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Practical solutions for Fieldbus in hazardous areas

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Introduction and background

In the mid 1980's, both IEC and ISA published guidelines for the standardisation of a fieldbus suitable for use in process control and factory automation applications. These specified that appropriate versions should be suitable for hazardous area applications, such as those found typically within petrochemical plants in the process industries, using the established technique of intrinsic safety (IS). The author's involvement in the standards development began in early 1989 when Measurement Technology Ltd (MTL) was invited to give a presentation to the Physical layer sub-committee of ISA SP50 on the application of IS to fieldbus. The subsequent presentation and discussion demonstrated adequately both the author's very scant knowledge of fieldbus and the sub-committee's similar ignorance of intrinsic safety. Fortunately, over the intervening four years this situation has improved and the author has been privileged to play a small part in framing the Physical layer standard now published by ISA (as ISA S50.02-1992) and approved for publication by IEC. This standard specifies systems both at low data rates (31.25kbit/s) and high (1.0Mbit/s) suitable for implementing in an IS format.

It is encouraging that this standard has been adopted by both ISP and WorldFIP fieldbus groups for their systems. From the point of view of certifying IS equipment and system configurations, this holds out the hope of one common solution. However, the generation of a standard on paper does not in any way guarantee that its contents will lead to reliable systems that can be implemented in practice.

The International Fieldbus Consortium (IFC) was formed in 1990 by companies and individuals active in the fieldbus standards area. Its objective is to carry out field trials of the evolving fieldbus standards to demonstrate their performance and to provide information feedback to the appropriate standards bodies. MTL has been an active member of the IFC since its inception.

This paper describes the tests carried out and the results.

Fundamentals of intrinsic safety for fieldbus

Most of the work done by the IFC to date has focused on the Physical layer standard, as the development of this standard has, throughout, been in advance of corresponding documents on the Data-link, Application and User layers of the international standard fieldbus. However, before describing the trials and proving work carried out with respect to the Physical layer, I must briefly outline the essential elements of an IS fieldbus system to set the requirements into the right context.

The ignition characteristics of flammable gas mixtures are characterised by:–

a) the minimum spark ignition energy required to create an explosion in a specified flammable gas
b) the minimum temperature of a hot surface that will have the same effect

These two parameters are generally not related; eg, hydrogen has a low minimum ignition energy (20μJ) but needs a relatively high surface temperature for ignition (560°C).

Hazardous area terminology varies considerably between Europe and North America. To avoid confusion this paper refers only to European (CENELEC) terminology since this is broadly identical with that adopted for the relevant IEC standard; IEC79-11:1991. At present, North American classifications differ significantly from those specified by the IEC. However, it is expected that there will be a much closer correspondence following the anticipated revisions to the US National Electrical Code expected in 1996.

Gases are generally classified into one of the following three gas groups depending upon the minimum energy needed to ignite them:–

IIA (highest ignition energy):	typical gas is propane
IIB (medium ignition energy):	typical gas is ethylene
IIC (lowest ignition energy):	typical gases are hydrogen and acetylene

For hot surface ignition, gases are divided into the following six temperature classifications for which T1 is the highest and T6 the lowest:–

T1 (max. surface temp. 450°C):	typical gases are hydrogen and propane
T2 (max. surface temp. 300°C):	typical gases are ethylene and butane
T3 (max. surface temp. 200°C):	typical gases are kerosene and naptha
T4 (max. surface temp. 135°C):	typical gases are acetaldehyde and ether
T5 (max. surface temp. 100°C):	typical gas is carbon disulphide
T6 (max. surface temp. 85°C):	

For most practical purposes a T4 temperature classification is adequate (except when carbon disulphide is present).

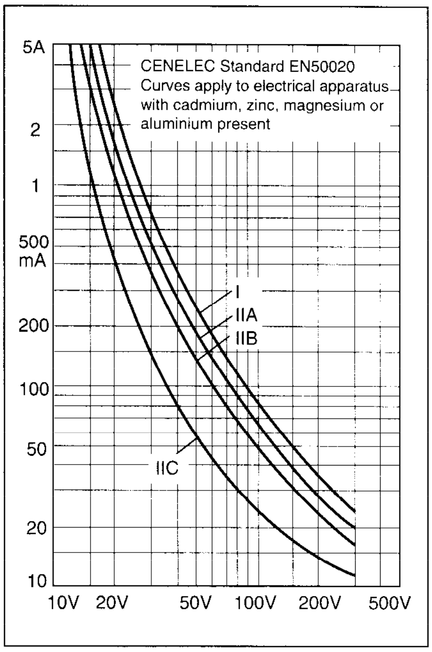

Figure 1. Ignition curves

'Hazardous areas' themselves are classified in terms of three zones, depending upon the likelihood of the flammable material being present:–

Zone 0:	Continuous hazard (more than 1000hours/annum)
Zone 1:	Intermittent hazard (between 10 and 1000hours/annum)
Zone 2:	Hazard under abnormal conditions (between 0.1 and 10hours/annum)

IS systems operate by limiting electrical circuits in potentially flammable atmospheres (hazardous areas) to voltage and current levels too low to cause ignition of the gas. Each circuit must therefore be protected in this way so that the combination of them is incapable of causing ignition – even in the presence of prescribed faults in the equipment and interconnecting cables.

