Updated from a paper of the same title first presented in India in 1981 see
'Appendix' on page 16 for details

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Intrinsic Safety Rules OK for Process Instrumentation

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ABSTRACT

The technique of intrinsic safety was originated in England for mine signalling, following a serious mine disaster in 1913. The first surface certificate was issued in 1936 and the first formal standard in 1945, but it was not until the 1960s that the technique came into its own for process measurement and control, with the development of the shunt-diode safety barrier based on the Zener diode.

This paper outlines the development of the technique and describes some typical applications of the shunt-diode barrier and its more recent companion, the isolating interface device. It also looks briefly at the new IS instruments being made possible by advances in low-power semiconductor technology.

1. HOW IT ALL STARTED

The concept of intrinsic safety, though not yet the name, was originated in England during the years 1914 to 1916. On 14th October 1913, a serious explosion in the Senghenydd colliery, Glamorganshire, South Wales, led to 439 Welsh miners losing their lives. The official report on the disaster gave the cause as an explosion of fire-damp, ignited by 'sparking from electric signalling apparatus or from falling rocks'.

1.1 Mine signalling

The bare-wire signalling system in use at the time comprised a pair of galvanized steel wires suspended along the roadway to a coalface and connected to a trembler bell or intermediate relay via a Leclanché cell. When a miner or the bell patrolman connected the wires together with his steel 'T-bar', or by hand, the bell would ring instructing the winch operator to haul back the tubs full of coal.

Although this technique had previously been regarded as safe, investigation by the British Home Office Experimental Station at Eskmeals, Northumberland, subsequent to the disaster, showed that the 'break-flash' occurring when the wires were separated, or at the contacts inside the bell, could in fact ignite flammable mixtures of methane and air.[1]

Further investigations by the same authority in 1915 and 1916, in co-operation with Durham University's Armstrong College in Newcastle-on-Tyne, showed that the break-flash was largely due to the energy stored in the inductive solenoid of the bell or relay and could be reduced to a safe level by suppressing the coil, limiting the supply voltage to 25V, and restricting the energising current by a non-inductive resistor.[2]

Devices following these rules were tested, certified, and in 1917 applied down British mines, where similar devices are still in use today.

1.2 Early standards

For the next 18 years the technique was used exclusively in the mining industry, during which time it became known by the name 'intrinsic safety'. Then, in 1936 the first certificate was granted, by the British Factory inspectorate, for a 'surface' application where gases other than methane could be present.[3] In this case, coke-oven gas was the hazard.

The first formal standard to be issued on the subject was BS 1259: 1945. This British Standard defined the term 'intrinsic safety' (shortened to IS in this paper), laid down rules for operating, testing and certifying IS equipment and, in a later version (1958), classified a wide range of commonly occurring flammable gases according to their ease of ignition by sparks[4].

Ten years later (1956), the American National Electrical Code recognised the concept[5] and in 1965 the Instrument Society of America issued its Recommended Practice RP12.2 on the technique.[6] In Germany the first formal standard dealing with IS appears to have been an addition to VDE 0171 in 1965.

Neither the British Standard nor the American Electrical Code dealt with the alternative mechanism of ignition by hot surfaces, but this concept was recognised in ISA RP12.2 (1965) and had been put forward by Germany in 1964 for eventual inclusion in IEC Standard 79-8: 1969. In Great Britain it was not formally documented until the issue of BS 4683: Part 1: 1971.

1.3 New process instruments

In the mid 1950s, after 40 years' gestation, intrinsic safety was still employed largely below ground. However, the invention of the semi-conductor in the 1940s had given rise to transistors, diodes and other devices in the 1950s, which in turn led to the development of improved field mounting instrumentation for process measurement and control in the 1960s. The new instruments were smaller, cheaper and more reliable than their predecessors and operated at much lower power levels, making IS a practical proposition for process control in hazardous areas.

1.4 Developments in Europe

The application of IS to the new instrumentation moved at different speeds in Europe and North America.

In Europe, the key event was the development of the shunt-diode safety barrier, Figs. 1 and 2. This was a self-contained device, which could be connected

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**Chairman & Chief Executive*

in series with the signal cables between a control room and the plant and would pass measurement and control signals without significant attenuation, while restricting the energy that could be transmitted under fault conditions to a safe level. It was based on a carefully specified fuse, the new semiconductor voltage-limiting component known as the *Zener diode*, and a series resistor that could not fail to short circuit. It stemmed from ideas put forward at a British Summer School held in 1961 on the design of instrumentation for use in hazardous areas.[7]

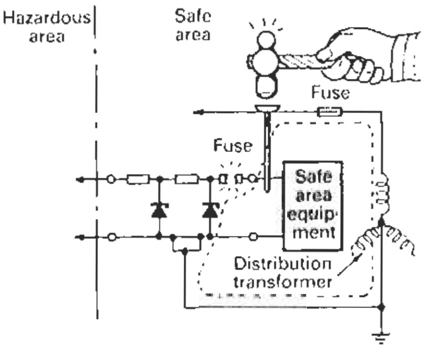


Fig. 1. Operation of shunt-diode safety barrier

The great advantage of the barrier approach was that it removed the need to certify recorders, controllers, displays and other instruments in the safe area, making the use of IS much simpler and more flexible. As a result, most European manufacturers of process instruments during the 1960s and early 1970s began to offer IS as an alternative to the traditional, more cumbersome, flameproof technique.

The safety barrier itself was progressively developed, becoming neater and smaller and easier to install, partly due to the introduction of 2-channel models in 1971. Fig 2 shows a modern design with vibration-proof terminals which accept field wiring directly. It mounts immediately under a nickel-plated brass or copper busbar to ensure that the vital earth connection is easy to inspect and cannot be forgotten. The double earthing studs are plated with a soft material and make high-pressure 'gas-tight' joints which are immune to vibration and corrosion.

Fig. 3 shows how large numbers of such barriers can be installed to form a comprehensive 'interface' between the safe and hazardous areas, with non-removable terminals for keeping cable screens safely earthed and provision for identifying both the barrier type and the loop number permanently at each location. Though usually mounted in a cabinet or behind a panel in the safe area, barriers sometimes need to be assembled in small groups, protected from casual interference or the weather, Fig. 4.

1.5 Developments in the USA

In the USA the safety barrier did not catch on, and most manufacturers and users of process instruments continued to employ the flameproof approach ('explosionproof' in American terminology) almost exclusively until about the middle 1970s.

A notable exception to this conservative philosophy was Motorola's 'Veritrak' line, the first complete system of electronic process instrumentation with integral intrinsic safety to be developed and marketed on a large scale.[8,9] This development by the Swartwout brothers used a common securely-regulated 24V dc supply for all field-mounted equipment, together with three wirewound resistors in each field circuit to limit fault currents. It was certified intrinsically safe by Factory Mutual in the USA and by Canadian Standards Association towards the end of 1965. It also, for the first time, converted the 4/20mA transmission currents into voltage signals on a common earth in the safe area, thereby eliminating the need to 'float' control room units and making it practicable to provide dc back-up power supplies.

Veritrak, evidently ahead of its time, helped prepare American opinion. Then, from the 1970s American companies involved in North Sea exploration provided many instrument engineers with first-hand experience of the difficulties of maintaining flameproof equipment in hostile environments - e.g. the enclosures would fill with sea water - and demonstrated the advantages of the new technique.

Today, many process instrument systems in America offer intrinsic safety either integrally or via barriers, and the use of the technique is increasing steadily.

Fig.2. Modern safety barrier.

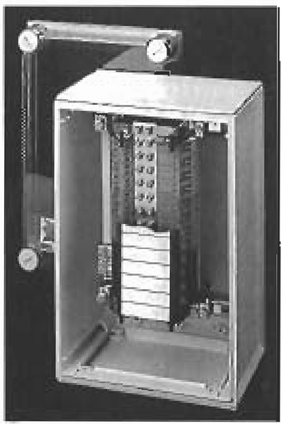


Fig.4. Weatherproof enclosure.

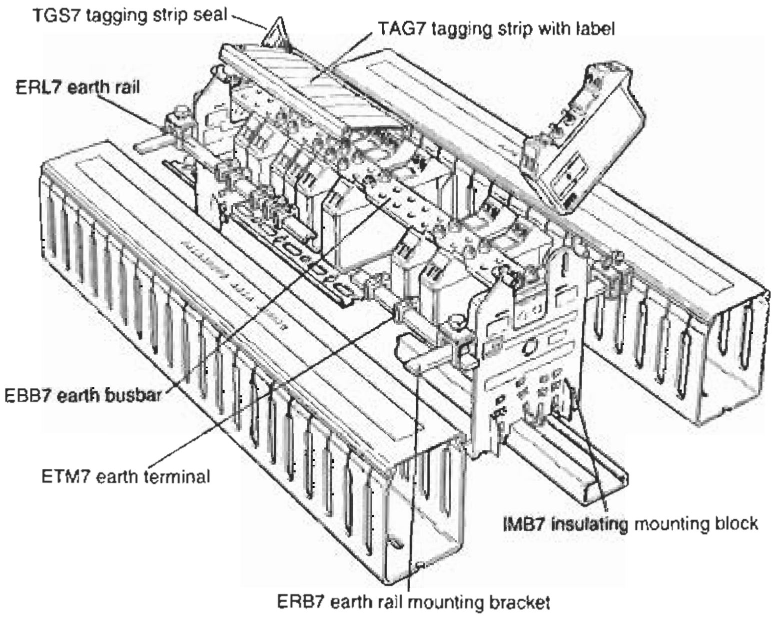


Fig.3. Mounting and tagging arrangements.

2. THE IS TECHNIQUE

Intrinsic safety is one of several techniques for preventing explosions in hazardous areas. It operates by limiting the electrical energy available in circuits and equipment to levels that are too low to ignite the most easily ignitable mixture of gas and air that is ever likely to be present.

Two ignition mechanisms are taken into account - namely, electrical sparks and electrically heated surfaces. The 'gas' can include other flammable materials such as dusts, fibres and flyings. The circuits and the equipment are designed so that safety is maintained both in normal use and under all probable fault conditions.

Intrinsic safety is essentially a low-power technique, restricted in practice to about 1W in hydrogen atmospheres, and therefore well suited to industrial instrumentation. It is of no use for high-power equipment such as electric motors or lighting, but it is often used to render safe the circuits that control them.

