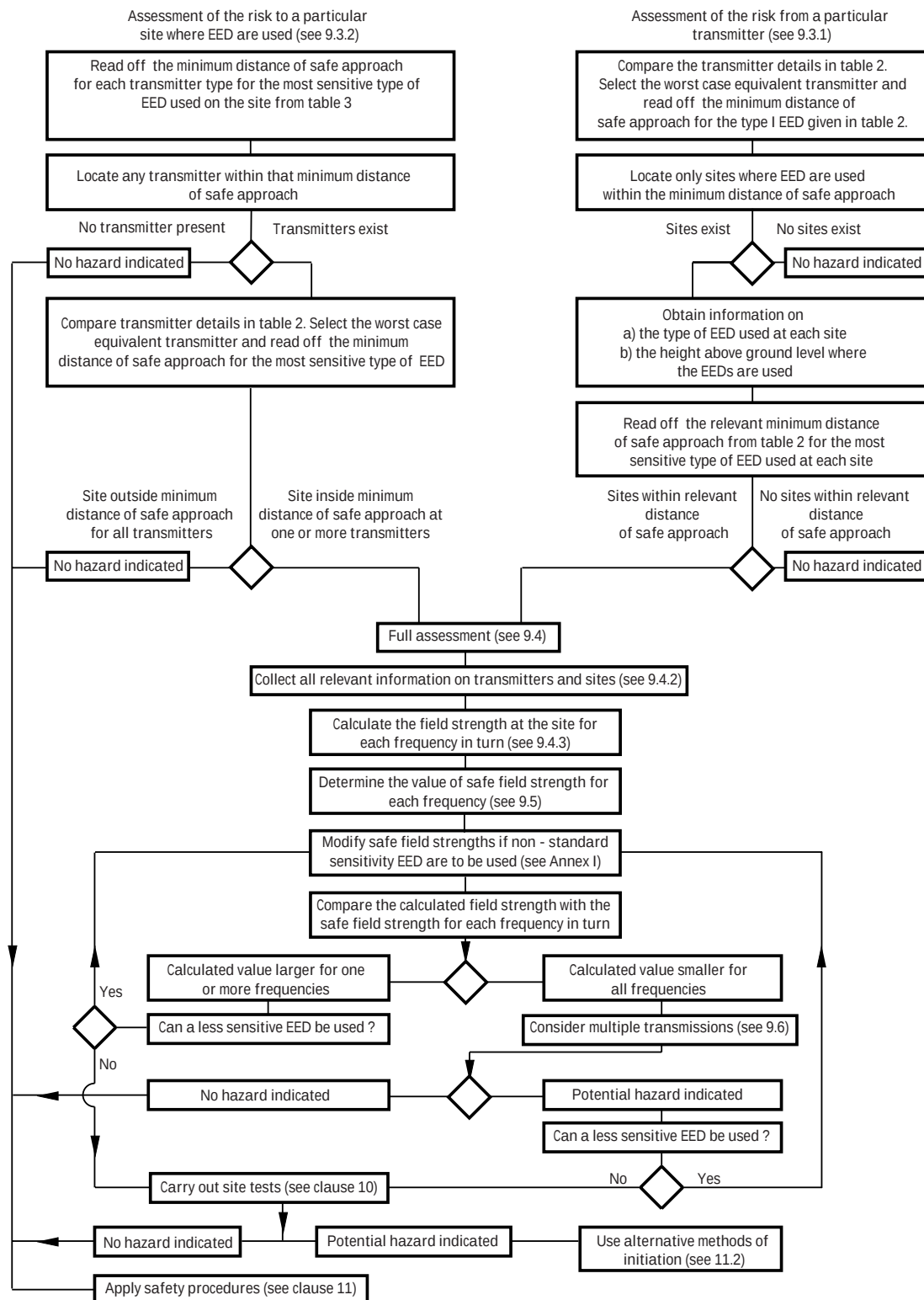
