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British Standard Guide to Prevention of inadvertent initiation of electro-explosive devices by radio-frequency radiation

Guide pour la prévention de l'amorçage intempestif des appareils pour
l'électro-explosion par rayonnements à fréquence radioélectrique

Leitfaden zur Verhinderung des unbeabsichtigten Auslösens einer elektrischen
Zündeinrichtung durch hochfrequente Strahlung

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Foreword

This British Standard has been prepared under the direction of the Electronic Equipment Standards Committee.

This standard, together with BS 6656, supersedes BS 4992 : 1974, which is withdrawn.

Radio-frequency (r.f.) currents and voltages are induced into any conducting structure situated within the electromagnetic field of a r.f. transmitter (including radio, television, radar, etc.). Such a structure acts as a receiving aerial.

If the conducting structure is the firing circuit of an electro-explosive device (EED), the r.f. induced current may be sufficient to cause inadvertent initiation of the device.

BS 4992 : 1974 presented practical considerations relating to the presence of flammable substances or EED in the radiation field of a transmitter. A later amendment warned that some of the numerical information contained in BS 4992 was incomplete and that certain clauses were being given further consideration. Measurements of currents induced in typical blasting circuits were subsequently carried out, and those measurements form the basis of the assessment procedures contained in this standard.

This guide reviews the theoretical and practical aspects of the problem relating to EED and, assuming the responsible adoption of certain simple precautionary principles, derives 'safe' distances outside which it is considered that there will be no hazard. These safe distances are intended to focus attention on the limited areas within which more specific potential hazard assessment is required. Procedures that may be applied to define the safe distances more accurately within these limited areas are described.

NOTE. The numbers given in square brackets used throughout the text relate to the bibliographic references given in D.3.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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Guide

1 Scope

This British Standard provides guidance in assessing the possibility of inadvertent extraction of energy from an electro-magnetic field propagated from communication, radar or other transmitter aerials and the coupling of this energy to an EED in a manner capable of causing initiation. It does not cover the similar hazard arising from electro-magnetic fields generated by other means, for example electrical storms, electricity generating plant or power transmission lines, nor does it cover the potential hazards that may arise in oil and gas exploration and production operations.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this British Standard, the definitions given in BS 4727 apply, together with the following.

2.1 duty cycle. The product of pulse duration (in seconds) and the pulse repetition frequency (in pulses per second).

2.2 electro-explosive device (EED). A 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 conform with general practice within the industry.

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

2.4 safe distance. A distance outside which it is considered that there will be no hazard.

2.5 no-fire energy/power/voltage/current. The 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 allowed during the production of EED will cause normal statistical variation in their firing characteristics. The most sensitive EED permitted by these variations sets the appropriate no-fire level, which is generally accepted as a probability no greater than 0.01 %.

2.6 round of charges (shot). One or more primed explosive charges or shots, e.g. main charge, primer (if used) and detonator.

2.7 pop shot. A shot used for secondary breaking of materials.

2.8 toe shot. A shot designed to clear the foot of a face.

2.9 hazard area. An area, which may be of any shape, containing the transmission source or sources and bounded by the surface at which the radiation magnitude equates to the designated hazard threshold.

2.10 hazard threshold. The mean power flux density or field strength that would permit only a negligible probability of EED initiation.

2.11 exploder. The means whereby a round of charges (shot) is fired electrically.

3 Responsibility for safety

The r.f. environment is becoming increasingly severe, with the proliferation of transmitting sources, increased transmitter powers and the exploitation of new techniques. The potential hazard of induced initiation of EED is real although it depends upon the coincidence of phenomena, each of which may have a low probability of occurrence.

Current United Kingdom legislation requires that employers safeguard their employees and others who may be placed at risk by their activities. Hence, both operators of r.f. transmitters and users of EED have a responsibility to ensure safe operation.

Users of EED should ensure that the safety procedures given in clause 11 are understood and are applied.