National and international standards for IS are based on a common set of minimum ignition curves generated by research and experience of testing with a spark-test apparatus. A typical example (taken from CENELEC standard EN50 020) is illustrated by figure 1. This reproduces curves for IIA, IIB, and IIC gas groups. Any system (including fieldbus) must operate within the permitted region of these curves (with an appropriate applied safety factor). However, there are also other factors, not apparent from figure 1, which also

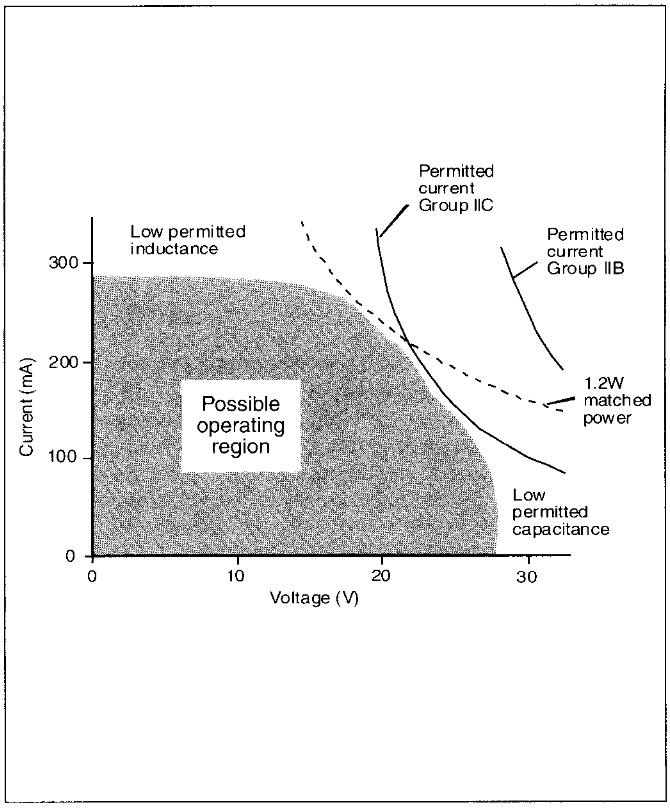

Figure 2. Possible operating region

limit the possible operating region of any practical system. These are:–

a) A significant decrease in the maximum permitted capacitance as the working voltage increases
b) A rapid decrease in the maximum permitted inductance as short circuit current increases

In practice, these further constraints limit the characteristics of any interface components between safe and hazardous areas to the region illustrated in figure 2.

Another important factor for the designer of any apparatus intended for approved installation in a hazardous area is the level of electrical power transferred to the device under worst case (matched power) conditions. This will apply to manufacturers of fieldbus devices such as transmitters and 'smart' valves intended for hazardous-area installation. There are internationally agreed relaxations for the testing of such designs to achieve a T4 temperature classification provided the power supplied to them does not exceed 1.3W for a maximum ambient temperature of 40°C (with corresponding figures of 1.2W at 60°C and 1.0W at 80°C). This applies to all components with a surface area between $20mm^2$ and $10cm^2$. Many manufacturers are likely to want to take advantage of this simplification in the design and certification of their equipment, thus figure 2 illustrates the modifying effect of a 1.2W constant power curve.

One final general topic for mention is that of counted faults in the certification of apparatus. Equipment for installation in hazardous areas is certified as type 'ia' or 'ib'. Type ia equipment is certified safe with up to two internal faults applied to it and can be used in all hazardous areas. For this type, current limiting must be done by resistive means. Type ib is certified safe with a single fault only applied to it. For the latter, semiconductor devices can be used to limit current and power to hazardous areas. Type ib may not, however, be used in zone 0 (continuous hazard) areas. More important, because of the differences between Europe and North America, it is not easy to apply type ib certified equipment in systems under North American practice. For this reason, there is much to be gained (in terms of simplification) if initially all equipment supplying fieldbus systems in hazardous areas is designed using the 'ia' approach with resistive limiting techniques that offer consistent and easily understood system parameters when certified in various parts of the world.

Characteristics of 31.25kbit/s fieldbus systems

The 31.25kbit/s option of the IEC/ISA wire medium standard (section 11) is flexible in the topologies it allows, providing for a variety of linear and tree topologies. For conformance test purposes, a particular $0.8mm^2$ single twisted pair screened cable is specified and, using this cable, a total bus length of 1900m must be achieved. Three other cable types, with less desirable transmission characteristics, are defined in an annex for operation with reduced bus lengths. An important feature of the fieldbus at this data rate is its ability to operate on the types of cable installed for analogue instrumentation in existing process plants.

The most widely quoted topology for this type of fieldbus is the 'chicken foot' configuration, shown in figure 3. This consists of a relatively long main trunk (or 'home run') cable from the field to a safe-area control-room. A number of fieldbus devices are connected at the field end, probably using a convenient field junction box. Devices are connected via spur cables which will generally be short (120m maximum) by comparison with the main trunk.

