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FISCO-MODEL VERSUS CONVENTIONAL INTRINSIC SAFETY EVALUATION IN FIELDBUS TECHNOLOGY

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The paper describes the new Fieldbus Intrinsically Safe Concept – "FISCO" and its implementation into modern intrinsically safe fieldbus power supplies, repeaters and bridges. The FISCO-model is explained and a comparison with the conventional intrinsic safety evaluation, the so-called "entity model", is explained. The two major advantages of the FISCO-model – increased power on the intrinsically safe bus line and a simplified intrinsic safety conformity evaluation – are described in detail. Some examples of implementations into various fieldbus devices underline the practical relevance. The paper closes with a brief summary on the world-wide activities to promote the FISCO-model.

Fieldbus, Intrinsic Safety, FISCO, Repeater, Power Supply

1. Introduction

In the late eighties the technology of serial data communication and the decreasing price of µController components allowed first installations of serial communication bus systems in the direct factory and process environment, the so-called field. The shorter plant and manufacturing equipment lifecycles of the factory automation led to a breakthrough in fieldbus applications already in the first half of the nineties. This fieldbus activities also evolved from proprietary solutions to open standards defining the physical layer, the data link layer, and the application layer as the layer 1, 2, and 7 of the ISO model of communication (Pech, 1996). One of the first accepted open

European standards were Interbus-S and Profibus DP. But this serial bus systems mostly connected I/O blocks or Remote I/O-Systems to a PLC or PC, and only very seldom intelligent devices were hooked directly on these serial communication busses. Thus the process automation industry always hesitated to call this bus systems fieldbus.

2. Fieldbus system for the Process Automation

A fieldbus following the definition of the process industry (Pfleger, 1985) does not only communicate with intelligent field devices like sensors and/or actuators directly, the fieldbus has to provide a limited amount of power to these devices to allow systems with an adequate low power consumption to operate without any additional power supply. Furthermore a subset of the fieldbus definition must allow the implementation of a totally intrinsically safe fieldbus communicating with and feeding intrinsically safe field devices. It is evident that standard physical layers for serial communication like RS 232, RS 422, and RS 485 cannot fulfil these requirements.

3. The physical layer IEC 1158-2

It is interesting to mention that both the Fieldbus Foundation and the Profibus User Organization almost at the same time were setting up standards for fieldbus physical layers including the requirement to have intrinsic safety as an option and later on both decided to use the IEC Standard 1158-2 as their lowest level for both, Foundation Fieldbus H1 and Profibus PA.

The topology of the IEC 1158-2 has its background from the 4…20 mA current interface feeding a transmitter or similar devices with up to 4 mA and putting the analog information on top of this base current. For digital information the IEC 1158-2 uses a base current of at least 10 mA. A logical "1" subtracts 9 mA of this by cutting down the input current momentarily and logical "0" adds another 9 mA. The data transmission speed depends on the capacitive and inductive load of the fieldbus derived from the cable as such and from the devices. The IEC 1158-2 uses a lowest frequency of 31,25 kBaud which creates almost no restriction on the impedance of cable and devices.

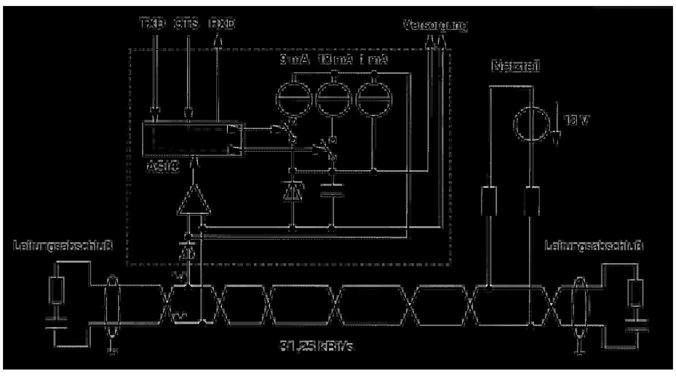

Fig 1. Current source model of IEC 1158-2 from (Schmitz, 1996).