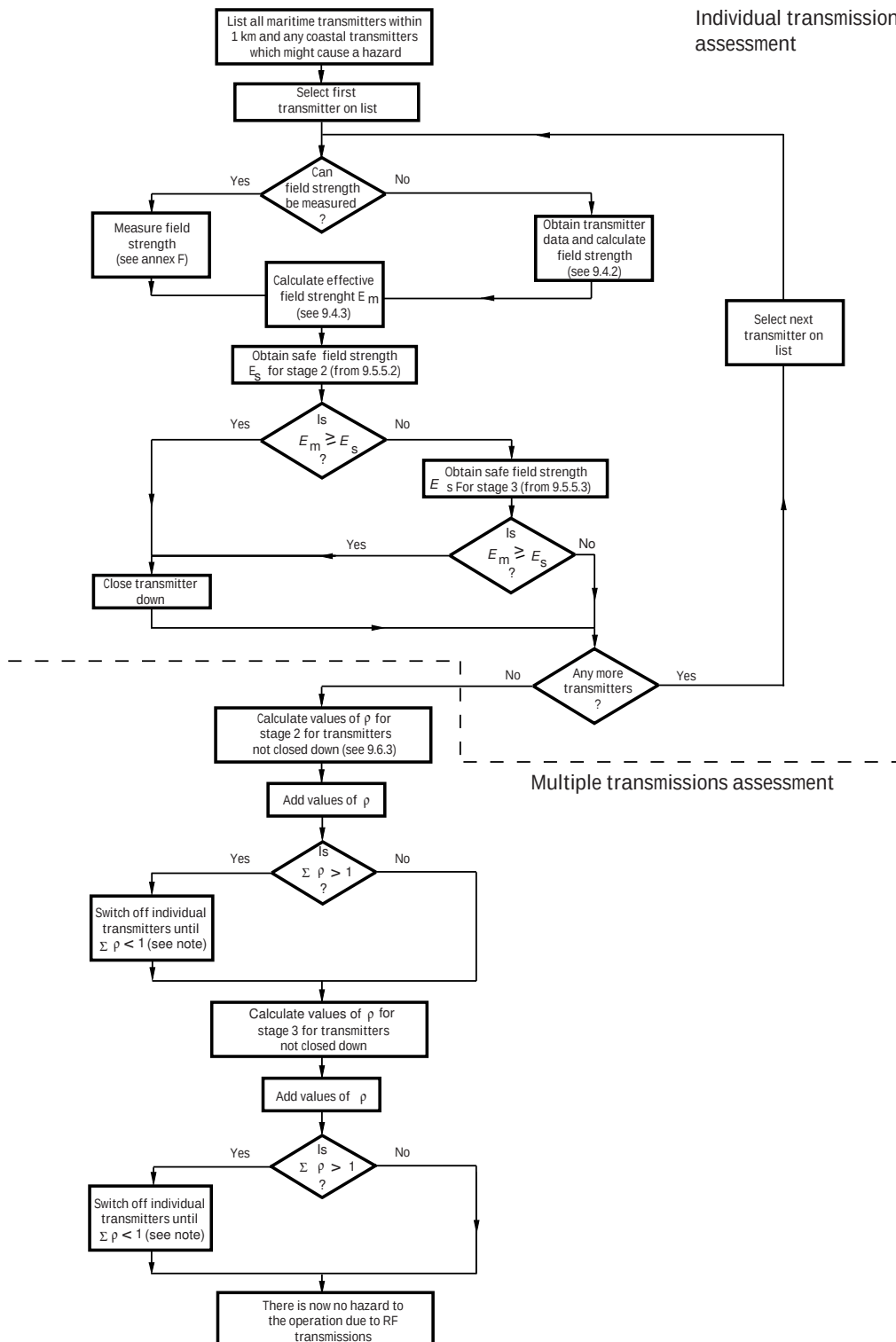