A bus terminator is needed at each end of the trunk cable, the value of 100Ω being chosen to match approximately the characteristic impedance of the cable. At maximum specified bus length, the performance can still be largely described in terms of lumped parameters, although transmission line theory cannot be ignored totally. Data signals are Manchester Biphase L encoded and their high frequency content is reduced by specifying a trapezoidal wave shape to limit crosstalk between adjacent cables. An idealised waveform is depicted in figure 4.

Power for fieldbus devices will normally be supplied through the bus by a fieldbus power supply. This must have a low output resistance output under dc conditions but a high impedance (3kΩ minimum) in the signal band (between 8 and 40kHz). For hazardous-area systems, this power is supplied to the fieldbus through an IS interface. The bus

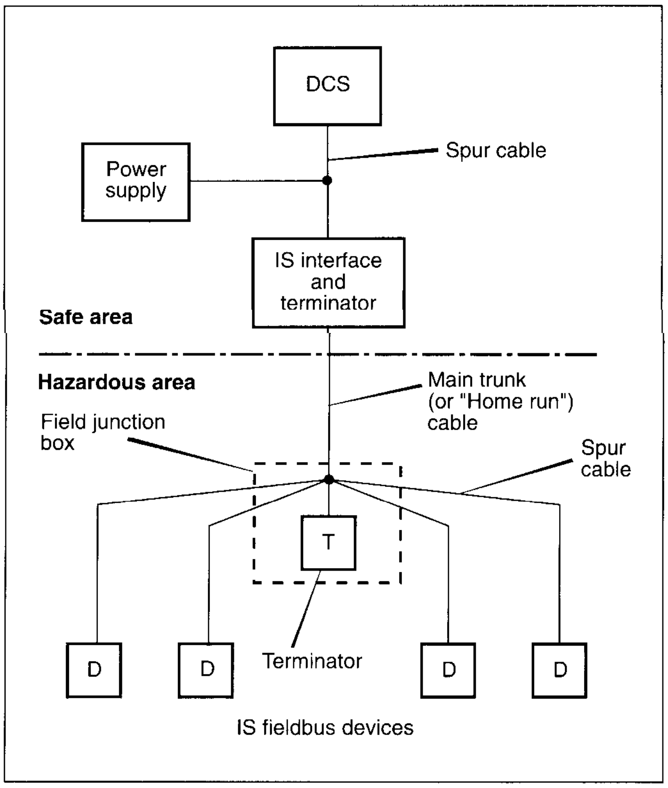

Figure 3. IS fieldbus topology

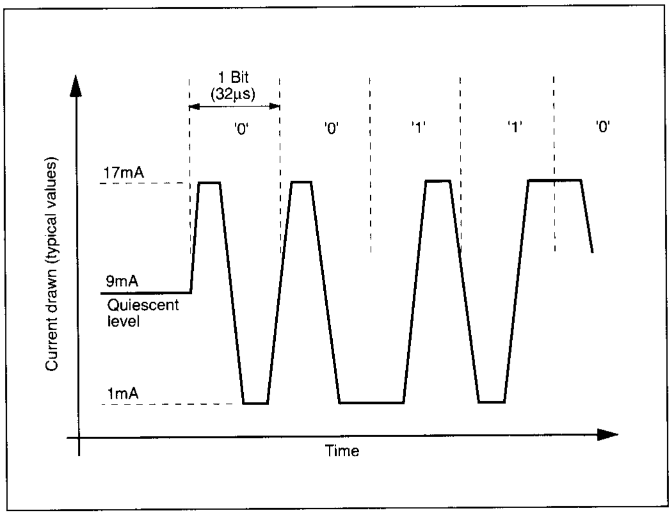

Figure 4. Fieldbus device signal (bus-powered)

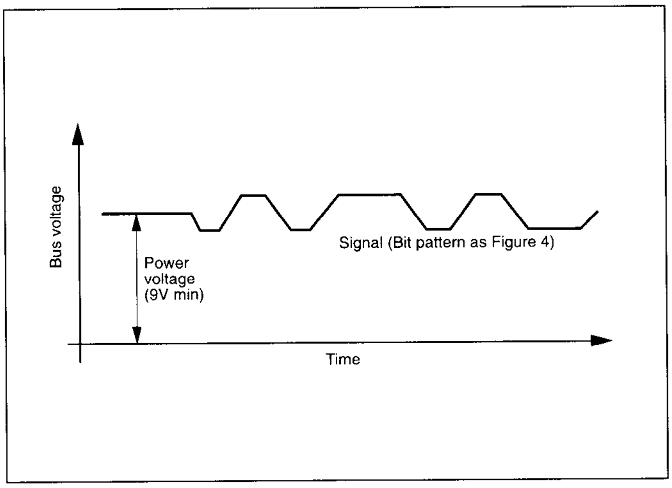

Figure 5. Bus waveform

must remain balanced about earth at signal frequencies and all field trial and demonstration systems so far have achieved this either by a combination of a fully floating power supply and IS barrier channels balanced about earth or an IS galvanic isolator incorporating a power supply.