The base current on the IEC 1158-2 fieldbus line has to be 10 mA at minimum while the maximum value is not limited at all. Limitations do not arise from the communication, but from the voltage drop along the bus line feeding, e. g. several Amps. of current. The field devices need a certain minimum voltage at the end of the line (9V as defined in IEC 1158-2) and are only able to accept a certain maximum voltage at the power feeding point of the line. At a later stage practical values for the feeding voltage and the maximum current will be mentioned.

3.1 Reliability and fault tolerance of the IEC 1158-2

The IEC 1158-2 is also defining a specific way of coding the information, the so-called Manchester II Coding described in Fig. 2

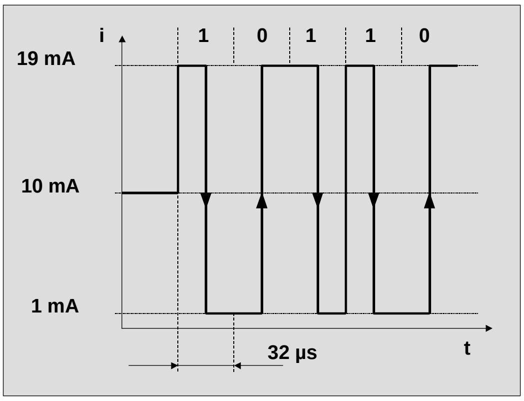

Fig 2. Manchester II coding representing "0" and "1"

There are other coding algorithms like the NRZ-Coding formerly used in the Profibus Standard but the Manchester II coding combines two major advantages:

a) DC bias free
b) High fault tolerance

The fault tolerance is expressed with the so-called Hamming Distance (Schnell, 1996) which is an almost proportional value to the number of fault bits per telegram that could be recognized without any errors in the information. The necessary coding algorithms are normally described in the data link layer but for the IEC 1158-2 this security mechanism is already described and mandatory in layer 1. It consists out of the a.m. basic Manchester bit coding, start and end delimiter and a 16-bit CRC which guarantees a Hamming distance of 4 not taking into account the basic security of the Manchester coding as such.

4. Intrinsically safe IEC 1158-2

The IEC 1158-2 as a coding principle is, of course, easy to approve intrinsically safe. The limiting factor is the maximum current and voltage on the line to feed the field devices. Since the costs for fieldbus segment master devices and power supplies are high an extreme limitation of the a.m. current and voltage would reduce the cost efficiency of an intrinsically safe fieldbus drastically.

It is evident that the intrinsic safety evaluation should be done in a way that allows the absolute maximum of power on the bus line to raise the cost efficiency of Ex-i fieldbus. Otherwise solutions with Remote I/O-Systems would eventually be more cost effective for intrinsically safe signals.

5. Fieldbus model for Ex-i evaluation

In general the Ex-i evaluation requires certain fixed parameters and conditions. Basically these requirementstypically are (Johannsmeyer, 94):

- Intrinsic safety ib or ia according EN 50020 and IEC 79-11, Class I, Division 1 according to US standards.
- Only one active source (power supply) per system
- All nodes act as passive current links consuming at least 10 mA.
- All nodes have negligible inner inductance and capacitance ($L_i \leq 10\ \mu H$, $C_i \leq 5 nF$).
- Variety of cables shall be considered
- Bus line is properly terminated at both ends (R = 90 … 100 Ω, C ≤ 2,2 nF)

The overall picture of the field bus system is shown in Fig. 3 from (Johannsmeyer, 94).