2.1 Advantages of low power

All other methods of protection - e.g., pressurisation, use of flameproof enclosures or oil filling - rely on the maintenance of a physical barrier between the explosive atmosphere and the electric circuit. Out on the plant and difficult to monitor, this rigid 'Maginot line' has only to be breached at one point for protection to become non-existent. In contrast, and uniquely, IS gives inherent protection by restricting the energy at its source and as a result has the following technical and commercial advantages:

a) Live maintenance: It is not necessary to obtain a gas-free certificate or close down the loop before calibrating or otherwise servicing field equipment. Glanded or magnetically-coupled controls through flameproof housings are not needed.

b) Lower cost: Enclosures are lighter, less cumbersome and cheaper, and costly armoured cables or screwed conduit can be replaced by ordinary wiring. Thermocouples, resistors, switches and other 'non-energy storing' field equipment can be to ordinary (weatherproof) specifications.

c) Greater reliability: The system remains safe if seals fail, diggers cut through cables or the covers of enclosures or conduit boxes are improperly replaced, perhaps with nuts lost or incorrectly tightened. Switches do not require long, thin flame-retarding air gaps which are prone to corrosion and seizure.

d) Safer: Personnel cannot be harmed by the low voltages used in IS circuits.

e) Wider applications: For practical purposes it is the only explosion-protection technique that can be used in Zone 0 (high risk) hazardous areas.

2.2 Gas classification

The more important of the two ignition mechanisms, and the one that was first recognised (in 1914), is *ignition by electrical sparks.* A huge volume of experimental work, carried out on 'break-flash' apparatus in laboratories all over the world, has produced empirical but generally agreed 'ignition curves' for the most easily ignitable mixtures of air with all commonly found flammable gases. There are three curves for every gas, according to the type of circuit. They are:

(i) *For resistive circuits:* minimum igniting current against voltage.

(ii) *For inductive circuits:* minimum igniting current against inductance.

(iii) *For capacitive circuits:* minimum igniting voltage against capacitance.

Designers could use these curves, with suitable safety factors added, for designing IS circuits and equipment. However, in practice and for simplicity, all gases are classified into just a few 'groups' according to their ease of ignition, and each group is typified by a common and easily reproducible 'representative' or 'test' gas to simplify routine testing of equipment. Therefore, IS equipment in practice is designed for safe operation in a particular gas group.

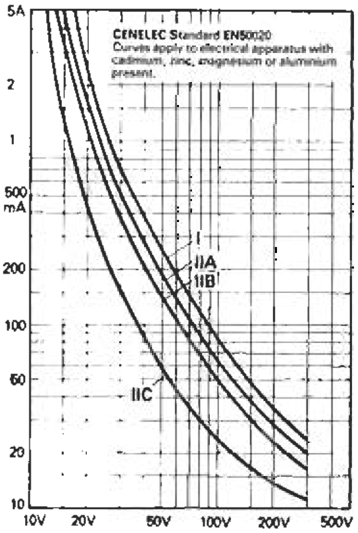


Fig. 5. Minimum igniting currents for resistive circuits.

Certifying authorities now issue agreed ignition curves for this purpose, based on the representative test gases. Fig. 5 shows the CENELEC (European) standard curves for resistive circuits in Group I and Groups IIA, IIB and IIC gases. The curves are repeated for systems containing and not containing cadmium, zinc, magnesium or aluminium, since these metal surfaces aid ignition. But in practice almost all certification is for the worst case, with these metals assumed to be present.

Two systems of classification are in common use today, one by countries following IEC and CENELEC standards,[10,11] and the other in the USA[12] and Canada: they are shown in Table 1.

All certified IS equipment carries a statement of the gas group it has been approved for, and obviously equipment that is safe for a particular group will also be safe for all groups that are less easily ignitable.

Representative (test) gas	Industry	Gas classification IEC countries (includes Europe)	 USA & Canada	Ignitability
Acetylene Hydrogen Ethylene Propane	Surface	Group IIC Group IIC Group IIB Group IIA	Class I, Group A Class I, Group B Class I, Group C Class I, Group D	↑ More easily ignited
Metal dust Carbon dust Flour, starch, grain		(Dusts not classified)	Class II, Group E Class II, Group F* Class II, Group G	↑ More easily ignited
Fibres & flyings			Class III	
Methane	Mining	Group I	Unclassified	

*Combined with G in USA from 1985 to 1987

Table 1. Gas classification: the two main systems.

Temperature classification	Maximum surface temperature	Desirability
T1	450°C	↓ Better equipment
T2	300°C	
T3	200°C	
T4	135°C	
T5	100°C	
T6	85°C	

Table 2. Universal temperature classification system.

IEC countries	USA & Canada
Zone 0: explosive gas-air mixture continuously present, or present for long periods	Division 1: hazardous concentrations of flammable gases or vapours –or combustible dusts in suspension – continuously, intermittently or periodically present under normal operating conditions
Zone 1: explosive gas-air mixture is likely to occur in normal operation	
Zone 2: explosive gas-air mixture not likely to occur and, if it occurs, it will exist only for a short time	Division 2: volatile flammable liquids or flammable gases present, but normally confined within closed containers or systems, from which they can escape only under abnormal operating conditions. Combustible dusts not normally in suspension nor likely to be thrown into suspension
UK (Germany)	
Zone Z (Zone 10): combustible dust is, or may be, present as a cloud during normal operating conditions	
Zone Y (Zone 11): accumulations of combustible dust may be present under abnormal operating conditions and give rise to ignitable mixtures of dust and air	

Table 3. Area classification: the two main systems

2.3 Temperature classification

Since gas-air mixtures can also be ignited directly by hot surfaces, the *surface temperature* of equipment is an important consideration.

As a result of work done largely in Germany and the UK, full information now exists on the ignition temperatures of all commonly found gases. Equipment to be installed in hazardous areas is therefore classified according to the maximum temperature that can be produced under fault conditions (at an ambient temperature of 40°C, or as specified), and the user must ensure that the temperature class of the equipment is below the ignition temperature of any gas-air mixture that may arise.

The system of classification, which was initiated in Germany and is now universally used, is shown in Table 2. It applies to all techniques of explosion protection, not merely to intrinsic safety.

It is interesting to note that there is no correlation between ease of ignition by hot surfaces and by sparks; the two mechanisms of ignition are entirely different. For example, hydrogen is easily ignited by a low-energy spark (20μJ) but has a high ignition temperature (560°C), whereas acetaldehyde requires a high-energy spark (150μJ) but has a low ignition temperature (140°C).

2.4 Area classification

Besides the two ignition mechanisms just defined, a third factor must be taken into account - namely, the degree of probability that an explosive atmosphere will be present. This factor, like the previous one, applies to all techniques of explosion protection and it determines which forms of protection are acceptable, according to their reliability.

Again, two systems are in common use today, as shown in Table 3. They are basically similar to one another except that the IEC's 'Zones 0 and 1' are both embraced by the North American 'Division 1', and North America classifies combustible dusts along with flammable gases or vapours, whereas the UK and Germany have adopted separate area definitions for dusts and a similar IEC standard is under consideration.

In any plant, the classification is carried out by the plant operation team, assisted by codes of practice issued, as a rule, by user bodies such as the Institute of Petroleum (UK) or the American Petroleum Institute.

To meet the reliability requirements for the different zones, European IS equipment is made and certified in either of two forms, having different degrees of redundancy in the key components, thus:

Ex ia: Safety maintained with up to two 'countable' component or other faults. May be used in, or connected into, Zone 0 hazardous areas (or Zone Z provided that the hazardous-area equipment has suitable IP protection).

Ex ib: Safety maintained with up to one 'countable' component or other fault. May be used in or connected into Zone 1 hazardous areas (or Zone Y provided that the hazardous-area equipment has suitable IP protection).

Certain components, such as wirewound resistors, are regarded as 'infallible' in respect of certain types of fault as are certain methods of assembly; the standards define which faults must be counted and which may be ignored. Obviously Ex ia equipment can be used in Zones 1 and 2 as well as in Zone 0 and, although it costs a little more, it is often adopted as standard for a particular plant in order to simplify maintenance procedures and reduce inventory.

In the USA, all IS equipment is certified to a single standard and can be used in or connected into Division 1 hazardous locations. American safety barriers are similar (electrically) to European Ex ia barriers, but without some of the mandatory component testing. Japan has adopted a similar 'ia-only' approach for intrinsic safety from 1985.

Flameproof equipment, by contrast, is not permitted in Zone 0 hazardous areas and effectively cannot be used in IIC atmospheres because of the extremely narrow air gaps that would be necessary. Although in principle it can be used in American Division 1 areas, current practice is to exclude it if the hazard is continuous - i.e. there are signs of a *de facto* recognition of the need for a third area category.

2.5 Marking

To summarise the requirements for intrinsic safety; all IS equipment is designed and certified to meet three criteria, two of which are common to all other techniques of explosion protection. These criteria are:

Area classification

Gas classification (specific to IS)

Temperature classification

It is also marked to suit. Thus an item of equipment certified for installation in high-risk hazardous areas, where hydrogen-group gases might arise, and suitable for use with gases having ignition temperatures down to 135°C, would be described and marked as follows:

IEC countries: EEx ia IIC T4

USA & Canada: Class I, Division 1
Groups A,B,C,D;T4

'Associated apparatus' certified for installation in safe areas only (where temperature classification is not relevant) but suitable for connection to equipment in a high-risk hazardous area, would be marked:

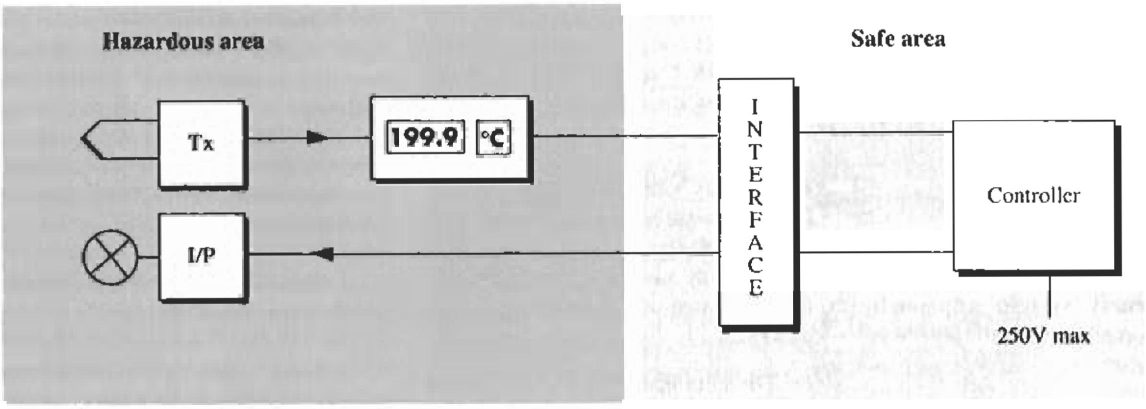


Fig. 6. Typical IS process control loop.

IEC countries: [EEx ia] IIC

USA & Canada: Class I, Division 1
Groups A,B,C,D

Note: 'EEx' stands for explosion protection to European standards, and the square brackets indicate that the equipment must be located in a safe area ('non-hazardous location' in America).