Each fieldbus device draws a constant current from the fieldbus wires and signals by increasing and decreasing the current it draws to transmit Manchester encoded digital data. Bus terminators convert these current changes to a voltage variation on the bus which other devices can receive (figure 5). This form of signalling makes it possible to construct an IS fieldbus with only a single source of energy (the fieldbus power supply). Without this, general certification of any system for hazardous-area use would be very difficult to achieve.

The intention is for each fieldbus device to draw a current of approximately 10mA from the bus and to operate with a voltage between lines of 9 to 32V. These values, together with the characteristics of the IS interface (barrier or isolator), define a limit to the number of devices an IS fieldbus will support. For conformance tests the standard specifies a minimum of six bus-powered devices on an IS fieldbus at 31.25kbit/s, of which four can be in the hazardous area. In the meantime, investigations by the IEC/ISA Physical layer standards committee are continuing to try and effect a modification which will allow more devices to operate on an IS fieldbus.

Not all devices on an IS fieldbus will be located in hazardous areas or be approved for connection to IS circuits. For example, it is unlikely that DCS vendors will choose to certify their whole interface for direct connection to IS circuits. Therefore, systems will need to accommodate a bus segment in the safe area to which devices such as a DCS or bus analyser can be directly connected. Such devices can either take their power from the bus or, more likely, be separately powered. In the latter case their transmissions can be transformer-coupled onto the bus and consist of signals alternately sinking and sourcing current onto the bus.

It is however important that hazardous-area devices do not adopt this technique, otherwise the IS approval of the fieldbus will be compromised and certification of a general system will prove very difficult. Some hazardous-area equipment, such as analysers and magnetic flowmeters, will obviously need power from other sources in addition to that available from the bus. Such equipment will generally use IS combined with other techniques such as increased safety (Ex e), flameproof (Ex d) or encapsulation (Ex m). For IS fieldbus systems to be certified in a generalised way, it is important that the fieldbus output of separately powered equipment mimics that of a bus-powered device.

Proving work on 31.25kbit/s IS fieldbus systems

During 1991, five active members of the IFC (Fisher Controls, Foxboro, Honeywell, MTL and Rosemount) carried out extensive trials at an Exxon Chemical plant in Linden, NJ, USA. These were intended to demonstrate the robustness of the then evolving IEC/ISA Physical layer standard at 31.25kbit/s. Among the configurations tested were IS systems using both earthed barriers and a galvanic isolator supplied by MTL. The interest lay in proving the operation of the bus at the specified power levels and the tolerance, to injected noise and anticipated fault conditions, of the signalling system, wiring runs and system configurations. No elements of the Data-link or Application layer standards were used. Instead, pre-determined messages of various lengths were transmitted through the system with different cable lengths and numbers of devices connected and the frequency of various types of bit errors and CRC errors measured. The types of tests carried out, on an IS system incorporating a ±12V balanced IS barrier, were:–

a) Normal (reference) conditions
b) Bad CRC
c) Bad message
d) Missing terminator
e) Open spur
f) Addition/removal of a device during operation
g) Cross talk
h) White noise
i) RF interference

All the test results were acceptable. Specifically, during the tests there were:–

j) 13 million messages exchanged comprising 3 billion bits
k) Only 26 errors (all detected) under reference conditions
l) Error rates in all tests much less than required by the standard

Two types of prototype MTL safety barriers with resistive outputs of ±12V, 72Ω and ±10V, 45Ω respectively were used in these tests and also a combined galvanic isolator and power supply with a resistive output characteristic of 21V, 92Ω. The basic configuration of the barriers used is shown in figure 6 and the isolator in figure 7.

More recently, further testing has been completed during phase 1 of an IFC trial at BP Research, Sunbury-on-Thames, near London's Heathrow Airport. This involved approximately 40 IFC members (including MTL) installing and testing prototype fieldbus equipment previously demonstrated at the 1992 Interkama Exhibition. The scope of these tests included a small subset of the evolving IEC Data-link and Application layers to prove inter-operability of the various elements. The system configuration is reproduced in figure 8 and test conditions in table 1. These extended tests provided an opportunity to test IS barrier and isolator systems over cable lengths up to 150% of those specified by the standard in an electrically noisy process environment. The test results are summarised in table 2 – which also indicates the overall success of the tests.

