

Intrinsic safety and high frequency

The ignition behaviour of electrical circuits at frequencies above industrial alternating currents

by W. Dill and R. Hauke

Both the technical-scientific and the normative roots of the explosion protection measure now called 'intrinsic safety' can be traced back to the use of electrical devices in the firedamp-hazard areas in coal mining. The fundamental tests commissioned by the Preußischen Schlagwetterkommission (Prussian Firedamp Commission) conducted at Aachen Technical University in the year 1886 and the subsequent tests in 1898 conducted at the BVS [1] still concluded that every electrical spark was capable of causing an explosion. It was Professor Wheeler's fundamental investigations following the explosion accident at the Senghenydd mine on October 14, 1913 (causing the deaths of 439 persons) which laid the foundation for experimental determination of the ignition limit of electrical sparks in communication and instrumentation equipment. British Standard BS 1259 : 1945 which is based on this, could, without hesitation, still be used today with its full wording as a test instruction in the sense of an 'Essential Health and Safety Requirement' in accordance with Directive 94/9/EC. Close cooperation between Wheeler and the BVS Director Beyling probably also led to the fact that even Standard VDE 0170: 1926 contains a reference to the admissibility of equipment whose sparks are not capable of causing an explosion.

'Spark test apparatus' for direct current and industrial alternating current

The experimental set-up used by Wheeler was modified and further developed in many countries. In Great Britain, it was the 'Breakflash No. 3' and, in France, it was the 'Éclateur Rapide' which were used for testing in accordance with national standards for intrinsic safety. From Russia, it is reported that there was a device on which the breaking spark of the circuit was generated by shooting to pieces a conductor with a rifle bullet – not unlike a German proposal for tearing wires apart. The efforts aimed at international standardisation of the test procedure were made very early at IEC level. During a meeting of Committee IEC 31G in Prague in 1967, after submission of the results of many comparative tests, a decision was taken to standardise the test apparatus [2] developed by a member of staff at Sie-

mens in Berlin in the form still used today in IEC 60079-3. The minutes of the meeting include a limitation of the circuit parameters to 300 V/1.5 A/1 H. The entire technological environment of this empirically established test apparatus is aimed at direct current circuits or circuits with industrial alternating currents with the voltages conventional for control and instrumentation circuits.

The devices used at the time in hazardous areas did, admittedly, also use higher frequencies to a slight extent, e.g. for capacitive measuring methods or for data transmission with TFSK methods. This was followed, at a later date, by hand-held radio-telephone units and other high-frequency applications on which, however, the circuits relevant to safety were the power supply circuits and the associated capacitors and coils. In general, it was decided not to conduct an analysis of the high-frequency section in relation to high-frequency energy.

Knowledge of the spark test apparatus – standardised nationally in 1965 in VDE 0170/0171 and standardised on a European basis in 1977 in EN 50020, and its use for checking the intrinsic safety of electrical circuits were (and still are being) refined constantly.

Essential milestones were the investigations into the influence of cables and lines (e.g. those conducted by Schebsdat [3, 4], into the ignition process caused by inductances (e.g. conducted by Vogt [5]) and investigations into the ignition process caused by capacitors with a fundamental clarification of the physical interrelationships in energy conversion in the ignition spark conducted by Johannsmeyer [6].

Proposals for optimisation dealt with improving the repeatability of the results and adaptations for higher currents.

Specific statements on the upper cut-off frequency in relation to applicability of the method were avoided. Initially, there was little cause to bother about this aspect, but the increasing use of radio equipment, the use of higher frequencies for energy transmission and considerations of specific industrial situations, such as radio transmitters near refineries, brought the problem to light.

The Spark test apparatus in accordance with IEC 60079-11 as a spark generator

The overall concept of the device is aimed at simulating sparking in the case of an open circuit of a conductor or in the case of short circuit of two conductors in such a manner that contact material, movement of the contacts and energy supply occur wherever possible under worst-case conditions and with a high

repetition rate. From the various published curves for the ignition limit of simple circuits and a comparison with the known values of the minimum ignition energy of gas-air mixtures, we can deduce that the spark test apparatus can be used to achieve a power adaptation for the circuit under test, at which, for instance, frequently only approx. 50% of the stored energy is converted in the spark in the case of a coil energised with direct current while the other half is consumed in the internal resistance of the power source, at the rotary transmitter of the contact assembly and on the contact assembly itself.