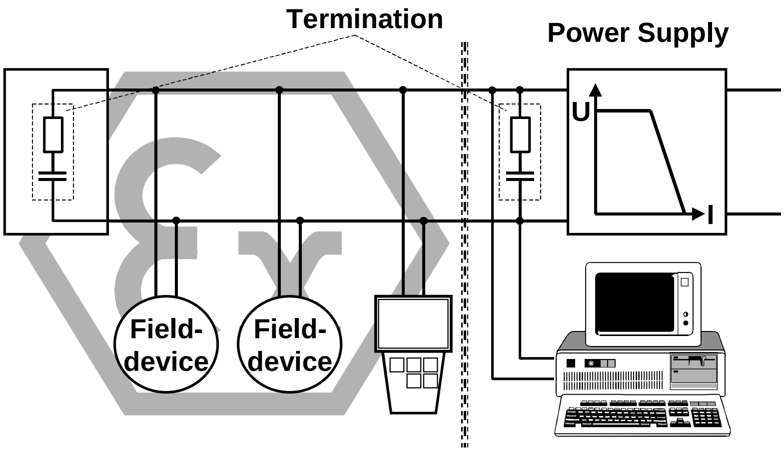

Fig 3. Overall structure of Ex-i field bus system

5.1 Conventional evaluation of intrinsic safety of IEC 1158-2 fieldbus

The outstanding problem of the conventional method of evaluating intrinsic safety is the representation of the cable like shown in Fig. 4

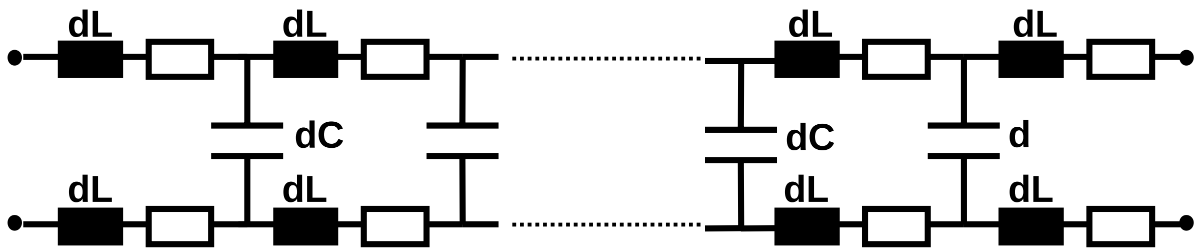

Fig 4. Cable equivalent circuit with differential reactances

The conventional method represents the a.m. network with differential capacities, inductivities, and resistance values and adds up all these residual values to the value of the field devices and terminations Ci, Li, Ri. With a given maximum voltage Uz out of the power supply the maximum current Isc and/or maximum cable length can be obtained out of the standard equations of power limitation for Ex-i evaluation. Hence the the cable inductivity per meter multiplied with a cable length of e.g. 1000 meter easily creates a total inductivity of 0,5 mH or more, the equivalent ignition curve for inductive circuits out of (Johannsmeyer et. al., 89) has to be used. If Uz is 15 V and the total inductivity would be 1 mH the maximum current for gas group II C would for example be only around 70 mA

The necessary consideration of the cable inductivity leads to the requirement to use the ignition curve for inductive circuits, which is always more restrictive than the ignition curve for resistive circuits.

Differences in cable and cable length have to be considered each time when intrinsic safety conformity is required.

The maximum power fed through the intrinsically safe fieldbus decreases with increasing cable length.

5.2 FISCO model of evaluating intrinsic safety

The FISCO model uses a general approach to verify the impact of the differential reactances of the cable by performing realistic ignition tests described in (Johannsmeyer et. al., 89). The set-up included common assumptions like partly implemented in the IEC 1158-2. The supply units should be considered as ia and ib type.

5.2.1 Supply units in category “ib”

The ib type power supply should provide an electronic current limitation with an internal resistance as small as possible giving a rectangular output curve withe.g. Uz = 15 V output voltage. Assuming that the ignition test shows no influence of the cable inductivity the ignition curve for resistive circuit out of (Johannsmeyer et. al., 89) can be used, giving a maximum short circuit current of Isc = 130 mA with gas group IIC. Changing the gas group to IIB would even give much higher currents of up to 270mA.