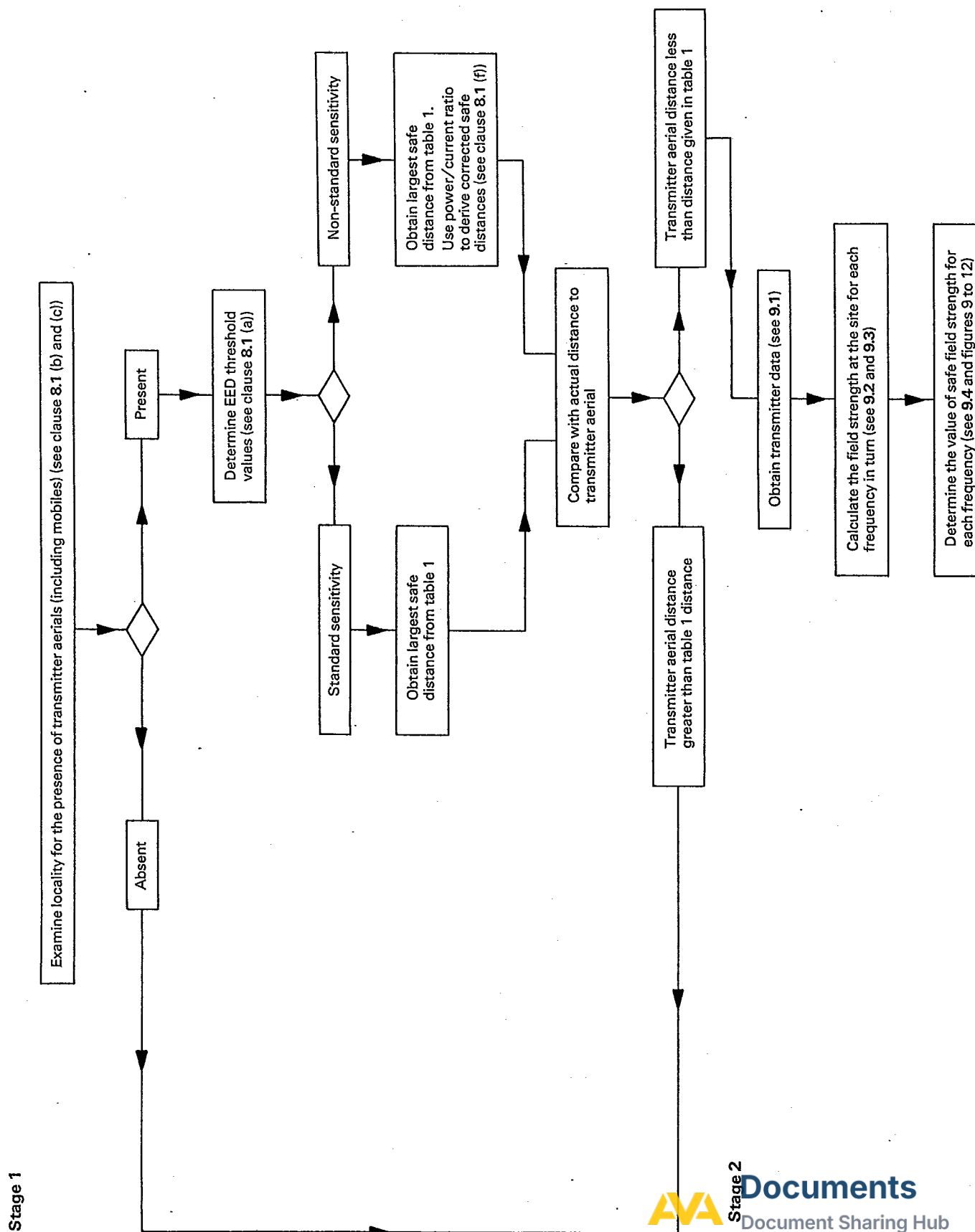
4 General

Radio-frequency sources causing a possible hazard are not restricted to fixed transmitting stations but include mobile transmitters. This guide reviews the theoretical and practical assessment of the hazards that arise from these sources and the use of EED. A purely theoretical approach can only lead to unduly restrictive safety criteria, partly because the analysis of real situations is extremely complex and supporting theory is incomplete. The 'safe' levels given in the later parts of this guide are therefore the result of the application of engineering judgement to the experimental evidence and theoretical work available at present. The safe levels may require amendment as more practical data and additional validated theories are forthcoming. However, adoption of the guide should give assurance of safety without being unduly restrictive.

The procedure adopted in this standard is one of successive separation of safe sites, and is shown in the form of a flow chart in figure 1. The initial separation using table 1 identifies all sites that would not be at risk from the most powerful known UK transmitter operating at each frequency, and the second more rigorous separation uses dipole and loop theory allied to specific transmitter data to further identify safe sites. The final stage in the separation procedure involves on-site measurements and should be only occasionally required.