Figure 7 — Flow diagram for hazard assessment for sites situated on land



NOTE Alternatively consider the effect of detuning (see 9.6.3.2 and 9.6.3.3).

Figure 8 — Flow diagram for hazard assessment on offshore drilling platforms

9.2 Basis of the theoretical assessments for land sites

9.2.1 General

There are three types of theoretical assessments. These should be carried out in the following situations:

- a) the initial assessment recommended in 9.3.1 should be followed when potential risks from a particular transmitter site are being ascertained;
- b) the initial assessment recommended in 9.3.2 should be followed when the risks to a particular existing or planned site using EED are being ascertained;
- c) the full assessment method given in 9.4 should be carried out if one of the initial assessments indicates a potential hazard.

The initial assessment methods compare the basic parameters of the situation (the transmitter details, the distance between the transmitter and the site, and the types of EED that might be found on the site) with tables of distances that define the minimum distances of safe approach. The full assessment method involves evaluating the hazard for the particular existing or planned sites that are under consideration.

Table 2 and Table 3 define the minimum distance of safe approach around a transmitter or particular EED under worst-case conditions, and the appropriate table should be used in the initial assessment methods.

NOTE 1 The distances given in Table 2 and Table 3 have been calculated on the basis of safe threshold field strength data together with a multiple transmission factor that takes into account the presence of a number of different transmitters on a given site. It makes some allowance for the existence of a second transmitting site just outside the minimum distance of the safe approach and gives distances for the different types (sensitivities) of EED.

NOTE 2 For convenience, where a minimum safe distance of approach is given the numbers have been rounded up.

Available knowledge on the behaviour of EED either by themselves or in blasting circuits as outlined in Clause 7 and Clause 8 has been used to construct Figure 12, Figure 13, Figure 14, Figure 15 and Figure 16, which illustrate the relationship between the safe threshold field strength and frequency of the transmission for single unmodulated transmissions for the types of EED specified in Table 1.

At low frequency (l.f.) and medium frequency (m.f.) the multiple transmission factor takes account of the frequency separation between transmissions (see 9.6). The effective total radiated power is assumed to be twice that of the most powerful m.f. transmitter; this factor is derived from experimental data. At high frequency (h.f.) the effective power is assumed to be four times that of the most powerful transmitter. This factor is considered adequate for up to six separate co-sited transmitters, each having the same power, because h.f. transmissions are normally radiated from directional antennas which point in different directions and thus would not sum arithmetically.

NOTE 3 In calculating the minimum distance of safe approach, the powers for the single transmitters listed in column 4 of Table 2 were multiplied by the multiple transmission factors given in column 6.

Table 2 gives the minimum distances of safe approach for the most common transmissions found in Europe. The list is not exhaustive but it is considered that the majority of transmissions which are likely to be encountered have been included. For every category, the most powerful transmission has been listed, and in the case of m.f. broadcast transmissions a range of commonly used transmitter powers and antenna gains has been stated.

Table 3 gives the minimum distances of safe approach for the worst case for each type of EED for a typical transmitter. It is based on the figures given in Table 2.

Table 2 — Minimum safe distances for commercial EEDs

1	2	3	4	5	6	7	8	9	10	11		12	13	14	15 ^a
Serial no.	Type of transmission	Frequency	Transmitter power	Modulation code ^{b c}	Multiple transmission factor ^d	Antenna gain (dBi) ^e	Polarization code ^{f g}		Minimum distance of safe approach (in m) ^{h i j k l}						
								Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII	
1	Navigational (Omega)	10 kHz to 14kHz	100 kW	1 sec pulse	1	- 5	V	1 050	875	775	775	550	370	440	
2	v.l.f. communications	14 kHz to 20kHz	650 kW	FSK	1	- 5	V	1 150	950	825	825	600	400	550	
3	l.f. communications	20 kHz to 70kHz	300 kW	FSK	1	0	V	2 450	1 700	1 500	1 500	1 100	725	370	
4	l.f. communications	90 kHz to 110kHz	135 kW	FSK	1	0	V	1 650	1 000	675	675	400	270	280	
5	l.f. communications	110 kHz to 150kHz	325 kW	FSK	1	1	V	2 900	1 750	1 150	1 150	430	280	310	
6	l.f. broadcast (long wave)	150 kHz to 283kHz	2 000 kW	AM	1	8 ^m	V	25 200	15 200	10 200	10 200	3 850	1 200	3 700	
7	l.f. broadcast	150 kHz to 283kHz	500 kW	AM	1	4	V	8 100	4 850	3 250	3 250	1 250	370	500	
8	l.f. broadcast	150 kHz to 283kHz	50 kW	AM	1	3	V	2 300	1 400	925	925	340	190	330	
9	Radio beacons	285 kHz to 525kHz	1 kW	MCW	2	2	V	380	230	160	160	120	75	120	
10	m.f. ship communication (land)	415 kHz to 525kHz	5 kW	MCW	2	4	V	900	550	360	360	140	80	330	
11	m.f. ship communication (sea)	415 kHz to 525kHz	800 W	MCW	2	0	V	230	140	110	110	75	50	85	
12	m.f. broadcast	0,53 MHz to 1,6 MHz	500 kW	AM	2	8	V	12 300	7 500	5 100	5 100	1 950	575	12 500	
13	m.f. broadcast	0,53 MHz to 1,6 MHz	1 000 kW	AM	1	8	V	12 300	7 500	5 100	5 100	1 950	575	12 500	
14	m.f. broadcast	0,53 MHz to 1,6 MHz	150 kW	AM	2	8	V	6 900	4 200	2 800	2 800	1 100	320	8 000	
15	m.f. broadcast	0,53 MHz to 1,6 MHz	50 kW	AM	2	8	V	4 000	2 450	1 650	1 650	625	190	5 050	
16	m.f. broadcast	0,53 MHz to 1,6 MHz	20 kW	AM	2	8	V	2 550	1 550	1 050	1 050	390	120	3 350	
17	m.f. broadcast	0,53 MHz to 1,6 MHz	10 kW	AM	2	5	V	1 300	775	525	525	200	75	1 800	
18	m.f. broadcast	0,53 MHz to 1,6 MHz	1 kW	AM	2	5	V	410	250	170	170	80	55	600	
19	h.f. broadcast ^{h n}	3,95 MHz to 4 MHz	500 kW	AM	4	16 (Elev 18°)	H	490√ <i>h</i>	380√ <i>h</i>	310 √ <i>h</i>	310√ <i>h</i>	190√ <i>h</i>	110√ <i>h</i>	1 300	