On circuits with coils, the energy input to the sparks is optimised by the fact that the spark formed during contact breaking and whose base points, after all, move quickly away from each other is maintained for longer owing to the rising induction voltage.

Historic and design details of the spark test apparatus clearly indicate that the design was intended primarily for investigation of circuits with power supply from direct current sources.

Intrinsically safe circuits with frequencies in the range of up to 100 kHz for energy transmission

It was already known at a very early point – for example from publications by Bittner [7] and those by Burstow, Loveland, Tomlinson and Widginton [8], that the electrical values required for an ignition rise in the case of AC circuits with frequencies above a few kHz, this primarily being attributable to a breakdown of the sparks at zero crossing of the voltage.

Since this effect showed a clear rise at frequencies up to approx. 100 kHz, the obvious approach was to use it for intrinsically safe transmission of electrical power values, which lay clearly above the values which could be achieved with direct current.

The interrelationships were initially investigated by the Bergbau-Forschung GmbH, which was incorporated in the DMT, in coop-

eration with the BVS, within the framework of the 'Fundamentals for Intrinsically Safe Power Supply' project (1981-1984) [9] and, thereafter, by the BVS within the framework of the 'Investigation into Determination of the Limits of Intrinsically Safe Energy Transmission with High Frequency' project, promoted by the European Coal and Steel Community (ECSC) and, subsequently, in the 'Investigation into the Possible Applications of Intrinsically Safe Circuits with High Frequencies in Underground Mining' project, promoted by the BMWi (German Federal Ministry of the Economy) (1985-1987).

The first technical innovation utilising this effect related to intrinsically safe lighting devices whose fluorescent lamps with power ratings of 7-9 W were operated with intrinsically safe circuits (for methane) (Figure 1).

The main advantage of these devices used for coalface lighting was the possibility of being able to continue operation of the lighting system which did, after all, have a better light efficiency than incandescent bulbs, but required a high starting voltage, even if the non-intrinsically safe circuits needed to be



Figure 1: Intrinsically safe lighting device with 8 W fluorescent lamp

switched off due to an elevated CH_4 content of the mine atmosphere. The systematic investigations of the BVS aimed at determining the ignition limit values were extended, right from the very start, to cover the potentially explosive mixtures of air with methane, ethylene and hydrogen but – owing to problems with the safety factors – not the special mixtures used in the IEC as adapted from the GOST Standards.

For various reasons, the following restrictive boundary conditions were defined for these:

- Internal resistance of the source 50 Ω (as low-inductive as possible) or up to 3 k Ω ,
- Number of sparks increased by a factor of 10^2 in comparison with the conventional test method of the Standard in order to counteract the reduced probability of the occurrence of optimum spark conditions deduced from the sampling theorem,
- Voltage waveforms: sinusoidal, delta and square-wave.

The results are shown by way of example in the diagram in Figure 5. In comparison, Figure 6 shows the results of investigations conducted by other research groups. The results



Figure 2: Test set-up for measurement of the ignition limit values for frequencies up to 100 kHz

were presented in extract form in 1984 in Antwerp [9] and at the IEEE Conference in 1988 in London [10].

The concluding report of the ECSC project 'Investigation into Determining the Limits of Intrinsically Safe Energy Transmission with High Frequency 1987-1990 ECSC' was not published in its entirety, but was made accessible only to other testing institutes.

With all due caution, it was possible to deduce from these results that approximately the following power values applied to 50 Ω (not taking into account the safety factor or propagation factors per unit length) still did not pose the risk of explosion in the frequency band 50 kHz to 100 kHz, referred to the most interesting aspect – the maximum transmittable power:

- Methane: 32 W
- Ethylene: 13 W



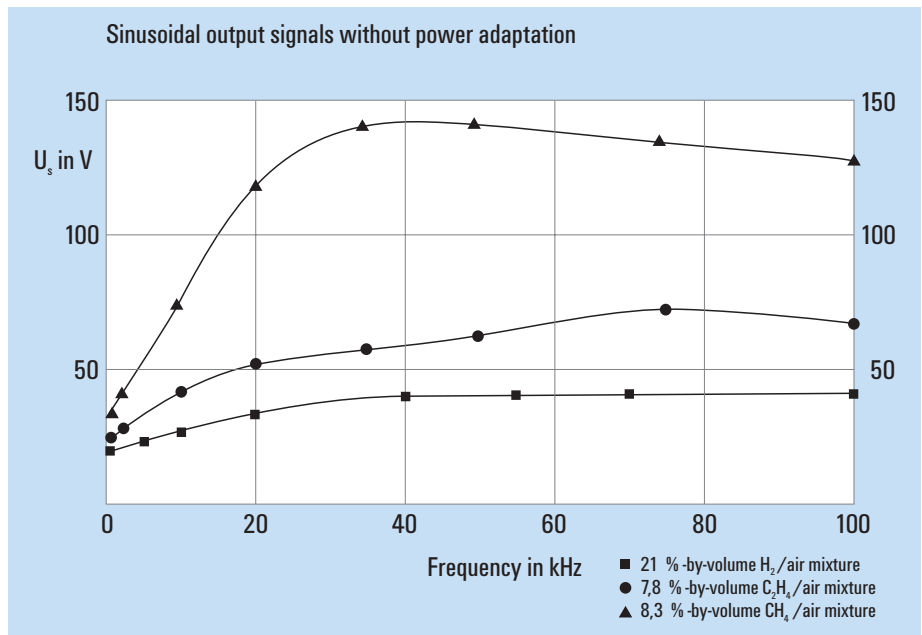


Figure 5: Ignition limit values at high frequency for hydrogen, ethylene and methane / air mixtures

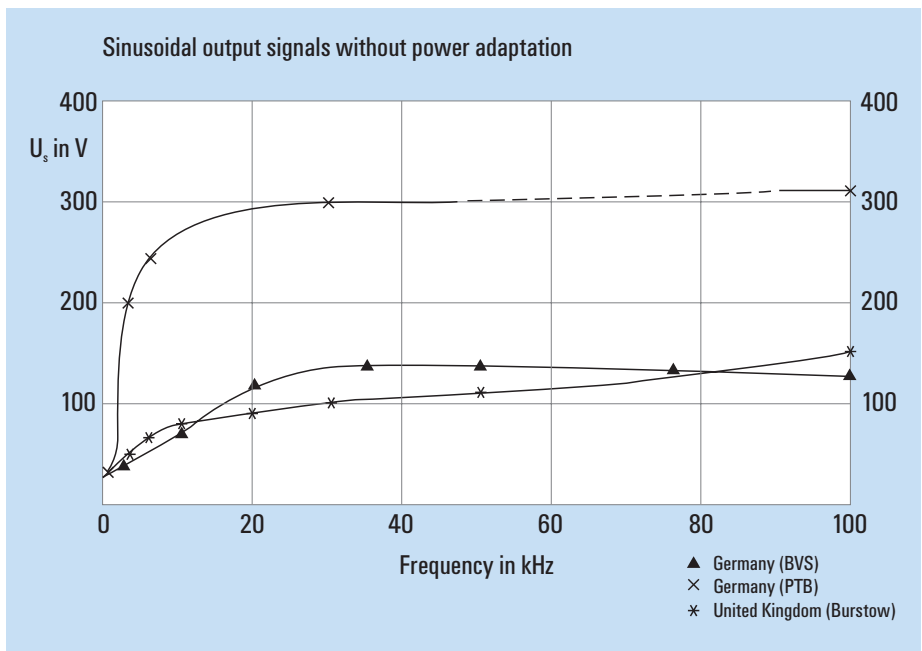


Figure 6: Ignition limit values at high frequency for methane/air mixture, Comparison with results of various testing institutes (from the years 1976 - 1984)

EEx ib(ia), additional disconnection devices):

- For hydrogen/air mixture IIC, whereby $f = 80 \text{ kHz}$, 10 W up to 100 m cable length 5 W up to 400 m cable length.