3. ENERGY STORAGE

Besides the ignitability of the gas and the probability of its being present, it is necessary to consider the question of energy storage in hazardous-area cables and equipment. Clearly there is no point in limiting the transmitted voltages and currents if they can be stored up in capacitors and inductors over a period and then released in a burst of greater magnitude. This possibility must either be eliminated by design or quantified and allowed for.

Consider the typical IS process control loop shown in Fig. 6. It can be divided into three parts:

(i) *Safe-area equipment:* Provided that it does not actually embody the interface, this may be of ordinary uncertified design and can be exchanged or modified at will, subject only to the easily met rule that it contains no voltage greater than 250V rms or dc and is supplied via the usual isolating power transformer protected by a suitable fuse.

(ii) *The safety interface:* This may comprise shunt-diode barriers or some form of isolating interface device not needing an earth, and by design will be non-energy storing.

(iii) *Hazardous-area cables and equipment:* This is the area where energy storage matters.

3.1 Hazardous-area circuits

The capacitance and inductance of long cables from the interface to the plant will store a certain amount of electrical energy in normal operation and even more under fault conditions. There is no simple way in which this effect can be suppressed, so the certificate for the interface always specifies the maximum values of capacitance and inductance that are permitted for the associated cables. These 'cable parameters' depend on the ignitability of the gas but, in practice, they seldom constitute a limitation, even when the gas is hydrogen.

Since the resistance per unit length of a cable (R) damps the effect of its inductance per unit length (L), a third criterion (L/R) may be used instead of inductance, and is less stringent for long cables.

IS circuits are subject to a few other obvious rules: for example, to avoid an escalation of fault energy, they must not be connected to any other IS circuit, including 'earth returns'.

If they are protected by shunt-diode safety barriers, they should also be insulated from earth, see Section 5.2.

3.2 Hazardous-area apparatus: non-energy storing

All certifying authorities now allow devices that neither generate nor store significant amounts of energy to be added to hazardous-area circuits without certification or special marking.

BASEEFA (UK) terms them 'simple apparatus'. In America they are known as 'non-voltage producing', while CENELEC standard EN 50 014 (Electrical apparatus for potentially explosive atmospheres - general requirements) now defines them specifically as 'devices in which, according to the makers' specifications, none of the values 1.2V, 0.1A, 20μJ or 25mW is exceeded'. Factory Mutual (USA) and RIIS (Japan) have recently adopted the same definition.

The definition includes a wide range of devices such as switches, resistors, thermocouples, photocells and light-emitting diodes; and recently (1985) certain apparatus such as loop-powered local indicators, designed to look the same electrically - see Section 8.3. Being able to use them freely is a joy to everyone.

3.3 Hazardous-area apparatus: energy storing

Any 'complex' electronic equipment, such as a 2-wire transmitter or a current-to-pneumatic (I/P) converter, can easily store dangerous amounts of energy in its internal capacitors and inductors and will often do so. Such equipment cannot be used in a hazardous area unless designed and then certified for the purpose.

The design techniques used to make complex equipment intrinsically safe include (i) incorporation of resistors to limit the discharge current of capacitors and (ii) suppression of inductors by shunt diodes. These safety components may be duplicated for reliability. Critical parts of the circuit are then encapsulated in a suitable insulating compound to prevent their being tampered with and to contain the spark if, for example, the coil of an inductor should fracture. Construction also must follow rules governing insulation thicknesses and creepage and clearance distances between conductors. The equipment then has to be approved by the relevant certifying authority.

Certified energy-storing equipment of this type usually appears resistive at its terminals, though sometimes components such as RF filters, which of necessity are external to the main circuit, may endow it with a small amount of residual inductance or capacitance.

4. APPROACHES TO CERTIFICATION

4.1 Rôle of certifying authority

In most countries, responsibility for the safety of a plant falls squarely on the owner. He must convince his local factory inspector that the plant is safe and may try to do so, if he wishes, from first principles. However, in practice his task is made much easier, to say the least, if he can provide documentation to show that relevant items of electrical and electronic equipment have been tested and certified as safe and are connected together in a safe manner.

4.2 The early 'system' approach

Since almost all process instruments end up in systems, they interact with each other from the safety point of view. Hence the way in which authorities tackle the certification of interconnected instruments and devices is of great importance.

In the early days of intrinsic safety, due to lack of experience and knowledge, the authorities then in being certified each IS 'system' as a whole, e.g. a recorder together with its thermocouples or a transmitter with its power supply. Any change in any item required re-certification of the lot, leading to high costs, long time delays and slow acceptance of the technology.

4.3 A useful advance

With the advent of the safety barrier, it became widely accepted that thermocouples, resistors, switches and the like did not contribute significant fault energy and so did not need certifying. Although it was many years before the non-energy storing/non-voltage producing concepts were formally quantified and defined, this was a valuable simplifying step in the right direction. However, a system certificate was still needed for a transmitter, listing permitted barriers by maker's name and type, thus maintaining an effectively closed market. Apparatus certificates were also required for each individual item. Factory Mutual (USA) continued with this approach until 1979, when it adopted the 'Entity Concept'.

4.4 The Japanese anomaly

Although the RIIS eliminated system certificates from 1981, it was 1985 before Japan accepted the non-voltage producing concept. Between these two dates it required apparatus certificates for 'low-energy storing' sensors, a unique approach which inhibited the use of IS technology locally and caused difficulties for importers. But even in 1992, IS is not widely used within Japan because the electrical limits defining 'simple apparatus' (1.2V, 0.1A etc) have been 'applied' to the associated barrier - a misunderstanding if ever there was one.

In 1985 Japan adopted almost all the CENELEC 'rules', including its gas and temperature classification systems and the definition of 'simple apparatus'; though, like the USA, it opted for only one equipment reliability category, equivalent to 'ia'.

4.5 Today's modular approach

Except in some countries in East Europe, all authorities as far as is known, now accept a fully modular approach to certification, based on the following principles:-

a) The certificate for a safety barrier states the maximum permitted cable parameters and the maximum voltage and current that it can deliver under fault conditions.

b) The certificate for a transmitter states the maximum voltage and current that it can receive and the values of any residual inductance and capacitance.

c) The transmitter can then be used safely with any barrier whose maximum voltage and current are equal to or less than the maxima for the transmitter.

d) The maximum permitted cable parameters for the combination are derived by deducting the transmitter's residual figures from the values for the barrier.

e) The concept extends to take account of any number of items. (Though this is not always quite as simple as it sounds!)

Each instrument or interface device is certified as apparatus in its own right and no system certificate is needed. Manufacturers can apply for certification of their products without reference to competitors' products and users can mix different brands without special approval. Progress is faster in the resultant open market and the queues at the test houses are diminished.

PTB in Germany adopted this approach some 15 years ago and pursued it with customary rigour, refusing to provide system certificates since they were not necessary. Other authorities in Europe and elsewhere then followed in PTB's wake, although some will still provide system certificates for the asking.

The USA has been implementing the approach since 1979[12] under the name 'Entity Concept'.

In South Africa, SABS still requires to vet the assembly of units and cables in each individual system but now does so on the basis of the Entity Concept.

4.6 National affiliations

Table 4 shows the affiliations of some countries to international standards and legislation in respect of intrinsic safety. All the countries voting for or against International Electrotechnical Commission Standard IEC 79-11, 1976, 1984 and 1990 editions, are included.

Column 2 shows how the countries voted on the IEC standard.

Column 3 shows which of the countries are members of the European Committee for Electrotechnical Standardisation (CENELEC) and consequently are required to give CENELEC standards national status.

Column 4 shows which of these countries have published national versions of all seven CENELEC harmonised standards dealing with the commonly recognised methods of explosion protection.

Column 5 indicates which countries are members of the European Community (EC) and therefore are bound not to 'prohibit the sale or the free movement or use' of equipment having a 'certificate of conformity' to CENELEC standards issued (since August 1980) by any EC-approved test house (Column 6).

Column 7 lists the initials of national certifying authorities, where known. Note: although certification authorities are sometimes combined with standards bodies, most countries have an independent factory inspectorate.

5. EARTHING OF SHUNT-DIODE BARRIERS

Since shunt-diode safety barriers work by diverting fault currents to earth, their connection to this magic place must be both effective and secure and the associated circuits on both sides of the barrier must normally be earth free so as to avoid multiple earth connections.

5.1 The earth connection

All countries recommend that shunt-diode barriers should be insulated from surrounding metal so that they can be earthed in a defined manner. Most standards require the earth cable to be insulated to prevent invasion by fault currents, protected mechanically if there is a risk of damage, and identified to indicate its purpose. This is normal engineering practice and not expensive.

They also require that the earth cable should have an uninterrupted run to the nearest high-integrity earth point, defined

1	2			3	4	5	6	7
Country	Voted for IEC79-11			CENELEC member country	National CENELEC standards published	EC member country	EC approved test house	National certifying authority
	1976	1984	1990					
Argentina								INTICITEI
Australia	√	√	√					SA
Austria	√			√				ETVA
Belgium	√	√	√	√	√	√	√	ISSeP
Brazil		√	√					CEPEL
Canada	√	√	√					CSA
CIS (USSR)	√		Against					VNIIVE
China		√	√					
Czechoslovakia			Against					FTZU
Denmark	√	√		√	√	√	√	DEMKO
Egypt		√	√					
Finland	√	√	√	√	√			SETI
France	√	√	√	√	√	√	√	LCIE & INERIS
Germany	√	√	Against	√	√	√	√	PTB & BVS
Greece				√		√		
Hungary	√	√	√					BKI
Ireland			√	√		√		
Israel	√	√						
Italy	√	√	√	√	√	√	√	CESI
Japan	√	√	√					RIIS
Korea	√							
Luxembourg				√		√		
Netherlands	√	√	Against	√	√	√		
Norway	√	√		√	√			NEMKO
Poland	√		√					GIGKDB
Portugal	√			√		√		
Romania	√		n.r.					SMIP
S. Africa	√							SABS
Spain		√	n.r.	√	Allocated	√	√	LOM
Sweden	√	√	√	√	EN 50 020			SP
Switzerland	√	√	√	√	√			SEV
Turkey	√							
USA	Against	√	n.r.					FM & UL
UK	√	√	√	√	√	√	√	BASEEFA HSE (M) & SCS.
Yugoslavia	√	√	n.r.					S.Comm.

Table 4. National affiliations at July 1992 *n.r. =no reply*

slightly differently in different countries, and that the total impedance to earth should not exceed 1Ω. The length and cost of installing such a cable therefore depends on the distance to the nearest substation, 'ground reference point' or 'potential-equalising conductor'. It is seldom significant in large plants with many barriers but may be so in small or scattered installations.

Since the resistance to earth must be checked from time to time it is good practice to install two cables, connected separately to the busbar. It is then a simple matter to break one cable and measure the resistance of the loop without running temporary wires.