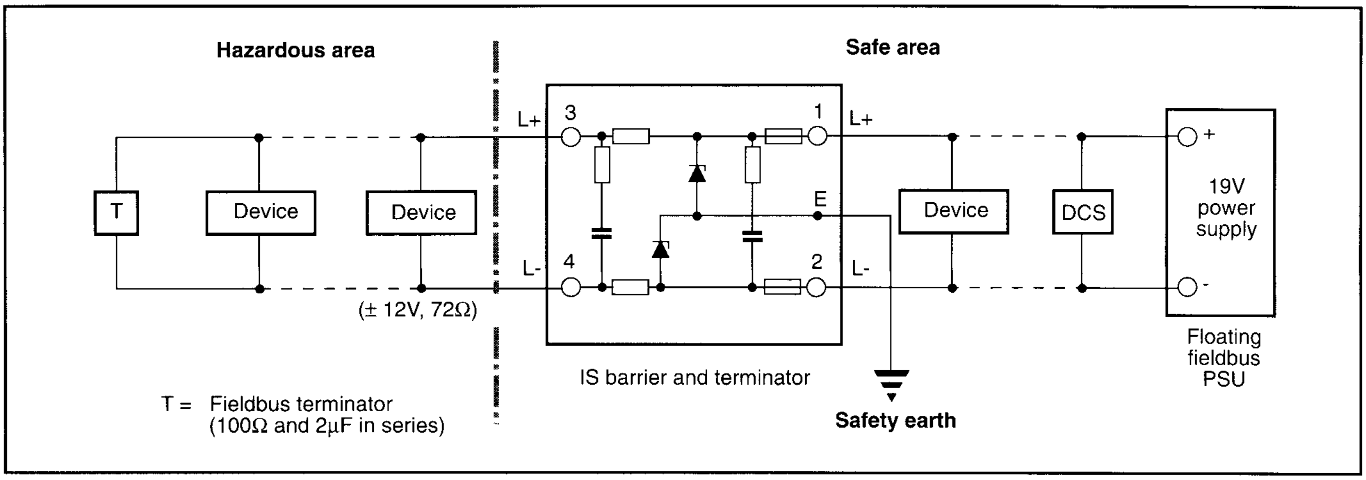

Figure 6. Earthed barrier configuration

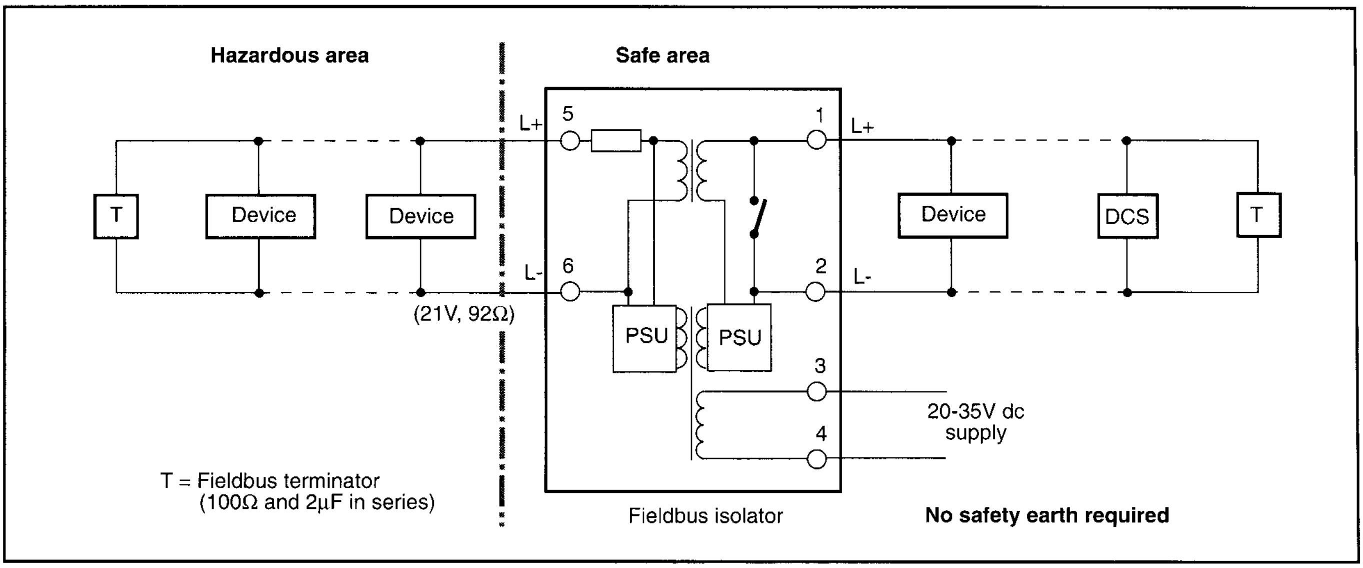

Figure 7. Galvanic isolator configuration

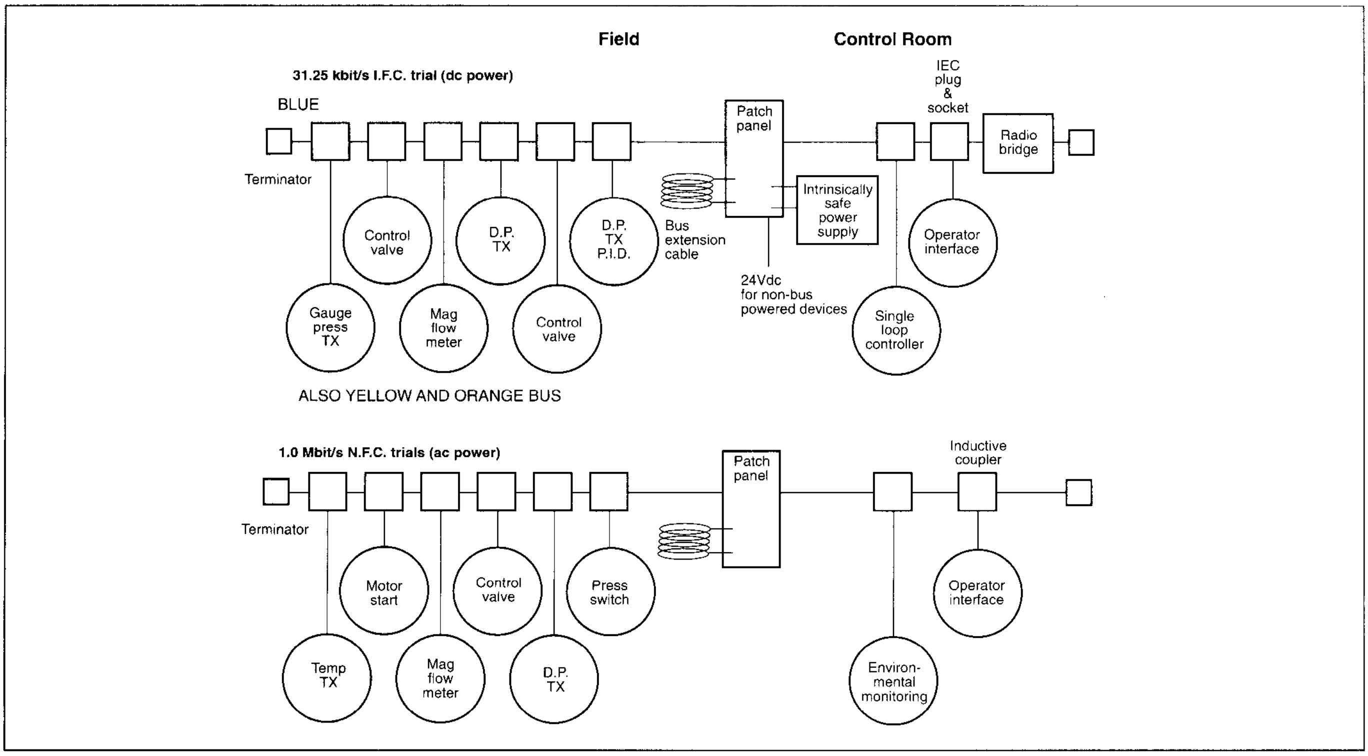

Figure 8. General arrangement of BP phase 1 trial

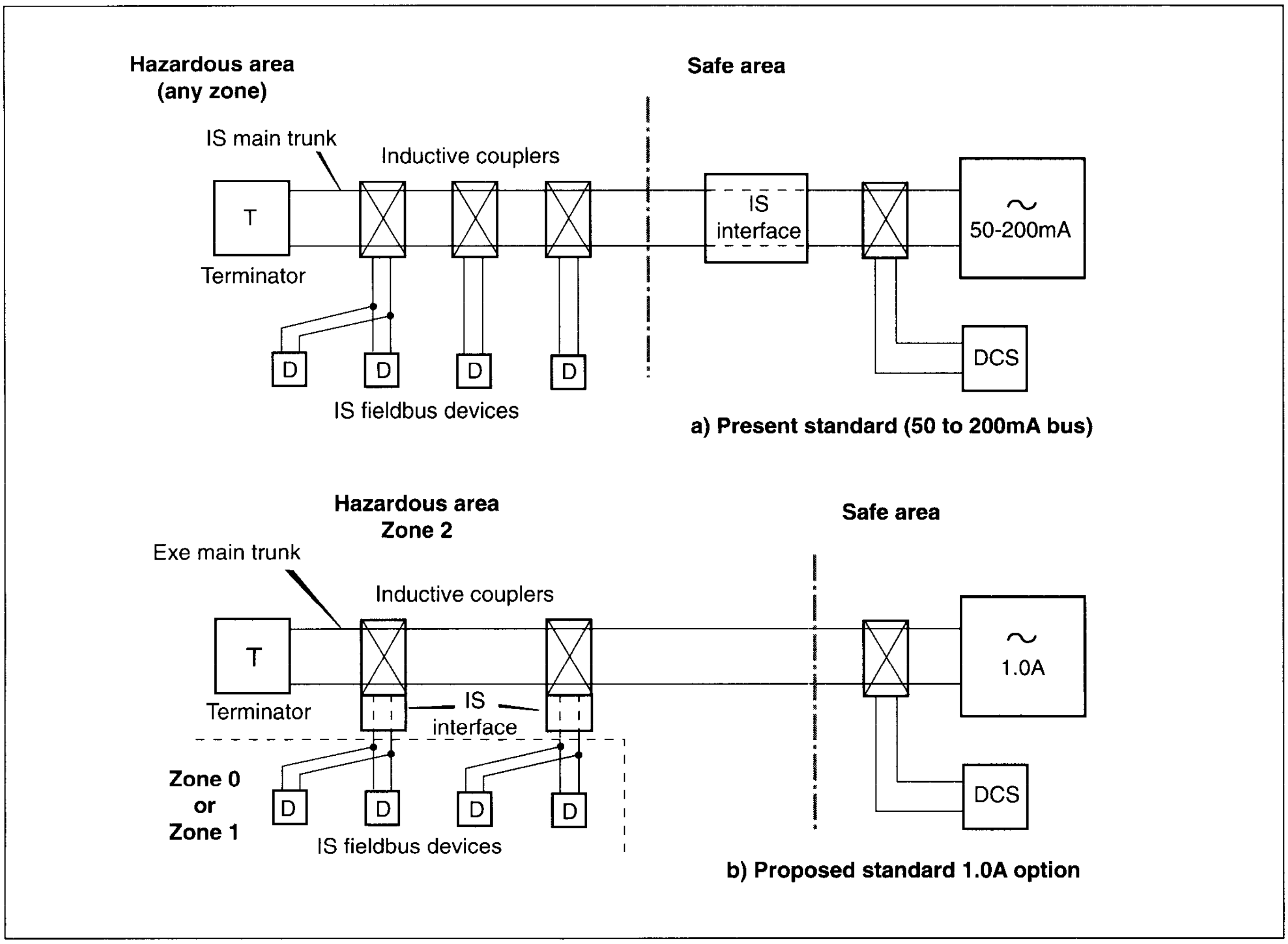

Figure 9. 1.0Mbit/s ac powered current mode fieldbus

Table 1: Test conditions for the BP phase 1 trial

Cable types	Description		IEC length	
IFC 31.25kbit/s A	Single twisted pair		1900m	
IFC 31.25kbit/s B	Multi-twisted pair		1200m	
IFC 31.25kbit/s C	Multi-twisted pair		400m	
IFC 31.25kbit/s D	Not twisted		200m	
NFC 1.0Mbit/s E	Offshore ac		350m	
NFC 1.0Mbit/s F	Offshore ac		100m	
Line terminators	Characteristic impedance			
IFC 31.25kbit/s	100Ω			
NFC 1.0Mbit/s offshore	80Ω			
Safety devices	End-to-end dc resistance			
Safety barrier (1/bus)	80Ω			
Isolator (1/bus)	(ac Z only)			
Coupler (1/device)	(ac Z only)			
Power	Bus	Source	Field instruments	
Power				
31.25kbit/s	Blue	dc	6	0.93W
31.25kbit/s	Yellow	dc	4	0.45W
31.25kbit/s	Orange	dc	4	0.58W
NFC 1.0Mbit/s		ac	14	14W

Table 2: Test results from BP phase 1 trial

Installation checks	Test results
No safety barrier	OK
No additional cable	OK

Cable length checks

Location	Type	Nominal IEC length	50% of l *	50% of l †	100% of l *	100% of l †	150% of l *	150% of l †