The cut-off frequency of the spark test apparatus

Even as early as the above mentioned investigations conducted by the BVS in the years 1987-1990, the spark test apparatus had been modified in many respects (Figure 3):

- Optimisation of the rotary transmitters for transfer of the circuits to the rotating parts of the contact assembly, in particular for reducing the voltage drop and the parasitic inductance,
- a cruciform component in place of the square holder for the tungsten wires in order to reduce the parasitic capacitance.

The 'Investigation into the Possible Applications of Intrinsically Safe Circuits with High Frequencies in Underground Mining' research project, promoted by the Federal German Ministry of the Economy (1985-1987), involved the BVS, for the first time, systematically investigating the frequency-dependent characteristics of the spark test apparatus in accordance with EN 50020 for higher frequencies.

These investigations also included prototypes of spark test apparatus designed specifically for high-frequency circuits. Some of these units had been passed on by PTB employee Bittner to G. Vogt, Head of BVS's Intrinsic Safety Laboratory, in the late seven-

→ ■ Hydrogen: 8 W

In 1996, the subject was taken up again by the PTB. The investigation results were published in the Gerlach's 1999 dissertation entitled 'Intrinsically Safe AC-Powered Field Bus Interface' at Braunschweig Technical University [11].

Here as well, the 'driving force' was the interest in increasing the power for remote

powering of distributed equipment of a bus system, the so-called ES-BUS (PTB publication, see Ex Magazine 2002, Page 60).

The results, in turn considered only with reference to the transmittable power, indicate the following values which, however, are not directly comparable with the aforesaid values owing to other boundary conditions (impedance $\neq 50 \Omega$, safety factor in accordance with



Figure 3: Modified contact arrangement of the spark test apparatus

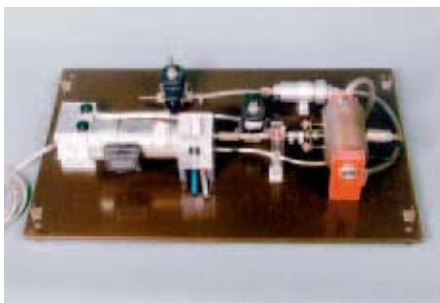


Fig. 4: Spark test apparatus with wave guide, suitable for HF

ties for the purpose of continuing the tests.

For the standard spark test apparatus, it was determined that, in the case of frequencies as of 1.5 MHz, the power reflected by the contact assembly becomes so significant that its use for technical safety assessment of circuits for ignitability in potentially explosive gas-air mixtures is at least not unproblematic [12].

Within the framework of the discussions in relation to Standard VDE 0848, Part 5, which, after passing through the Villamoura procedure owing to a parallel standardisation project of the BSI, could finally be published in 2001 as a White Paper, the frequency 1.5 MHz was stipulated as the limit value for the spark test apparatus. This limit value has now been included in the third edition of EN 50020.

In the case of the special designs of spark test apparatus designed for applications in high-frequency circuits, one type of construction proved to be particularly well-suited to HF operation (Figure 4). The design which partially takes the form of a wave guide had a very low reflection factor, at least in the frequency band up to 500 MHz (with contact assembly open), so that there was at least the hope that a higher percentage of the electrical energy is focussed on the point at which sparks are to be generated.

Intrinsic safety at 'high frequency'

What is actually meant by 'high frequency' depends on engineering semantics which is determined by the relevant priority technology.

In the chapter which follows, the term high frequency is intended to cover everything

in the frequency band above 1 MHz. Initial investigations into the subject of 'ignition of high frequency' were already conducted at a relatively early stage, e.g. by Bittner [7] and Widginton [8], to name but a few.

In some cases, authors also envisaged very specific scenarios, e.g. a high-power radio transmitter in the direct vicinity of a refinery or the radiation beam of radar equipment and refuelling aircrafts on an airfield.

Most of the studies assume that other areas subject to the risk of ignition may also exist, apart from the actual power supply circuit of the antenna. As soon as high frequency energy is radiated into free space, there is also the possibility of an unintentional reception pattern with and without transformation and – with a very low possibility and only at very high frequencies however – focussing. This circumstance was allowed for as early as 1985 in Standard VDE 0848, Part 3. The limit values for devices radiating high frequency that could radiate into hazardous areas was stipulated at 2 W.

The discussions were resumed in 1986 since only continuous sources had been dealt with and not pulsating sources, such as radar transmitters.