Table 2 — Minimum safe distances for commercial EEDs (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15 ^a
Serial no.	Type of transmission	Frequency	Transmitter power	Modulation code ^{b,c}	Multiple transmission factor ^d	Antenna gain (dBi) ^e	Polarization code ^{f,g}	Type I	Minimum distance of safe approach (in m) ^{h,i,j,k,l}					
									Type II	Type III	Type IV	Type V	Type VI	Type VII
20	h.f. broadcast ^{n,o}	5,9 MHz to 26,1 MHz	500 kW	AM	4	21 (Elev 9°)	H	921√ <i>h</i>	720√ <i>h</i>	690√ <i>h</i>	540√ <i>h</i>	360√ <i>h</i>	290√ <i>h</i>	2 800
21	h.f. communications (land)	1,6 MHz to 25 MHz	30 kW	FSK/SSB	4	12	V	5 100	3 250	2 300	2 250	875	270	6 900
22	h.f. communications (land) ^h	4 MHz to 25 MHz	30 kW	FSK/SSB	4	18 ^p	H	240√ <i>h</i>	190√ <i>h</i>	180√ <i>h</i>	160√ <i>h</i>	95√ <i>h</i>	80√ <i>h</i>	625
23	Marine m.f./h.f.	1,6 MHz to 4,4 MHz	400 W	SSB	2	5	V	160	100	65	65	30	18	330
24	Marine h.f.	6,2 MHz to 26 MHz	1,5 kW	SSB	2	5	V/H	185	135	125	90	50	35	110
25	h.f. communications (civil aircraft) ^q	2,8 MHz to 23 MHz	400 W	SSB	2	2	V/H	110	65	60	45	20	15	85
26	h.f. communications band	27 MHz to 30 MHz	950 W	FM	2	3	V	95	70	65	45	26	18	55
27	Amateur radio (fixed and portable) ^h	1,8 MHz to 2 MHz	400 W	CW/SSB ^f	2	5 (Elev 30°)	H	28√ <i>h</i>	22√ <i>h</i>	17√ <i>h</i>	17√ <i>h</i>	10√ <i>h</i>	6√ <i>h</i>	75
28	Amateur radio (fixed and portable)	1,8 MHz to 2 MHz	400 W	CW/SSB ^f	2	- 8	V	50	30	25	25	17	11	70
29	Amateur radio (fixed and portable) ^{h,s}	3,5 MHz to 29,7 MHz	400 W	CW/SSB ^f	2	10 (Elev 30°)	H	45√ <i>h</i>	35√ <i>h</i>	35√ <i>h</i>	25√ <i>h</i>	17√ <i>h</i>	13√ <i>h</i>	110
30	Amateur radio (fixed and portable) ^s	3,5 MHz to 29,7 MHz	400 W	CW/SSB ^f	2	5	V	210	130	100	85	35	24	110
31	Amateur radio (fixed and portable)	50 MHz	400 W	CW/SSB ^f	2	9	V/H	170	110	95	55	24	15	75
32	Amateur radio (fixed and portable)	70 MHz	150 W	CW/SSB ^f	2	9	V/H	75	45	40	22	10	6	35
33	Amateur radio (fixed and portable)	144 MHz	400 W	CW/SSB ^f	2	18	V/H	160	100	90	50	22	14	75
34	Amateur radio (fixed and portable)	430 MHz	400 W	CW/SSB ^f	2	19	V/H	60	40	35	18	8	5	28