Blue bus A	31.25kbit/s	1900m	–	OK	–	OK	–	OK
Blue bus B	31.25kbit/s	1200m	–	OK	–	OK	–	OK
Blue bus C	31.25kbit/s	400m	–	OK	–	OK	–	OK
Blue bus D	31.25kbit/s	200m	–	OK	–	OK	–	OK
Yellow bus A	31.25kbit/s	1900m	OK	OK	OK	OK	OK	OK
Yellow bus B	31.25kbit/s	1200m	OK	OK	OK	OK	OK	OK
Yellow bus C	31.25kbit/s	400m	OK	OK	OK	OK	OK	OK
Yellow bus D	31.25kbit/s	200m	OK	OK	OK	OK	OK	OK
Orange bus A	31.25kbit/s	1900m	OK	OK	OK	OK	OK	OK
Orange bus B	31.25kbit/s	1200m	OK	OK	OK	OK	OK	OK
Orange bus C	31.25kbit/s	400m	OK	OK	OK	OK	OK	OK
Orange bus D	31.25kbit/s	200m	OK	OK	OK	OK	OK	OK
			50m		350m			
NFC bus E&F	1.0Mbit/s	–	OK		OK			

NB: * with a shunt-diode safety barrier † with an isolating interface

Cable length margins checks with a mixture of cable types (eg, 150% of A with 100% of D)
Test results (typical cable lengths where performance becomes marginal)

Bus	*safety barrier	†isolator
IFC blue	–	150%
IFC yellow	200%	250%
IFC orange	200%	250%

1.0Mbit/s ac powered IS fieldbus systems

The 1.0Mbit/s ac powered IS option within the published IEC/ISA Physical layer standard is the result of work funded by BP at SI, an industrial research institute in Norway. In this system, ac powering is used for the fieldbus. Inductive couplers, transferring both power and signals, connect devices to the bus as shown in figure 9. Power is supplied at 16kHz from an ac constant current source. Operating power drawn by each device, through the inductive coupling, appears as a voltage drop on the bus. The present standard specifies a bus current amplitude range of 50 to 200mA. At this level it is possible to make the whole bus and all devices connected to it intrinsically safe – but with only a relatively small number of devices.

A further option is likely to be soon added to the standard, specifying and increased current (1.0A) in the main trunk. This will provide facilities for running a 1.0Mbit/s main bus in Zone 2 hazardous areas using increased safety (Ex e) and encapsulation (Ex m) techniques to permit more devices to be connected to the bus. Individual taps onto the bus can be designed to provide separate IS spurs for small groups of certified devices in Zones requiring a higher degree of explosion protection. The bus can have an overall length up to 350m with spur lengths up to100m.

First field testing of the ac powered system was conducted on a Norwegian offshore platform about 3 years ago. This established its ability to operate with low bit error rates even in the presence of a high level of electrical noise. To develop the system further, a consortium of companies was formed with some financial support from the Norwegian government. This is the Norwegian Fieldbus Consortium (NFC).