5.2 Insulation of hazardous-area circuits

Since earth potentials differ from place to place within most process plants, there is always the danger that multiple earths on a hazardous-area circuit could give rise to sparking. The 'return' circuits to single channel barriers are earthed at the interface and the 'live' circuits may conduct to earth at quite low voltages. It is therefore important, except in very special circumstances, that all hazardous-area conductors and equipment should be suitably insulated.

CENELEC (European) standards require that the entire hazardous-area circuit connected to a shunt-diode barrier should be capable of withstanding a test voltage of 500V rms to earth and that the wiring should be insulated to a thickness of 0.2mm (to resist abrasion). This requirement applies even in Zone 2 areas and includes the sensors and other equipment as well as earth returns and cable screens.

American standards to date seem to have avoided the problem, and even the latest (1987) version of ANSI/ISA-RP12.6: Recommended Practice: Installation of Intrinsically Safe Systems for Hazardous (Classified) Locations[13] gives no guidance. However, recent (October 1987) proposals[22] to amend the National Electrical Code NFPA 70-1987 are putting forward the view that 'it is important to recognise that more than a single connection to ground could jeopardise the intrinsic safety of the system...', so it appears that the USA may be moving towards acceptance of European principles in this area.

In practice there is seldom any problem, since most normally-used cables are adequately insulated and the great majority of sensors and field-mounted equipment meet the 500V test requirement. However, some sensors do not do so, for example fast-response thermocouples welded to a vessel, conductivity-type level detectors, some strain-gauge bridges and some semiconductor measuring elements. In such cases, the solution is to use transmitters or interface devices that incorporate galvanic isolation.

6. NEW INTERFACES

During the 1980s, two major advances have transformed the IS interface from the original conception, making it more versatile, more tolerant of supply variations and easier to use. They are the isolating interface device that does not need a safety earth and the 'super' shunt-diode barrier with built-in electronic overvolt protection and enhanced performance.

6.1 Advantages of isolation

The constraints imposed by the shunt-diode barrier can be reduced, at some increase in cost, by the use of isolating IS interface devices that do not tie the hazardous and safe-area circuits to earth .[14]

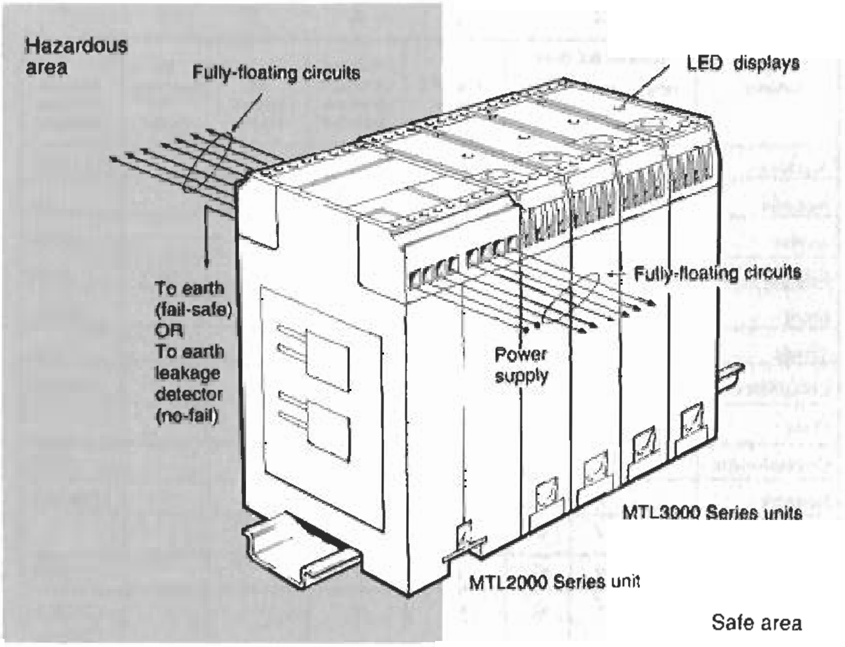


Fig. 7. Typical IS 'interface units'.

Then each circuit can be earthed at the most convenient point rather than at the barrier busbar and, provided that the isolator is suitably designed, there is no need for a special high-integrity earth connection to carry away fault currents. Nor is it necessary to worry about the polarity of the signal or the supply, since the isolator can always be appropriately connected.

In the safe area, power supply circuits can be more easily separated from signal circuits so that voltage drops in one do not affect the other, and some otherwise intractable problems can be solved, such as communicating with a control computer for which a separate earth connection is demanded by its makers.

In the hazardous area, thermocouples and other sensors can be earthed, incidentally meeting German application codes of practice for Zone 0. Or, if the circuits are left floating, they are immune to one earth fault, and higher levels of earth-fault protection can if necessary be provided. The cables must still be insulated, of course, but in practice this is never any problem.

Since all isolating devices require some power to energise their circuits, they almost inevitably incorporate voltage-regulating circuits, which protect them against excessive voltages. Typically they operate from 20-35V dc supplies or from the ac mains, though some may be loop powered from the signal.

By the same token, isolating interface devices lend themselves to the incorporation of amplifiers and relays. Thus, they need not be merely passive signal-transfer elements, but can provide a range of the basic electrical functions that are commonly required in process control applications.

For all these reasons, isolating devices are easier than shunt-diode barriers to apply and are growing gradually in popularity as new users come to recognise the advantages of IS but want to 'keep it simple' and are prepared to pay a premium not to have to think too deeply.

6.2 Isolating interface devices

Fig. 7 shows two types of isolating IS interface device manufactured by Measurement Technology Ltd. Between them they offer the following range of functions, most of which are repeated in each series.

On/off functions

- Relays operable by switches or proximity detectors in a hazardous area: 1, 2 or 3-channel.
- Relay to operate on hazardous-area circuits from a safe area.
- On/off power supplies or 'drivers' for solenoids, alarms and LEDs.
- Trip amplifiers for use with thermocouples and RTDs.

Analogue functions

- Repeater power supplies for 2-wire, 4/20mA transmitters, including 'smart' models.
- DC isolators for driving I/P converters from controller outputs.
- DC isolators for fire-detection systems.
- mV/mV converters for thermocouples.
- Thermocouple and RTD converters.

Other functions

- Digital isolators for signals up to 10kHz, including pulse frequency
- Bonding integrity monitor.
- Earth leakage detector.
- AC mains/24V dc power supply.

The MTL 2000 Series was introduced in 1979 and is believed to have been the first comprehensive range of such devices for use in process control to be available in any country. All models are basically mains powered from 110 or 240V ac, but can contain a dc/ac inverter for 24V dc operation. Because of their size, dictated by the mains transformer, some models are multi-channel.

Galvanic isolation is provided by the certified IS mains transformer, which provides power to both sections of each unit, together with certified IS cradle or reed relays in some models or a certified IS opto-coupler in others. The opto-coupler is employed to convey on/off information in either direction as needed.

Two forms of earth-fault protection are available on many models. If the appropriate terminal is earthed, switch relays, for example, 'fail safe' in the event of an earth fault, the relays becoming de-energised as they would on a power failure. Alternatively, if the same terminal is monitored by an earth leakage detector, any earth fault is brought to the notice of the operator while the unit continues working - a particularly valuable option for shutdown and other critical loops.

The MTL3000 Series, introduced in 1985, is a second generation, making use of the experience gained over the previous six years. Since two out of three of all 2000 Series units built were for 24V dc operation, the new range was designed for dc operation only and a small mains/dc unit was included for those applications where dc could not economically be provided. Larger dc supplies are available for larger installations, with battery back up if needed.

This not only reduced the number of models to be manufactured and held in stock worldwide by a factor of three, reducing both the maker's and the user's overheads, but also allowed the transformer to be operated at a much higher frequency and consequently reduced in size to the extent that it could be mounted directly on a single printed-circuit board carrying all the other components. As a result, MTL3000 Series units are mainly single-channel devices, half the previous width, cooler in operation and significantly cheaper.

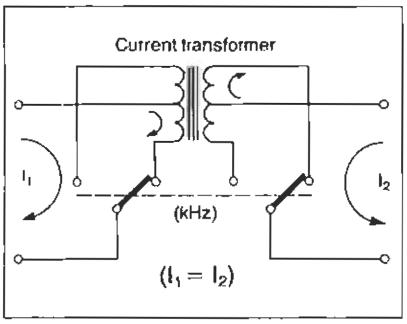


Fig. 8. Principle of dc isolation in 3000 Series.

As in the 2000 Series, galvanic isolation within (mechanical or solid-state-) relay based designs relies on a certified IS supply transformer and a certified IS relay or opto-coupler, but the analogue and other on/off models are different. In these, the isolation is provided by one or two transformers, fundamentally in the manner pioneered by Evershed & Vignoles Ltd over thirty years ago and subsequently employed in Kent Instruments' 'Transdata' converters and controllers, but updated to make use of modern materials and components.

Small low-loss ferrite current transformers, operating at a high frequency, co-operate with a modulator and a demodulator to provide two equal direct currents that are isolated from each other, as shown in Fig.8. These currents can be controlled from either side, according to the application, allowing some of the circuits to be thought of as 'dc transformers'. Where high accuracy and stability are particularly important, transformer losses are made extremely small by a novel 'zero-flux' technique based on the use of negative-resistance circuit elements. And since the circuits 'chop' 4/20mA currents directly rather than voltages derived from them, there are no expensive so called 'high stability' resistors to drift and cause inaccuracies.

Fail-safe operation is not provided for in this Series, but more rigorous protection can readily be achieved by connecting an earth leakage detector to the hazardous-area circuit.

6.3 'Super' barriers

Throughout its quarter century of life, the basic shunt-diode barrier has suffered from three drawbacks:

(a) The encapsulated fuse(s) could be blown by poorly regulated power supplies, shutting down the loop and necessitating barrier replacement. Occasionally errors in commissioning would cause the damage.

(b) The voltage available for 2-wire 4/20mA transmitters was often marginal, requiring either the use of lower-resistance barriers that were suitable for IIB gases only or that the barriers be operated very near to their maximum voltage from a closely regulated power supply. This increased both the initial cost and the risk of blowing barriers.

(c) The variety of barriers was so great, sometimes in the hundreds, that users had great difficulty in selecting the best model and manufacturers, distributors and users alike were faced with a significant inventory problem.

Quite recently (1988) these drawbacks have all been overcome by the addition of simple, inexpensive semiconductor circuits, enhancing the performance of some barriers, providing overvolt protection in others, and enabling as few as 7 'key' barriers in the MTL700 Series to meet the great majority of process-control requirements. As a result, the shunt-diode barrier is once again a strong competitor to the isolating interface device because of its inherent simplicity, lower cost and smaller size per channel.

Full details of these advances are described elsewhere[20,21] but one point is particularly worth noting. Overvolt protection is appropriate only for barriers connected to a power supply: most circuits cannot blow the fuse and do not need it. In practice it is provided in just 3 of the 'key' barriers in the MTL700 Series. This is a far better approach than fitting replaceable fuses in series with 'powered' barriers, as some users like to do, since these fuses must have a lower rating than those inside the barrier and are likely to blow with short circuits in the field. Moreover, they protect by shutting down the loop. The same arguments apply with even greater force if the fuses are fitted to the barrier itself, since this inherently implies all models and will be unnecessary in most cases. Table 5 lists the 7 'key' barriers in the MTL700 Series and their applications.