When the leading wires of an EED are opened up they can form a dipole that responds to radio waves. It is then possible with a fortuitous length of leading wire to achieve an optimum match between the dipole and the EED, with maximum transfer of power to the EED from the radio wave. If sufficient power is available at the fusehead it may ignite. Safe field strengths as a function of frequency for single EED with opened up leading wires are shown in 9.4.2 and from these are derived the associated minimum safe distance given in table 1 for specific transmitters.

At an intermediate stage in constructing a firing circuit, wires connected to a single EED may form larger dipoles. Safe field strengths for this situation are given in 9.4.3 assuming that the lengths of each of the connecting wires will not exceed 100 m. Table 1 gives the appropriate safe distances associated with specific transmitters.



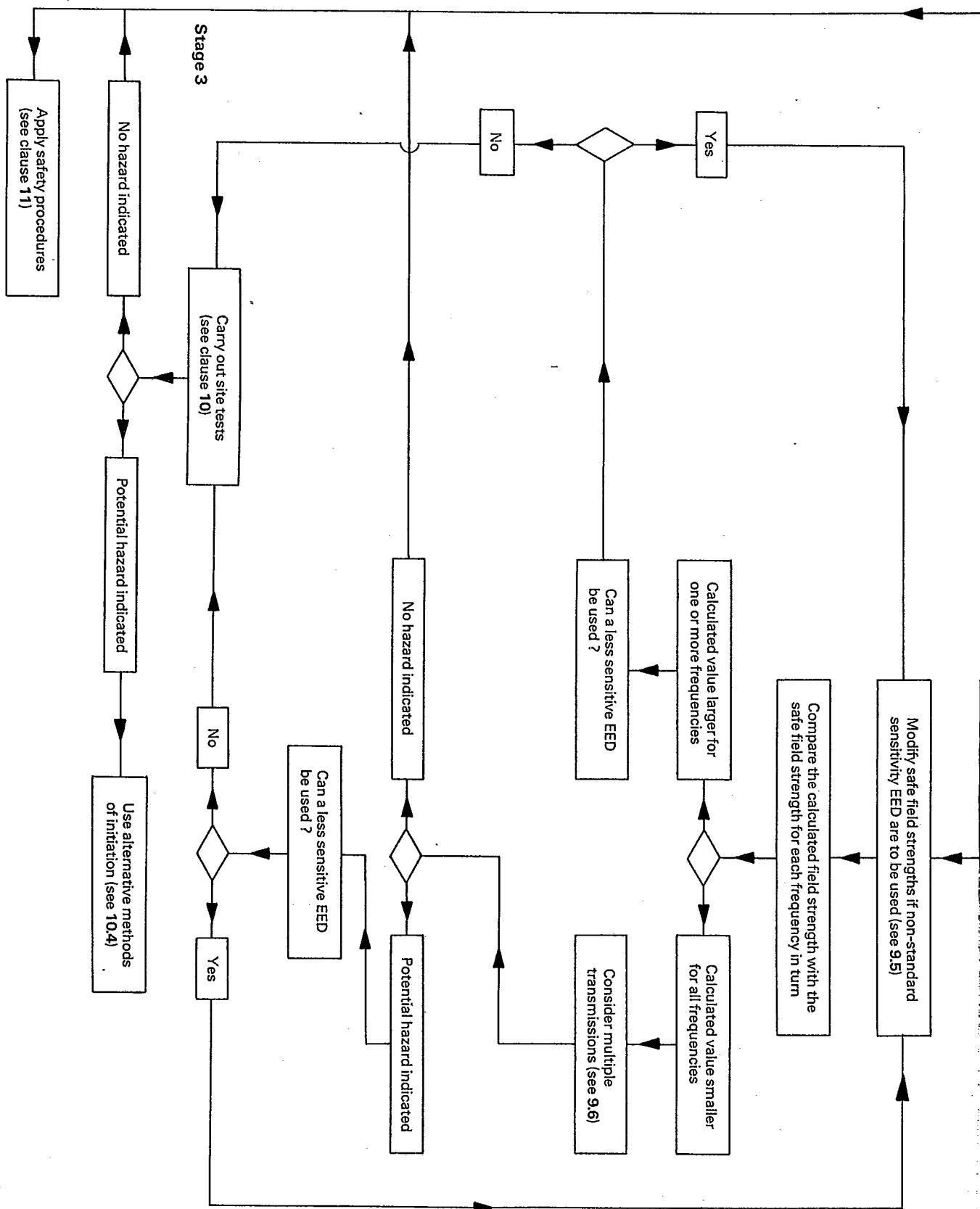


Figure 1. Operational procedure for sites at which EED are used or are proposed to be used

Finally, a number of EED may be connected up as a loop to form a complete firing circuit. Table 1 shows the appropriate safe distances for the transmitters listed.