Equipment on one of the four buses installed at BP, Sunbury, for the phase 1 trials was supplied by NFC members. This bus operated at 1.0A and used standard dc and ac offshore cable types used in the Norwegian sector of the North Sea. The configuration and the conditions for the tests are included in figure 8 and table 1. No attempts were made either to install the bus for hazardous-area use or to design devices for IS operation but the operating power levels were compatible with such requirements. The test results were all satisfactory and are listed in table 2.

The future for hazardous-area fieldbus

The initial demonstration and proving stages of a fieldbus based on the IEC/ISA Physical layer standard are now complete. Further demonstrations and trials on a more complete version of the various layers of the fieldbus standards are in the planning stage. A number of suppliers in both the ISP and WorldFIP fieldbus groupings are now developing and certifying IS equipment suitable for hazardous-area mounting on a 31.25kbit/s bus and these devices will certainly become available during 1994. Another company, Fieldbus International AS (FINT), has recently been formed to exploit the ac powered fieldbus concept and it is thus likely that 1.0Mbit/s devices will also be introduced in a similar time frame. Specialist suppliers of IS interface devices are also certifying safety barriers and isolators to allow communication with and powering of these devices.

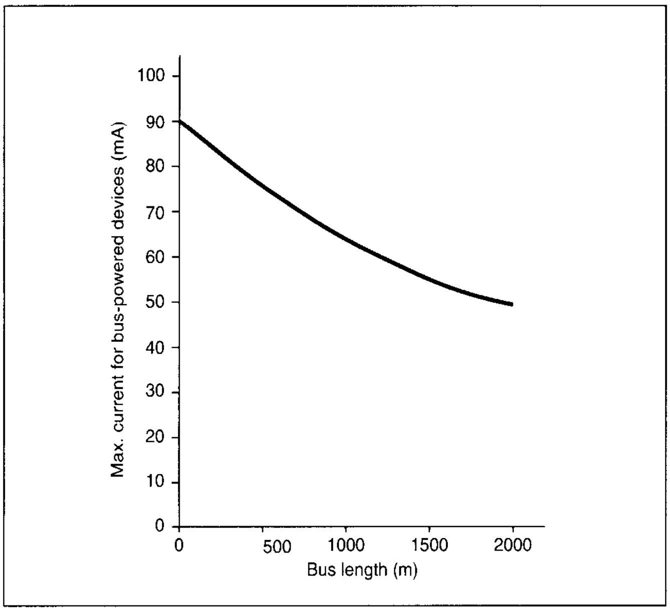

Figure 10. IS fieldbus current

The fieldbus concept is dependent upon devices from different vendors inter-operating and they must therefore be approved for connection to a single fieldbus. It is completely unacceptable for each installed fieldbus system to require an individual system certificate defining details of its individual components. This 'mix and match' requirement introduces a new dimension into the certification problem. While historically manufacturers have tailored approvals to their own equipment requirements, in future the documentation of IS interface equipment must cater for the connection of 'generalised' devices. To assist this process, it is crucial that device manufacturers take into account the following parameters:–

a) Device operating power must be minimised. On a traditional point-to-point analogue loop, all the power from the IS interface is available to power a single device. On a fieldbus, the available current (see figure 10) must be shared between all the devices present. Therefore, device designers must concentrate on low power operation (currently 10mA at 9V would be the ideal) if a reasonable number of devices is to be a practical possibility on an IS fieldbus.

b) Any source of external power (eg, Ex e) to a hazardous-area device must be completely segregated from the fieldbus circuit. It is important that no power can be transferred from the external source to the fieldbus under prescribed fault conditions.

c) Certification voltage and current parameters for hazardous-area apparatus should be chosen to allow flexibility. A voltage level of at least 22V should be chosen together with a current of not less than 220mA. These will be compatible with the evolving optimum parameters for IS fieldbus interfaces. Certified maximum power level should be at least 1.0W (preferably 1.2W) for compatibility with projected IS interface units. In most cases, higher levels than this will probably cause unnecessary approval problems for designers.

d) The residual capacitance and inductance of devices should be minimised. Ideally, each should be zero. The sum of these parameters for each device on the fieldbus must be subtracted for the permitted maximum values for the system. Any significant parameters from one device may both increase the difficulty of fieldbus approval and restrict the maximum bus length (particularly in gas group IIC gases).

Provided that equipment suppliers in the major fieldbus groupings realise the importance of these items and work to achieve them, then 'real' fieldbus systems incorporating IS technology should soon be available for installation in hazardous process areas.

Conclusion

The ability of a fieldbus using the IEC/ISA Physical layer standard to operate successfuly under the conditions of limited power necessary for IS operation in hazardous areas has been demonstrated adequately in trials. 'Real' equipment is now being designed and approved and commercial systems will certainly be installed within the next two years. Fieldbus promises radical changes to traditional process instrumentation and systems, bringing with it the benefits of reduced wiring and installation costs, better status and diagnostic information, and true inter-operation of equipment from different vendors. Using the approaches and technologies outlined in this paper, these benefits will become available in both hazardous and safe areas of process plants.

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