Application	Key Barrier	
Resistance temperature detectors	755	
Thermocouples, ac sensors	760	
Controller outputs, one line earthed	728+	
Controller outputs, neither line earthed	787S+	
	DC power supply	
	26.0V	20-35V
Transmitters, 2-wire 4/20mA	787S+	706+
Switches	787S+	707+
Solenoids, alarms, LEDs	728+	708+

Patents applied for on MTL706, 707, 708, 787S

Table 5. Key barriers summarised

7. APPLICATIONS

This section outlines some common applications of shunt-diode safety barriers and isolating interface devices. Its aim is to illustrate the principles, rather than to be exhaustive, and further information is given in Refs. 15 to 21. All the barriers and 'interface units' described are certified for worst-case areas (Zone 0) and worst-case gases (IIC).

7.1 Thermocouples

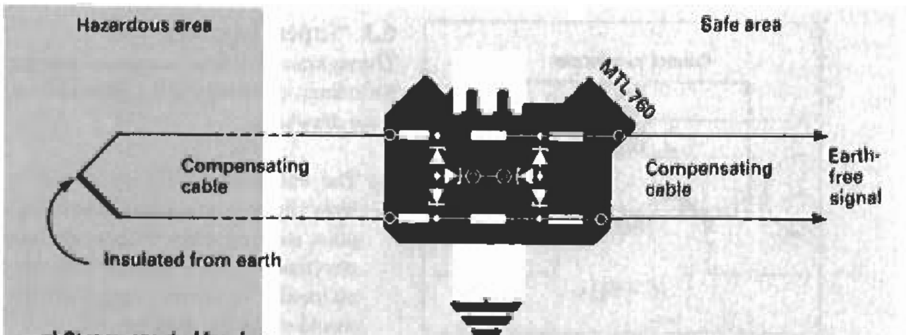
If the thermocouple is insulated, its output can be brought back through a shunt-diode barrier, Fig. 9a. A 2-channel non-polarised design is best since it rejects common-mode ac and dc interference and is unaffected by earth faults provided that the receiver's input circuit floats.

The 'star-connected' barrier shown is particularly suitable for thermocouple circuits. It is economical, requiring only 6 instead of the more usual 8 Zener diodes, and permits higher cable parameters since the voltage between the two channels cannot exceed the working voltage of either channel. (This is no drawback since the signal is so small).

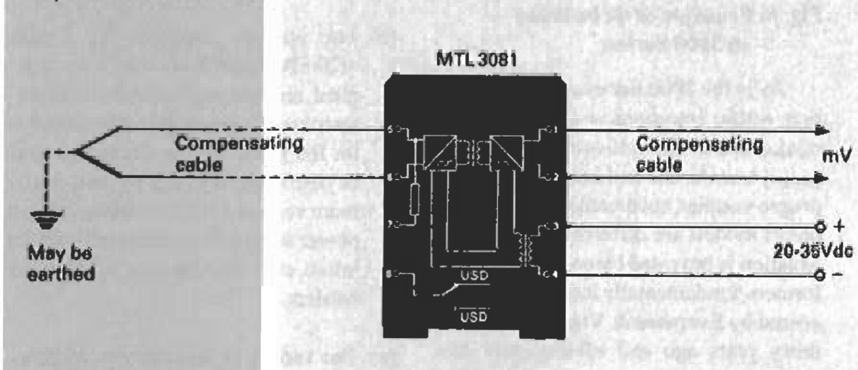
If the thermocouple is earthed, or if its insulation will not pass the 500V test, European (though not as yet American) safety regulations forbid its connection to a barrier. It is then necessary to use an isolating interface device, Fig. 9b. or a suitable transmitter.

In both arrangements the compensating cable should be continued from the interface to the receiver so as to eliminate errors due to thermal emfs.

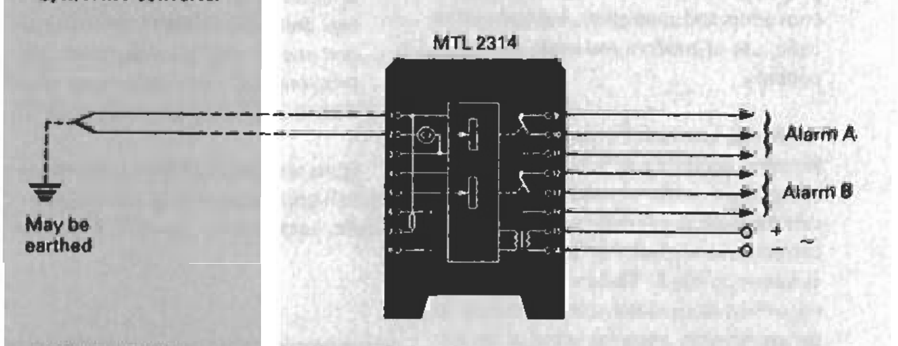
If transmission distances are long, a transmitter can be used together with a suitable interface device, Fig. 12, one or other (but not both) of which must contain the necessary isolation if the thermocouple is earthed. If alarm signals only are required, an isolating IS trip amplifier is the best solution, Fig. 9c.



a) Star-connected barrier



b) mV/mV converter



c) Trip amplifier

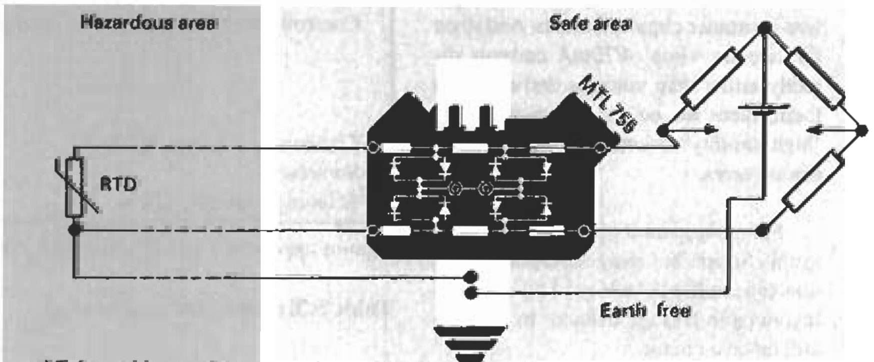
Fig. 9. Thermocouples.

7.2 Photocells, ac sensors

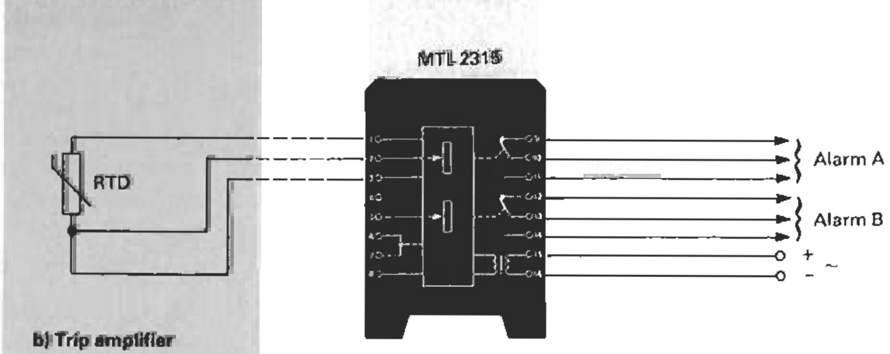
Similar arguments apply and the star-connected barrier of Fig. 9a is very suitable. This design handles signals up to 6V peak, which is more than sufficient. Most barriers pass signals up to several kHz: at higher frequencies the self capacitance of the Zener diodes - around 1000pF - may attenuate the signal.

7.3 Resistance temperature detectors

Resistance temperature detectors (RTDs) are normally insulated to withstand 500V and therefore can be connected to a shunt-diode barrier. If transmission distances



a) Balanced-low-resistance barrier



b) Trip amplifier

Fig. 10. Resistance temperature detectors.

are long, then an RTD transmitter should be used. Neither it nor the associated interface needs isolation.

For 3-wire circuits where the bridge is floating, the most economical solution is to use a 2-channel barrier having a low resistance, Fig. 10a. The barrier protects the two leads from the bridge arms, while the third lead is earthed to the busbar. The barrier shown has an end-to-end resistance of only 18.0 ± 0.15Ω to minimise recalibration, and the channels track within 150mΩ from -20°C to +60°C to minimise zero errors. Since this barrier is non-polarised, there is no need to check the polarity of the connections during installation.

If the bridge circuit is already earthed, a third barrier channel is needed, which in practice can be one half of another 2-channel barrier. 4-wire (constant current) circuits do not require matched barrier resistances and can be protected by two ordinary non-polarised barriers. If alarm signals only are required, an isolating IS trip amplifier is the best solution, Fig. 10b.

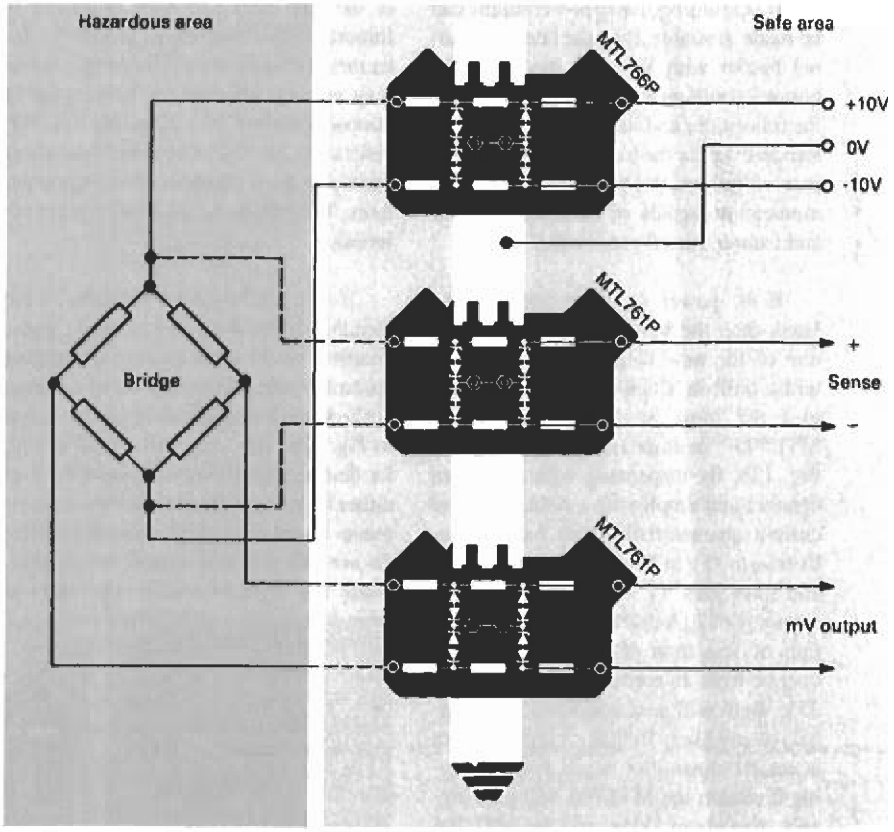


Fig. 11. Strain-gauge bridges.