While the procedure outlined in figure 1 applies to sites at which EED are to be used, any transmitter operator intending to install a new transmitting station should invert the initial search procedure to one of an examination of the area for sites at which EED are used, and then continue to use the flow chart method in order to establish whether or not the proposed transmitter would constitute a hazard to such a site.

5 Radio-frequency hazard

5.1 Factors contributing to the hazard

There are three interrelated factors that have to be present simultaneously to produce a hazard at a location:

- (a) a sufficiently intense electromagnetic field;
- (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.

5.2 Hazard area

The magnitude of an electromagnetic field decreases with increasing distance from the source. Surrounding each source there exists an area of potential hazard to EED, and the extent of this area is considered later.

This hazard can exist where there is significantly less mean electromagnetic field strength than that which may be injurious to health. Potentially hazardous areas are associated with any type of transmitter, or source, in both fixed and mobile roles. The powers received at a site from two or more transmitters should be added (see 9.6).

5.3 Hazard threshold

The hazard threshold (see 2.10) depends on both the power required to initiate the EED under the environmental conditions obtaining, and the efficiency of the power transferring medium, i.e. the receiving aerial.

5.4 Determination of hazard

The method to be adopted in determining whether a potential hazard exists consists of calculating the field strength at the site (see 9.2) and comparing this with the threshold field strengths obtained from figures 9 to 12, suitably amended if non-standard sensitivity EED are to be used (see 9.5).

NOTE. The full procedure is described in clauses 7, 8 and 9.

Whenever exceptional circumstances are thought to exist or whenever there is the slightest doubt, technical advice should be sought from the manufacturers or suppliers of the EED or expert advisers such as those listed in appendix D. Alternatively, the EED should not be exposed to the potential hazard.

5.5 Safety factors

The procedures in this standard for assessing the presence of a potential hazard are based on a number of reasonable 'worst-case' assumptions. 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.

5.6 Operational procedure

The procedure outlined in stage 1 of figure 1 should be used. If the distance from the transmitter aerial to the intended site is less than the minimum safe distance given in table 1 it will be necessary to proceed to stage 2. When the calculated safe field strength exceeds the safe maximum indicated by figures 9 to 12 it will be necessary to conduct site measurements (stage 3).

6 Practical considerations of the hazard

6.1 Introduction

EED can be inadvertently initiated by energy extracted from a radiated field. This can occur if the leads into the device, or the leads and the associated firing circuit together, constitute a form of aerial (see clause 4). EED may also be initiated by direct contact with a transmitting aerial or some metallic structure behaving as an unintended aerial.

6.2 Sources of r.f. energy

Sources of r.f. energy may be vertically and/or horizontally polarized. Possible sources of r.f. energy are:

- (a) fixed and mobile radio and television transmitters;
- (b) radar transmitters;
- (c) navigation beacon transmitters;
- (d) geophysical survey equipment.

Equipments in categories 6.2(a), (b) and (d) can be airborne and possible r.f. hazards from low-flying aircraft have to be considered.

6.3 Modulation

6.3.1 General. Radio-frequency transmissions may be unmodulated in which case the radiated power is constant and the quoted power can be used for assessment purposes. Such transmissions are sometimes referred to as continuous wave (CW). However most transmissions are modulated in order to convey information or to enable them to achieve specific tasks, e.g. radar. The characteristics of the principal modulating systems are described in 6.3.2 to 6.3.5. A factor m is used to take account of modulation when calculating the effective field strength (see 9.3).