In parallel with Standard VDE 0848, the limit value of 1 W (until 1996) and 2 W high frequency was also stipulated in the Explosion Protection Guidelines (now referred to as: Explosion Protection Rules/Explosionsschutz-Regeln (EX-RL) of the BG Chemie on a standard basis, regardless of explosion group and application.

The results of the BVS investigations from the years 1983–1984 are summarised in Figure 7.

A value of 8 W applied to a resistance of 50Ω at 1 MHz in a hydrogen-air mixture was achieved as the lowest limit value for ignition achieved with the 'test apparatus' used. The further rise in the determined ignition values with frequency is primarily attributable to a worsening of the high-frequency characteristics of the test set-up. Consequently it was not easily possible to apply the results to safety

standardisation. It must also be pointed out that ignitions have already been detected with 2 W (hydrogen), 7 W (ethylene) and 12 W (methane) [13] in circuits with higher impedances.

A research project promoted by the German Federal Agency for Health and Safety (Bundesanstalt für Arbeitsschutz und Arbeitsmedizin) [14] achieved no more recent findings. The opinion, expressed by the project team at the time, that the spark test apparatus used by the BVS was 'bell wire technology' (which, viewed superficially, is justified to a certain extent – it is the result of many decades of empirical research) was not able to be verified directly. The tests which were conducted with major effort and very high power precision led to ignition limit values which were only around one tenth as high as the results already known. The evaluation of the known test results and the known literature were reflected in VDE 0848, Part 5, in Tables 2 and 3.

Table 4 in VDE 0848, which is not cited here for reasons relating to space, is also important in this connection. It contains examples of the safety distance between an HF source and a hazardous area, dependent on transmission frequency and transmission power, calculated in accordance with VDE 0848. If it is not possible to theoretically determine the limit values, the BVS has available corresponding HF spark test apparatus for the corresponding practical tests as demanded in VDE 0848.

For example, a safety distance of at least 0.2 m, regardless of zone classification, is scheduled for a GSM mobile phone (890 MHz) with a power range of 2–4 W.

Danger of explosion resulting from mobile phones

In March 2002, there were reports in the USA from the ISA Newsgroup 'safetylist' of an explosion incident in which an engineer, working on a closed loop control equipment operated with natural gas, received a call on →

Continuous high-frequency sources

Ignition as the result of continuous high frequency discharge is not anticipated, if the effective power, which can be drawn from the reception pattern, averaged over the ignition induction time, does not exceed the ignition limit values P_{zg} specified in Table 2.

Table 2: Ignition limit values on the reception pattern for continuous high-frequency sources	
Explosion group	Ignition limit value of the true power P_{zg}
IIA	6 W, averaged over 100 μ s (see note)
IIB	4 W, averaged over 100 μ s (see note)
IIC	2 W, averaged over 20 μ s (see note)

NOTE: Averaging must cover the time spans of the specified ignition induction times, thus resulting in corresponding smoothing of the power curve.

Pulsatory high-frequency sources

The energy which can be drawn from the single pulse, for pulsatory electromagnetic fields (e.g. radar), on which the pulse duration is shorter than half the ignition induction time, but on which the time span between two consecutive pulses is longer than three times the ignition induction time, is a more suitable ignition criterion. Under these conditions, an ignition as the result of a pulsatory high-frequency discharge cannot be anticipated, if the maximum energy of the single pulse which can be drawn from the reception pattern does not exceed the ignition limit values W_{zg} specified in Table 3.

Table 3: Ignition limit values of the energy of the single pulse W_{zg}	
Explosion group	Ignition limit value of the single pulse W_{zg}
IIA	950 μ J
IIB	250 μ J
IIC	50 μ J