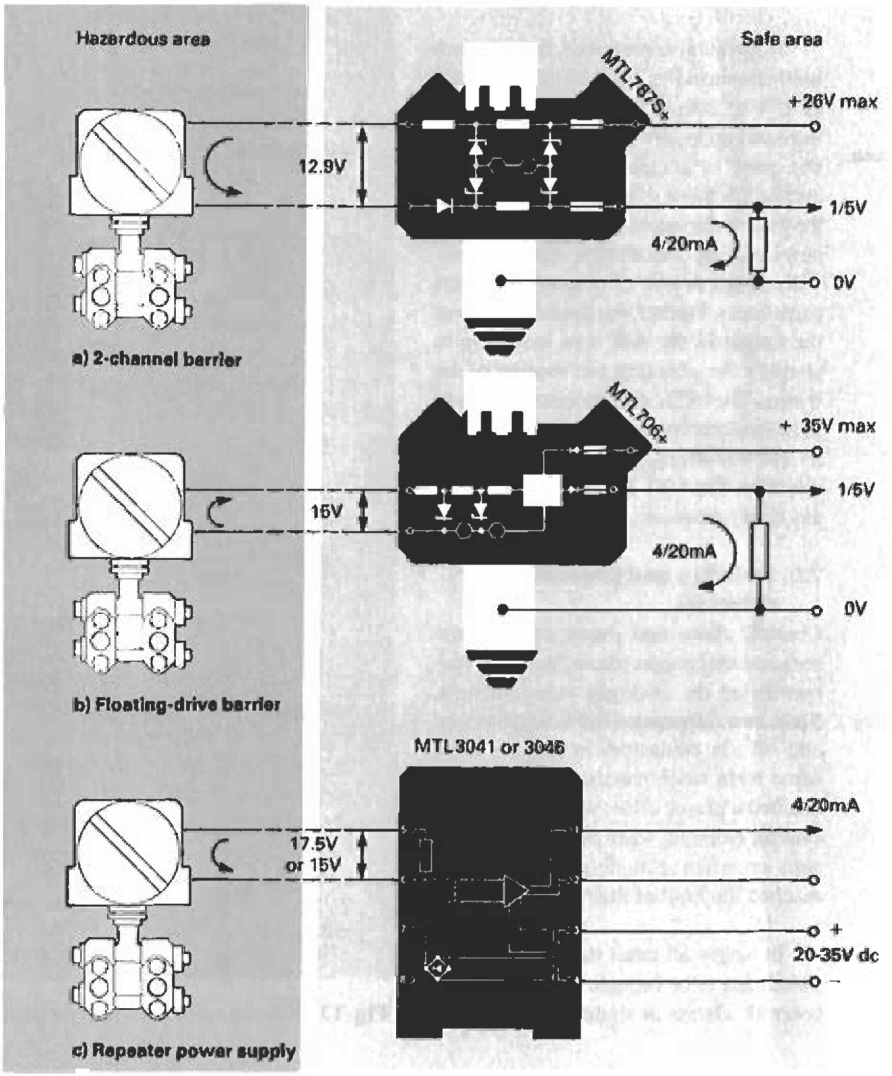
7.4 Strain gauges

Strain gauges are widely used for measuring pressure, force or weight: typically they are mounted on a diaphragm or some sort of spring in a loadcell. Since most will withstand the 500V test, they can be protected by shunt-diode barriers. Fig. 11 shows the basic arrangement for a single bridge. One 2-channel barrier transmits the energising power, another brings back the low-level output signal and - since high accuracy is usually required - a third can be added to allow the energising voltage to be sensed and held constant at the bridge despite variations in line resistance.

Since three barriers are involved, the whole arrangement is covered by a system certificate, which allows for the possibility of simultaneous faults on every channel in the worst possible combination. System certificates have also been obtained for other arrangements dealing with up to three strain gauges in parallel, since average measurements are often wanted.

7.5 2-wire transmitters

Transmitters are a challenge to the interface designer since they require significant power - typically 12V at 20mA - and the 4/20mA signal must be repeated accurately in the safe area. Moreover they are increasingly required to pass superimposed ac or digital communication signals to and from a 'smart' transmitter. The following are three up-to-date solutions:



a) 2-channel barrier

b) Floating-drive barrier

c) Repeater power supply

Fig. 12. 2-wire transmitters.

If a closely regulated power supply can be made available, then the latest 2-channel barrier with Schottky diodes in the return leg will provide 12.9V at 20mA for the transmitter and lines in addition to the standard 5V for the load, Fig. 12a. Like all passive barriers, this barrier will pass communication signals of all frequencies to and from a 'smart' transmitter.

If the power supply is poorly regulated, then the best low-cost solution is one of the new single-channel barriers with a built-in 'floating' dc drive to energise the loop, such as the patented MTL705[21] or its derivative the MTL706, Fig. 12b. By dispensing with the return channel and employing a rising voltage/current characteristic, both barriers deliver up to 15V at 20mA for the transmitter and lines plus 5V for the load, with an accuracy of 2μA (0.01%) and a consumption of less than 40mA. Both barriers operate from an earthed dc supply of 22-35V. Both will pass communication signals of any likely frequency coming from a 'smart' transmitter, while in the outgoing direction the MTL705 will pass signals over about 1kHz, and the MTL706 will pass signals of any frequency likely to be encountered.

If isolation is preferred, then the two units shown in Fig. 12c will deliver 17.5V or 15V at 20mA for the transmitter and lines and up to 16V for the load. They are not quite as accurate as a shunt-diode barrier, of course, (±20μA ± 1 μA/°C), but they allow the use of earthed sensors with non-isolating transmitters and can provide a high degree of protection against earth faults. Further, the floating nature of the output in the safe area may help to simplify the planning and routing of the wiring. The MTL3041 receives signals of most frequencies from a 'smart' transmitter but will not pass them in the outgoing direction. The MTL3046 passes signals of any likely frequency in both directions.

7.6 Switches and proximity detectors

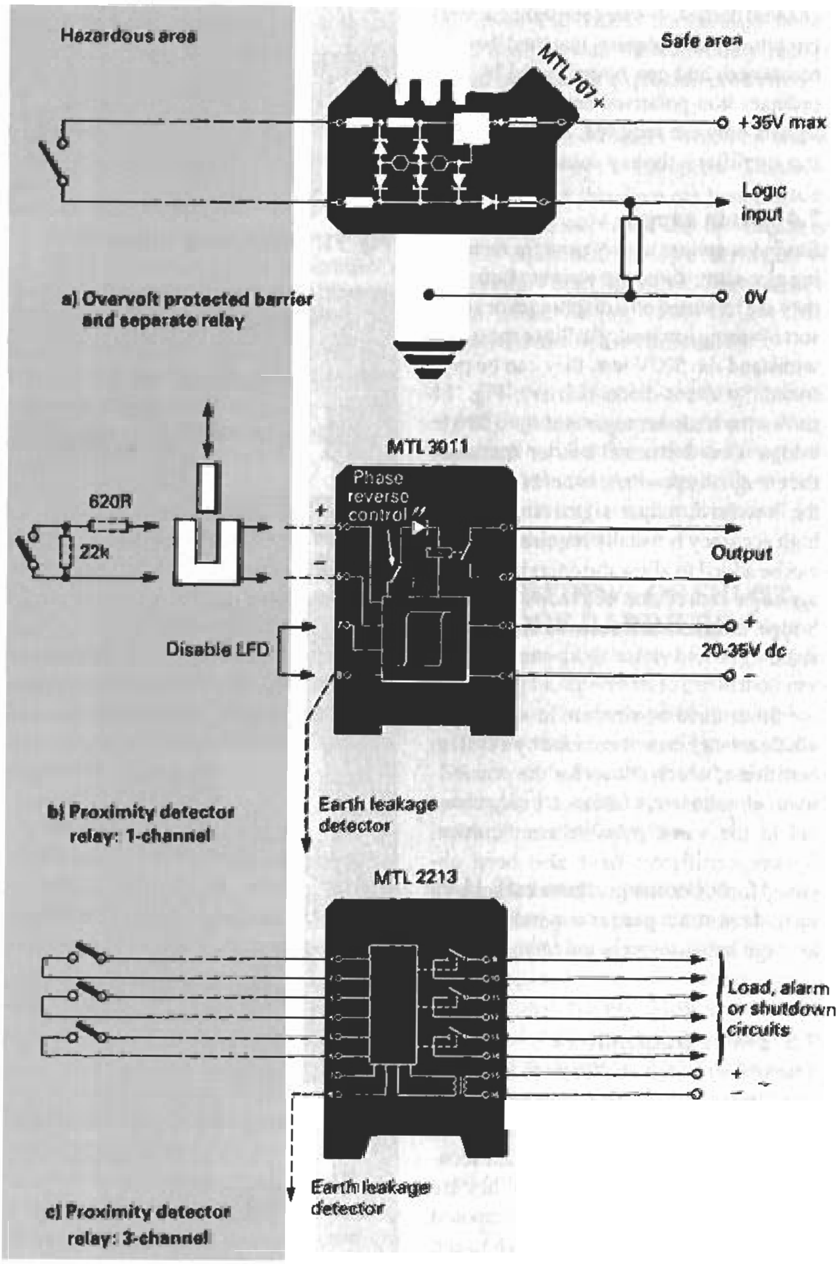
Control, alarm and status switches are common on process plants, typically outnumbering the analogue measurements. Some turn flameproof lights or motors on and off via contactors in the safe area, some warn when process variables have reached a preset value, while others indicate for example when doors are open or shut or when actuating devices have reached the limit of their travel.

In nearly all cases the status of each switch has to be brought back to operate controls, alarms or shutdown equipment in the safe area and high reliability is important. For this reason proximity detectors are being used increasingly, since they are less affected by contaminating atmospheres and their finite ON and OFF resistances can be distinguished from short and open-circuit faults on the connecting lines. The following are some typical solutions.

If separate relays are available or the switches are to drive, for example, optocouplers on the input to a programmable controller, the most economical solution is a 2-channel shunt-diode barrier as shown in Fig. 13a. The relay will then fail-safe, i.e. de-energise, if there is an earth fault on either of the two lines; whereas arrangements based on a single-channel barrier do not fail safe and should be avoided. Since this type of circuit inherently is powered from a dc supply capable of blowing the fuses in the barriers, the MTL 707 is protected against voltages up to 35V or inadvertent polarity reversal.