6.3.2 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) is a form of frequency

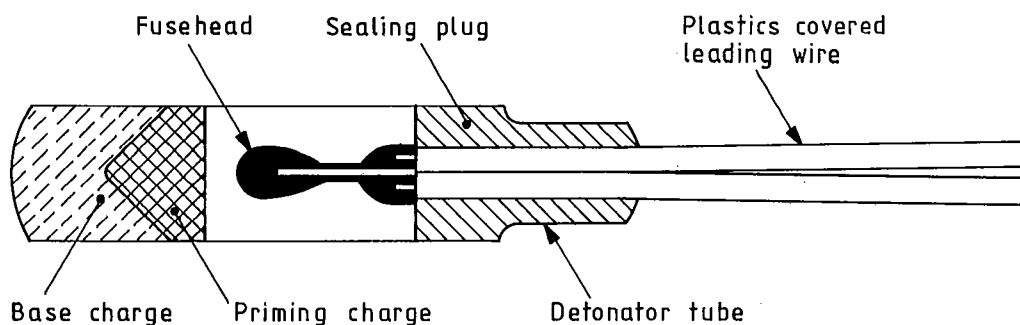


Figure 2. Section through a commercial instantaneous EED

modulation. Phase shift keying (PSK) and phase modulation (PM) are treated similarly in that no allowance for modulation is needed since the output power is not affected by the modulation.

6.3.3 Amplitude modulation (AM)

6.3.3.1 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.

6.3.3.2 Speech and music. When speech and music are transmitted, the power quoted 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, some allowance for the power increase has to be made when making an assessment; this can 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 has been found to be appropriate in calculations of effective field strengths for this kind of modulation.

6.3.3.3 Coded transmissions. A version of AM used for morse and other coded transmissions is known as modulated continuous wave (MCW). The carrier can be fully modulated by a continuous tone and a modulation factor m of 1.22 should be used.

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

6.3.4 Single sideband (SSB) operation. For single sideband (SSB) operation the peak envelope power is usually quoted and a value of 0.71 for the modulation factor m can be taken.

6.3.5 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 and a pulse repetition rate of n pulses per second. These are related by the equation:

$$P_o = \frac{P_m}{nt} \quad (1)$$

where

nt is the duty cycle.

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

6.4 Electro-explosive devices

6.4.1 General. The EED considered in this standard are of the wire bridge 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 the appropriate body (see appendix D).

EED fire as the result of some part of the device being heated by an electric current to a critical temperature. Any EED will have a characteristic no-fire current and no-fire power (see 2.5). The significance of this is that while the former dictates the safety level when considering EED with extended leading wires (see figure 10) and in loop circuits (see figures 11 and 12), the latter dictates the safety level in considering single EED (see figure 9).

6.4.2 Commercial EED. The wire bridge 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 2.

The characteristics of an EED can vary according to country of origin and type. The characteristics of a typical

EED in wide use in the United Kingdom are (in normal or circulating mode) as follows:

- (a) no-fire energy 2.3 mJ;
- (b) no-fire power 80 mW;
- (c) no-fire current 0.3 A;
- (d) no-fire voltage 0.27 V;
- (e) thermal time constant about 30 ms; the time taken for the EED to reach thermal equilibrium without firing may be taken as four times this value;
- (f) wire bridge resistance range 0.9 Ω to 1.6 Ω .

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, safe distances from various transmitters can be assessed as indicated in 8.1(f) and 9.5.

6.5 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 power. Alternatives to the latter (assuming a purely resistive load) are:

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

6.6 Common mode operation

Radio-frequency voltages may be induced between the EED leading wires and earth, and r.f. 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) r.f. bulk heating of dielectric components within the metal case;
- (b) r.f. voltage breakdown between the bridgewire and the metal case.

The first mechanism may be taken as being 10 times 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.

6.7 Typical blasting circuit layouts

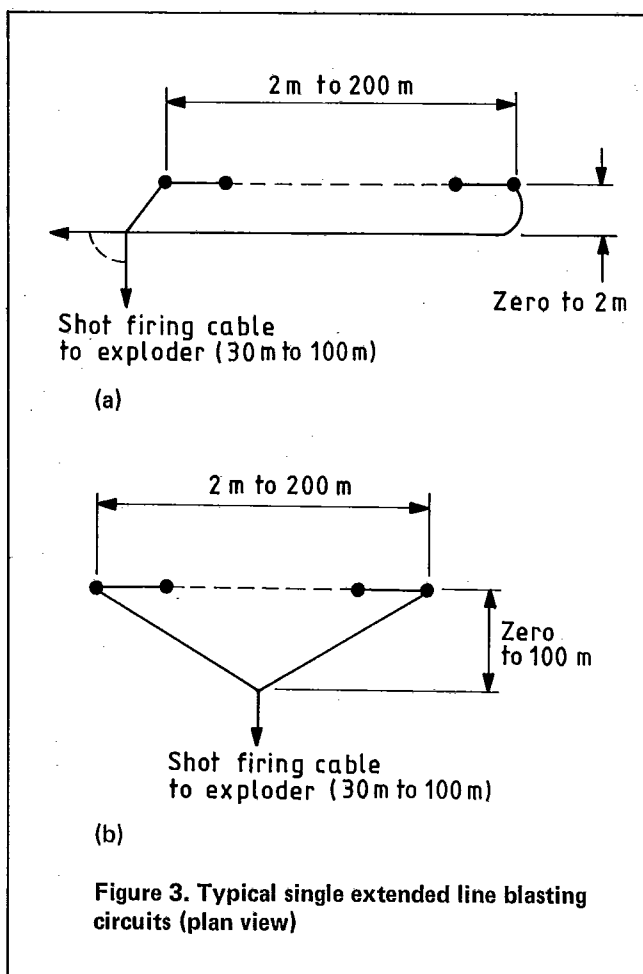
6.7.1 General. While in theory an infinite number of blasting circuit layouts are possible, in practice they can be condensed into five broad types:

- (a) extended line blasts;
- (b) benching or three-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.

Figures 3 to 6 show the extremes of circuitry that are known to occur, but the vast majority of practical circuits lie between the two extremes.

6.7.2 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 3.



In figure 3 the holes, from 0.5 m to 60 m deep, can be either top or bottom primed, with essentially one or two detonators on the surface or from two to 10 detonators down the holes. In the case of figure 3(b) the connection to the shotfiring cable may be made anywhere along the lines 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 4.

Figure 4(a) corresponds to a situation where retreating faces are being blasted and figure 4(b) to trench blasting. All the configurations shown in figures 3 and 4 may be on horizontal ground or on ground inclined at angles up to about 30°.

In blasts of the type shown in figure 4(a) the number of rows could vary from two to thirty. 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 (two to ten detonators per hole).

6.7.3 Benching or three-dimensional blasts. Possible situations in which this type of blast pattern might be used are those in which a single line quarry blast is coupled with one or more toe or pop 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 5.

In figure 5 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 in the former case and from two to ten in the latter case.

6.7.4 Multipattern blasts. This situation might arise where more than one of the previously described blast patterns are set up in close proximity to each other and so can 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.

6.7.5 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 1200 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.

Since r.f. signals do not propagate for more than a few metres underground without guides, the risk of accidental firing on site at the bottom of a shaft is remote.

6.7.6 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 zero to 100 m and the dimensions of the horizontal loops may range from zero to 50 m by zero 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 6. The largest loop should be taken as the effective perimeter of such circuits for hazard assessment purposes.

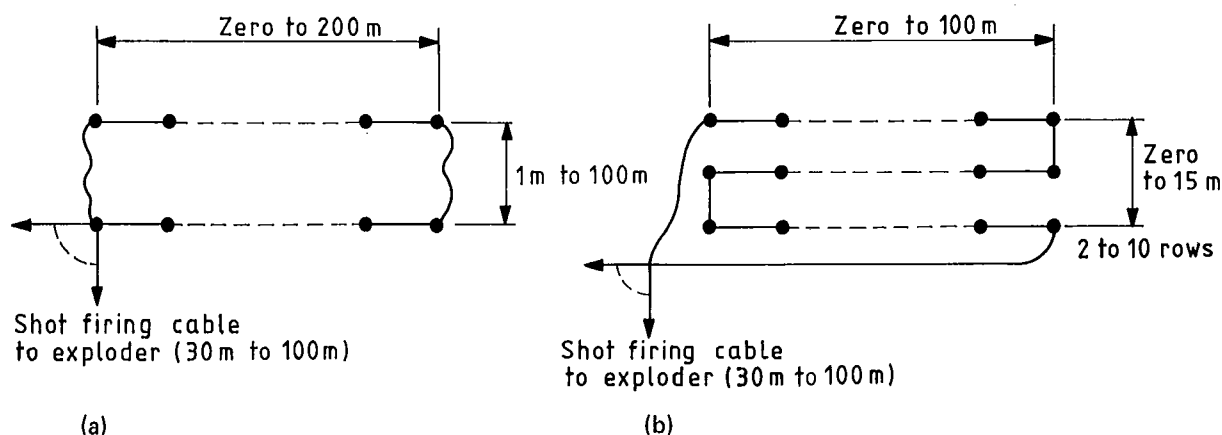


Figure 4. Typical multiple extended line blasting circuits (plan view)