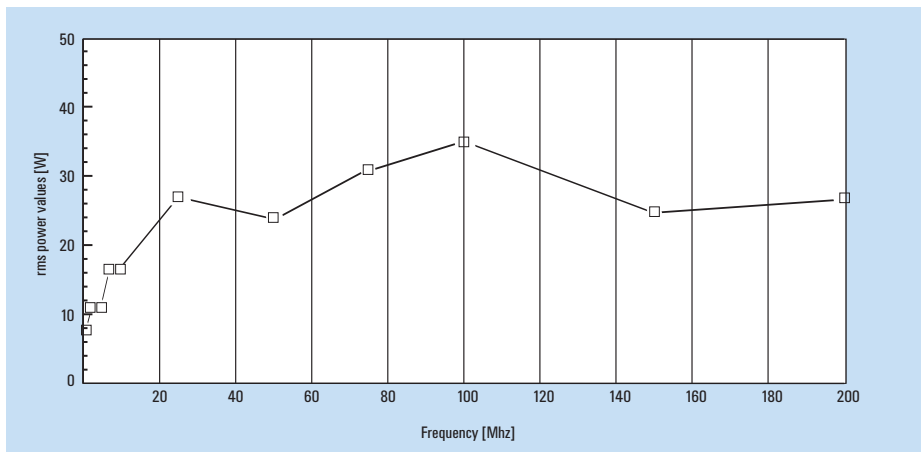


Figure 7: Minimum ignition power values for 21 %-by-volume H2/air mixture, sinusoidal output power without power adaption

→ his mobile phone, and, when taking the phone out of his pocket and answering the call, was singed slightly by igniting gas. Now, this information should also be read in the context of the fact that in the USA, portable electrical

devices, such as mobile phones and hand-held radio sets, are not subject to compulsory certification by an explosion protection testing authority.

Time and again, we read articles in the lay

press dealing with banning the use of mobile phones at petrol stations, but generally not corroborated, technically well-founded information. There are certain indications that the misgivings of service station operators are aimed more at unintentional influencing of electronic metering and billing systems than at the risks of explosion. The area in which mobile phones are likely to be used at service stations can, at worst, be classified as Zone 2, if we disregard the direct vicinity of the filler neck.

What potential sources of ignition does a mobile telephone have?

1. Electrostatic charging of the case
2. Short circuit/open circuit sparks on batteries, coils and capacitors
3. Heating of small components in the event of faults in other components
4. High-frequency radiation

We should not belittle the first aspect. Plastic enclosures and cases, particularly if they are partially metal-plated, can, in some cases, become charged excellently, in particular as the result of friction against clothing. The second aspect – e.g. ignition as the result of short circuit sparks in the case of mechanical damage – cannot be fully excluded without a more detailed consideration of the type of construction of the device. Point 3 must be assumed as being possible on the basis of the normative fundamentals of explosion protection but only as of Zone 1 or Equipment Category 2 in accordance with Directive 94/9/EC.

The fourth aspect only becomes relevant, if the radiated power of the mobile phone rises above the limit value (6 W for service stations), which, in view of the types of construction customary today, is possible only if the power control circuitry of the output stage is defective.

At least the 'European' approach that mobile phones must be independently tested and certified for use in Zone 1, as must any other electrical device, is simply a logical consequence of the safety aspect. However, this approach does have one handicap: the

type test in accordance with EN 50020 / IEC 60079-11 necessitates a check of the design documents and testing of a prototype for behaviour in accordance with the fault states to be assumed in accordance with the Standard – in particular overheating of small components in case of a short circuit of semiconductor components or inadequate creepage distances – and a stipulation of the type of construction. In view of the current pace of innovation in this sector and the known difficulty of obtaining complete circuit diagrams and component assembly diagrams from the manufacturer for such devices, this is already a very demanding project.

Summary

The known investigation methods for determining the intrinsic safety regarding the danger of ignition as the result of sparks from control and instrumentation circuits by application of standardised diagrams or using the spark test apparatus in accordance with EN 50020 and IEC 60079-11 can be used, as is well known, only within specific limits.

One of these limits is also the frequency of the circuit. On the basis of direct current, the intrinsically safe electrical values are, admittedly, significantly higher than is the case with direct current in specific frequency bands. However, as the frequency increases further, they do drop again.

An integral consideration of hazardous areas must not overlook the potential danger of ignition resulting from electromagnetic radiation from transmitters that may be arranged outside of the hazardous area either. This article discusses the subject only in respect of gas explosion protection. However, it is also a basic problem for areas subject to dust explosion hazard. Therefore, we must also note in this case that locally restricted overheating may occur dependent on the dielectric properties of the dusts and the frequency used at higher HF power values, for example also as the result of dipole resonance.

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