Mounting and interconnecting separate barriers and relays can be a costly nuisance, and many users are likely to prefer a composite interface device for this reason alone, while others may need the higher integrity that is made possible by the use of proximity detectors and suitable isolating interface devices.

For the highest integrity one should choose a single-channel unit, since each channel then operates independently of all the others. The design shown in Fig. 13b is suitable for use with switches or proximity detectors. When proximity detectors are employed, a line fault detection



a) Overvolt protected barrier and separate relay

b) Proximity detector relay: 1-channel

c) Proximity detector relay: 3-channel

Fig. 13. Switches and proximity detectors.

(LFD) feature can be brought into play to open the relay if the lines are shorted or go open circuit, while ignoring the ON and OFF states of the detector during normal operation. With ordinary switches, this feature must be disabled to prevent false alarms unless, for higher integrity, the switch is made to look like a proximity detector by adding two resistors as shown in the diagram. With either type of sensor, earth fault protection can be added by connecting an earth leakage detector, and a phase-reverse control enables the unit to signal an alarm condition for either state of the sensor to allow for e.g. opening or closing doors. A companion design contains a floating solid-state output switch that is compatible with logic circuits.

If shorted lines are not seen to be a problem and multi-channel units are acceptable, the 3-channel design shown in Fig. 13c is particularly economical. This provides all the features of the single-channel design except that the phase-reverse facility operates on all three relays together and the broken-line protection facility is confined to normal-phase operation. It has the further advantage that it can be powered from the ac mains as an alternative to 24V dc.

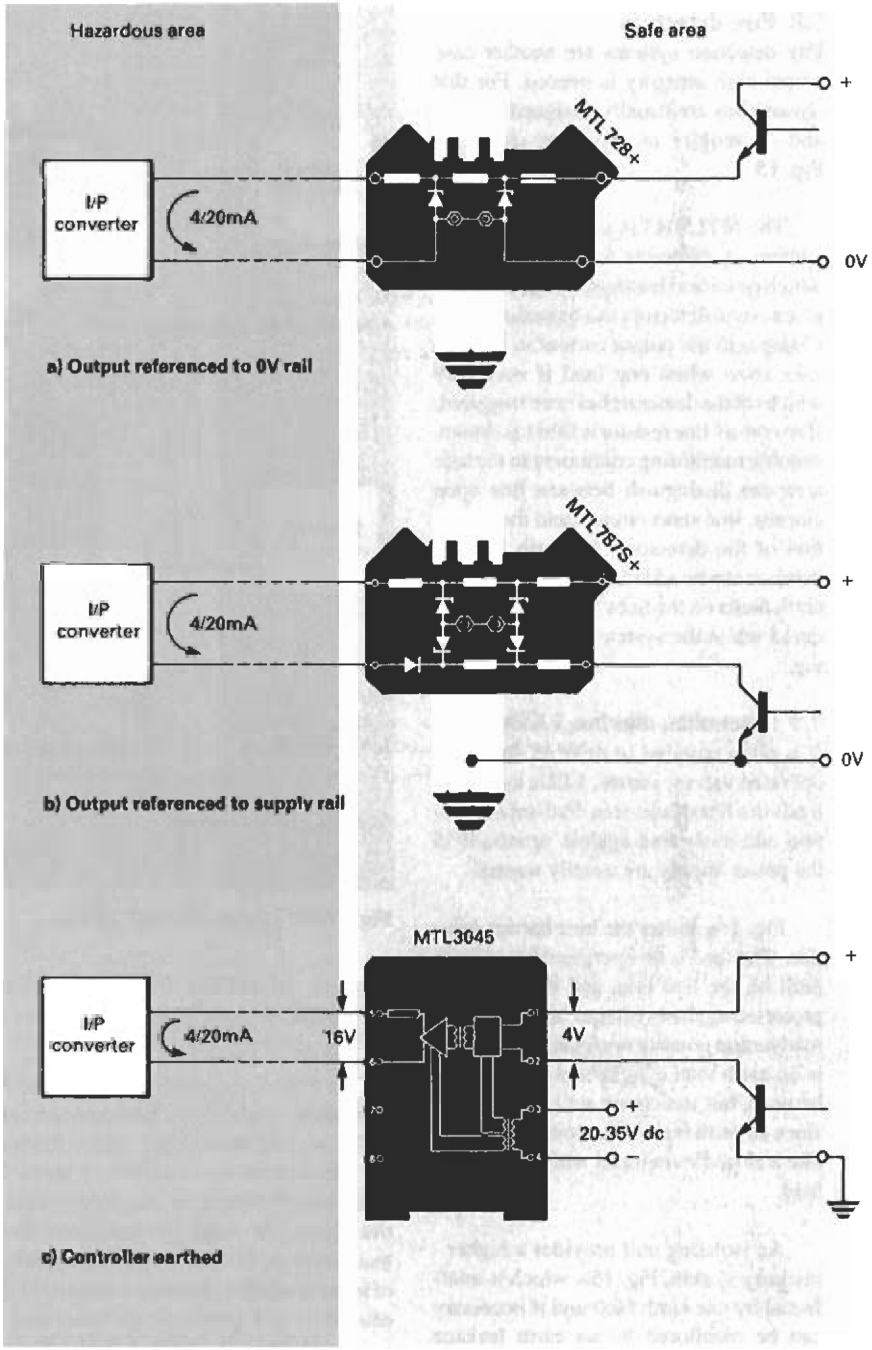
Many other designs of this general type are available, for example containing heavier duty 1 or 2-pole changeover relays and built-in fail-safe facilities.

7.7 Controller outputs

If the output current of the controller flows directly to its 0V rail, a 1-channel shunt-diode barrier can be used, Fig. 14a, provided that the 0V terminal can be earthed at the barrier busbar as is usually the case. The same solution applies if the controller output is fully floating (unusual). Overvolt protection is not needed in this application since virtually all controllers are incapable of blowing the fuses used in barriers.

If the output circuit of the controller is separated from the 0V rail, a 2-channel barrier is necessary, Fig. 14b. The series-connected diode in the return channel of this barrier makes its fault energy zero and allows it to handle signals up to 28V. As a result, the control signal can be turned right off and the barrier permits high cable parameters even in IIC atmospheres.

Fig. 14c shows the use of an isolating interface device, which eliminates the need for any information about the controller output circuit and makes the hazardous-area circuit immune to one earth fault. Since it is powered, its output capability is independent of that of the controller.



a) Output referenced to 0V rail

b) Output referenced to supply rail

c) Controller earthed

Fig. 14. Controller outputs.

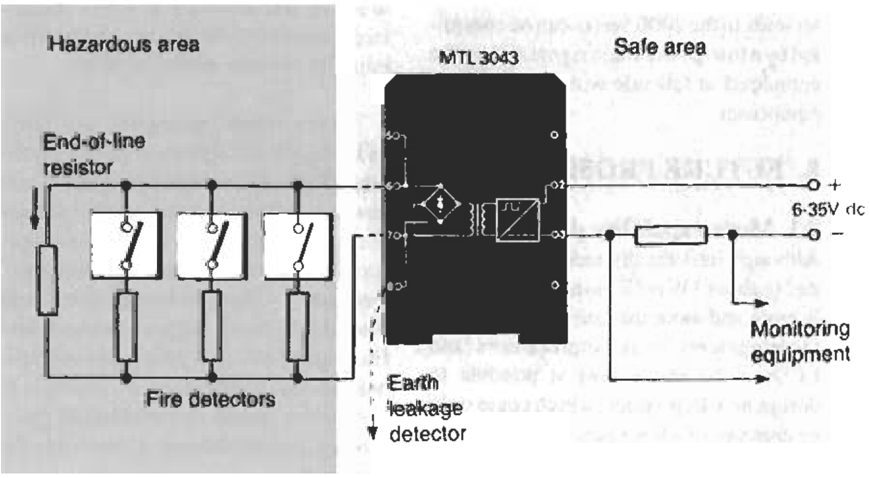


Fig. 15. Fire detectors

7.8 Fire detectors

Fire detection systems are another case where high integrity is needed. For this reason they are usually designed to float and so require an isolating interface, Fig. 15.

The MTL3043 is a loop-powered dc isolator of moderate accuracy and cost, which provides floating dc power to energise several detectors in a hazardous area. Changes in the output current in the safe area show when one (and if necessary which) of the detectors has been triggered. If an end-of-line resistor is fitted as shown, suitable monitoring equipment in the safe area can distinguish between line open circuits, line short circuits and the operation of the detectors. An earth leakage detector can be added if required, to allow earth faults on the lines to be detected and cured while the system continues working.

7.9 Solenoids, alarms, LEDs

It is often required to drive IS solenoid-operated valves, alarms, LEDs and other loads in a hazardous area. Fail-safe operation and protection against variations in the power supply are usually wanted.

Fig. 16a shows the best barrier solution. The load is de-energised by an earth fault on the live line, and the barrier is protected against voltages up to 35V and inadvertent polarity reversal. If the switch is on earth then a 2-channel barrier must be used, but the circuit will not fail safe since an earth fault on the lower line looks like a closed switch and will energise the load.

An isolating unit provides a higher-integrity system, Fig. 16b, which is unaffected by one earth fault and if necessary can be monitored by an earth leakage detector. It also allows the control switch to be on either side of the supply without prejudicing the operation of the unit. Similar units in the 2000 Series can be controlled by a low-power logic signal and can be connected to fail safe without additional equipment.

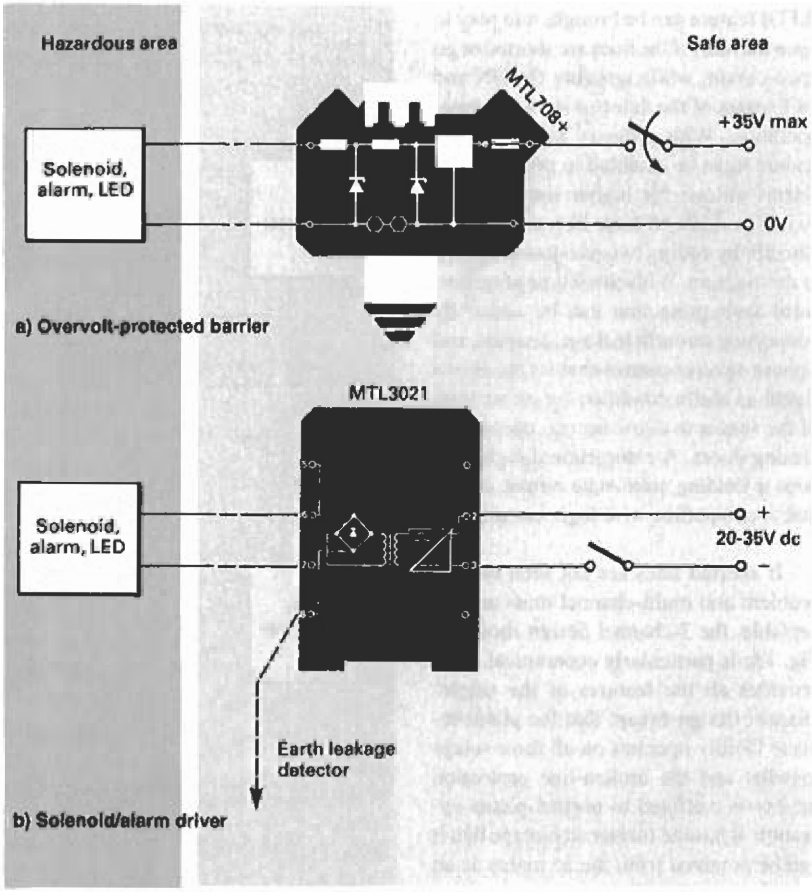


Fig. 16. Solenoids, alarms, LEDs.

8. FUTURE PROSPECTS

8.1 More capability per watt

Although intrinsically safe power is limited to about 1W in IIC atmospheres, there is more and more that one can do with it. Developments in microprocessors and LCDs alone are making it possible to design new IS products which could only be dreamed of a few years ago. As a result of these continuing advances, intelligence, access to information and the making of decisions are shifting significantly from the control room to the hazardous area.

Decentralising trends are nothing new and often sparked by developments in technology or knowledge, which render the old central mechanisms of control inadequate. For example, the electric motor overthrew the shaft-and-belt drive for machinery in factories, creating unheard of local flexibility. Printing and universal education took power away from potentates and gave it to the citizen. More recently, the demand for consumer goods to modern standards has spurred the devolution of responsibility in many centralised economies, which now give credit for initiative but low marks for Marx.

Decentralisation implies flexibility and a degree of sophistication, and in the case of process control it is hard to see how it could be achieved without the use of modern electronics. One of the consequences of the developments taking place, therefore, is likely to be that pneumatic control will never stage a comeback and fibre optics will gain only a limited foothold in the niche areas to which it is particularly suited. Some recent IS products are described below to underline the argument.

8.2 IS 'smart' transmitters

One direct result of the low-power microprocessor is the 'smart' 2-wire transmitter, which not only sends back a measured-value signal of 4/20mA dc, but also 'talks' about itself when asked and can be configured from a distance. Communication is by means of a superimposed 2-way ac signal, typically between about 200Hz and 2kHz.

Electronic memories and switches replace conventional controls and enable a temperature transmitter, for example, to be set remotely for use with any one of many types of thermocouple or RTD, allowing the user to standardise on a single model. They also enable the span, zero and other parameters such as broken-thermocouple alarms to be determined from a distance as required, and they remember the data needed to make the output linear with temperature. In differential pressure (dp) transmitters they provide the database for square-root extraction in flow applications.

The accuracy of a dp transmitter can be improved by a factor of as much as 5 to 10 by correcting automatically for errors caused by distortion of the body at high static pressures, or due to ambient or process-fluid temperature effects. The memory

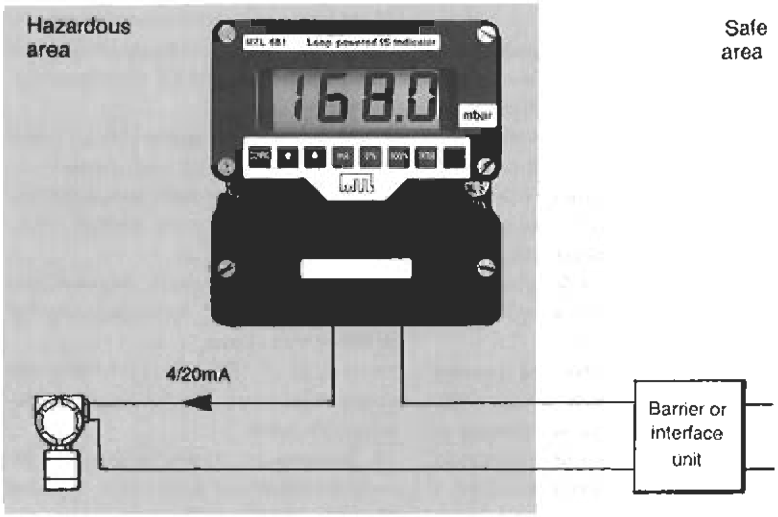


Fig. 17. Loop-powered IS digital indicator.

stores the results of an initial calibration and the transmitter measures the prevailing conditions. Moreover, the accuracy of flow loops can be more easily maintained since routine re-calibration is much simpler.

When interrogated, a smart transmitter is likely to report its given name and how it is configured, the measurement in hand, previous maxima and minima, the date of the last calibration, the state of the environment and whether or not it is in good working order. In some designs, self diagnosis is continuous.

These versatile transmitters are now becoming available for most process variables and already account for over 10% by value of the transmitter market. Their price initially was high but is coming down. Despite their complexity they can be made intrinsically safe and high reliability can be ensured by the use of surface-mount technology.

Communication with a smart transmitter at present takes two forms. If human intervention is the order of the day, the instrument engineer connects a handheld IS programming unit across the wires. If greater automation is desired, the control computer communicates directly. In this case, or if the hand-held unit is not IS, the intervening interface device must be transparent to the communication signal in both directions, see Section 7.5.

8.3 IS indicators

It is often useful to be able to display the value of a process variable near the point of measurement, either for calibration purposes or to allow local supervision and control of difficult or critical (usually batch) processes.

Until a few years ago the only instrument suitable for use in hazardous areas was the certified moving-coil indicator, with diodes connected across its terminals to prevent the release of stored energy. This type of indicator was relatively inaccurate (about 2%) and required a new scale when the range was altered. But more recently the LCD and sometimes microprocessors have enabled accurate and easy-to-range IS indicators to be created for many purposes.

For example, the $3^1/_2$-digit indicator shown in Fig. 17 is a loop-powered design which displays in engineering units the value of any process variable being transmitted as a 4/20mA signal. It is certified 'non-energy storing' at its terminals and therefore can be connected into almost any IS loop without further certification. It drops less than 2V at 20mA, which most IS loops can tolerate. A root-extracting facility is provided, and built-in references and a front panel membrane keypad make the unit easy to calibrate on site without special equipment.

Companion $4^1/_2$-digit designs cater for weighing and temperature applications where higher accuracy and resolution are needed. The MTL636 can measure the output of a strain-gauge or other bridge circuit against the energising voltage to eliminate the effect of supply variations. The MTL637 takes its input directly from a thermocouple or RTD, and provides a reading which is linear with temperature. It can trigger two external alarms via two circuits with adjustable trip points. Both these designs are microprocessor controlled and all their parameters are set by push buttons.

8.4 IS multiplexers

Plant cabling is inflexible, expensive and difficult to expand, and one of today's objectives is to reduce it. Methods include the distributed control systems of individual manufacturers, their hoped-for unification through a universal 'field-bus', short-range radio links and, at the simpler end of the market, various multiplexer/demultiplexer systems which economise on wires. All of these can be made intrinsically safe and none could be contemplated without the microprocessor.

Fig. 18 shows a simple IS multiplexer system, which brings back the status of each of 16 contacts or proximity detectors located in a hazardous area and reproduces it via 16 relays and/or a stream of data to a host computer. The transmitter is energised from the receiver via an isolating IS interface device and no power supply is needed in the hazardous area. The signal highway comprises just two wires and can be duplicated for maximum integrity.

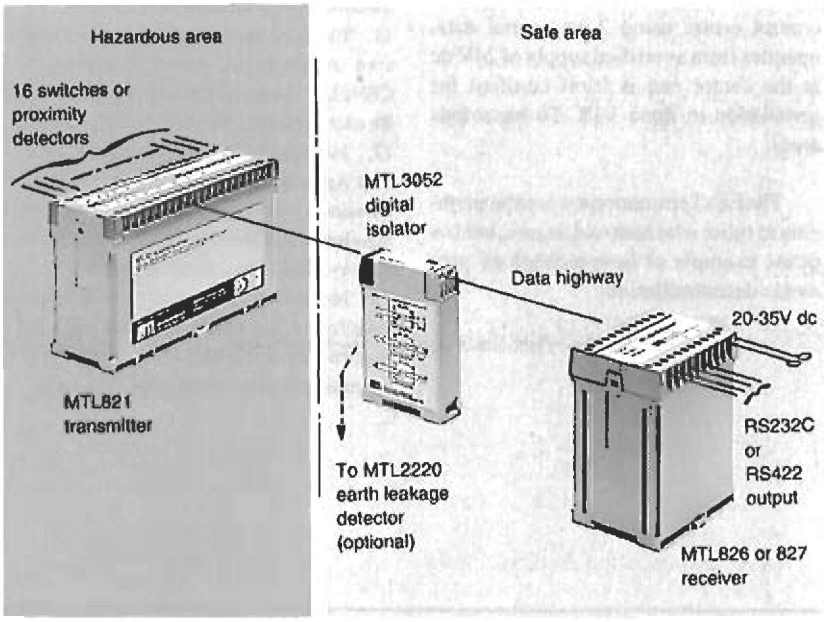


Fig. 18. IS multiplexer system

Similar, compatible multiplexer systems bring back signals from up to 32 thermocouples or RTDs.

8.5 IS control stations

Near the top in IS capability-per-watt is the Trion EExTerm 'Upfront control and display unit', Fig. 19, which essentially extends the control room into the hazardous area.

Complete with a powerful micro-computer, up to 128-element keyboards and large LCD display with graphics capability, this intelligent, independent station enables a local operator to access any information that he requires from the control centre and - provided that he is vested with adequate priority - to influence the process or modify the control arrangements as he decides is needed.

Fig. 19. IS control station: display and keyboard

The station communicates with the control centre using 2-way serial data, operates from a certified supply of 24V dc at the centre and is itself certified for installation in Zone 1:IIC:T6 hazardous areas.

The EExTerm concept would be anathema to those who hate to delegate, but is a prime example of how technology promotes decentralisation.

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APPENDIX

The paper was presented at the WISITEX 2nd World Instrumentation Symposium, Bombay, 1981; the IICA Symposium, Sydney, 1982 and the Instrumentasia Conference, Singapore, 1982. It was published in England in 1982 by the IMC, gaining the Honeywell prize; in the USA in 1983 by the ISA and in 1985 by the SCMA; in S. Africa in 1983 and in Pakistan. It was reprinted by MTL as TP1051 in English, French and Japanese.

In February 1986 it was revised as TP1075 to take account of the substantial advances in IS-system certification that had then been made in many countries and was published in New Zealand, Spain, Ireland, Singapore and India.

In January 1989 it was revised again as TP1091 to cover recent developments in IS interface devices and instruments for use in hazardous areas.

In October1992 it was revised as TP1106 with Tables 3 and 4 and section 4 (Japan) and some product references updated.

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