5.2.2 Supply units in category “ia”

These categories usually have "trapezoidal" output characteristics and can operate in gas group IIC for example with Uo = 34 V and R = 158 Ω and maximum output voltage of Uz = 15 V achieving a maximum current of 120 mA when assuming the same zero influence of the cable reactances on the ignition test.

5.2.3 Field devices

Like partially expressed already in IEC 1158-2 the field devices should operate with a minimum voltage of 9 V and guarantee a minimum current consumption of 10 mA. The internal capacities and inductivities are negligibly small with Ci < 5 nF; Li < 10 µH.

6. Result of the FISCO ignition tests

In applying the ignition tester at several places of the fieldbus test set-up described in (Johannsmeyer, 94) and in Fig. 5 the result was that the lowest current leading to an ignition was always without applying any cable. In other words: Any given set-up of the fieldbus test scenario was safer than the one without any fieldbus cable in the given boundaries of the test conditions.

Due to the test results the cable reactances have no negative influence on the ignition test results. Therefore the ignition curve for resistive circuits can be used and higher maximum output currents of the supply can be obtained.

The intrinsic safety conformity declaration does not require any consideration of cable length and cable reactance parameters.

The maximum power supply output is completely independent of the cable length in the a.m. boundaries.

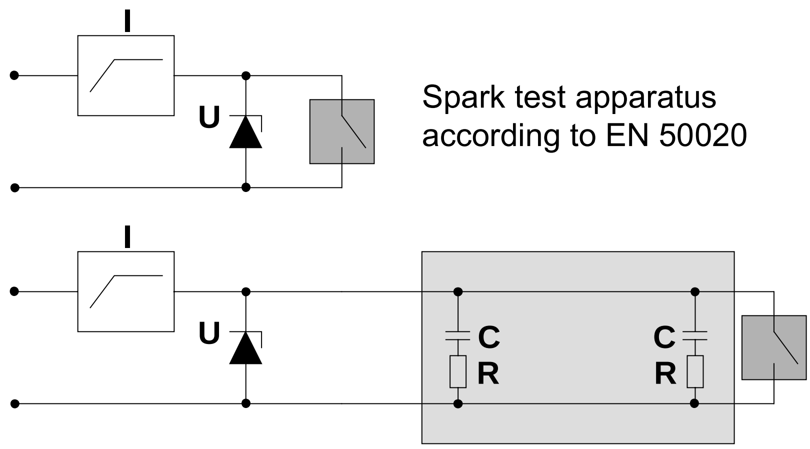

Fig 5. Examples of test set-ups of ignition tests

7. Practical relevance of the FISCO model

The FISCO model increases the maximum power on Ex-i fieldbus allowing up to 10 Ex-i field devices to be hooked on the bus. As long as the field device Li and Ci values (10 µH, 5 nF) are negligible and the cable reactance does not exceed maximum values (R' = 15 – 150 Ω/km, L' = 0.4 – 1 mH/km, C' = 80 – 200 nF/km including shield). Maximum cable length of up to 1 km can be installed without further consideration of Ex-i conditions. The increase of the maximum current leads to a significant increase of power on the Ex-i bus-line. For an ib supply with rectangular output characteristics and gas group II C this output power is 1,92 Watts at 15 V output voltage. In opposite to this the FF Ex-i application guide recommends a maximum power on the bus line of 1.2 Watts which is below the maximum value derived out of the entity model even for reasonable cable length. The reason is, that fora 1,2 Watt supply devices the design of field devices is considerably simplified because there is basically no need for a power limitation into the field device when operated in temperature class T4. Both, the FISCO model versus entity model and the limitation of the supply output power to 1,2 Watt lead to a significant difference in the supply's application:

	FISCO	**FF Entity**
Cable length	1000m*	1900m
Max. Spur length	30m*	120m
Max. number of devices	10	4
Cable reactances and length	Not to consider	To consider

* Maximum investigated length. Increased length should be possible if desired

Table 1: FISCO versus entity model power supply properties

To achieve a maximum flexibility in the design of several variations of power supplies considering either optimisation for maximum cable length (high output voltage) or maximum numbers of devices (high output current) the Ex-I field devices hooked on a FISCO model IEC 1158-2 fieldbus should be designed to accept both layouts of the supply extremes. This leads to more restrictive values for Ex-I parameters for the design of field devices in comparison to the FF entity model limiting the power to 1,2 Watt in general.

Ex-I field device parameters	**FISCO devices**	**FF devices**
Uo / Io	17,5 V/380 mA	24 V/250 mA
Po	5,32 W	1,2 W
Li / Ci	<10 µH / < 5 nF	< 20 µH / < 5 nF

Table 2: Ex-i design parameters for FISCO and entity model field devices

Therefore a number of different power supplies, active repeater and segment couplers were brought to the market incorporating the FISCO model.

7.1 Profibus PA segment coupler

The Profibus H2, the so-called Profibus DP, can be linked to intrinsically safe Profibus PA segments. A segment coupler does this interfacing and provides intrinsically safe power on IEC 1158-2.

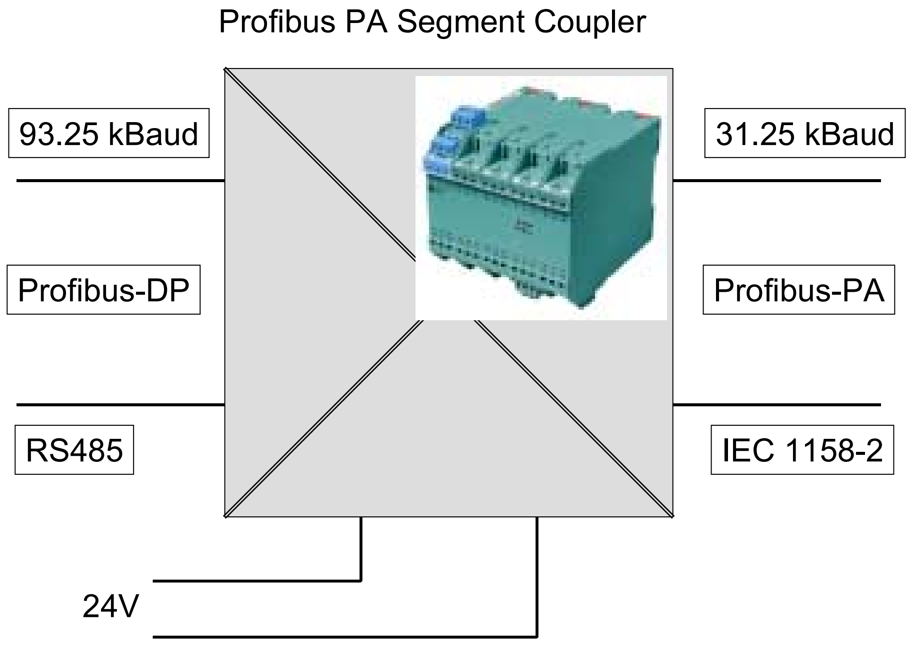

Fig 6. Profibus PA segment coupler

The coming generation represents Profibus PA segments as "proxies" at the Profibus DP allowing the H2 bus to communicate with up to 12 MBaud with the slow 31.25 kBd of up to 16 Profibus PA segments hooked on this hub-device.

7.2 Fieldbus Foundation Repeater and Power Supplies

For the Foundation Fieldbus a Repeater separating non Ex-i FF H1 segments from Ex-i segments also provides Ex-i power to the bus line.

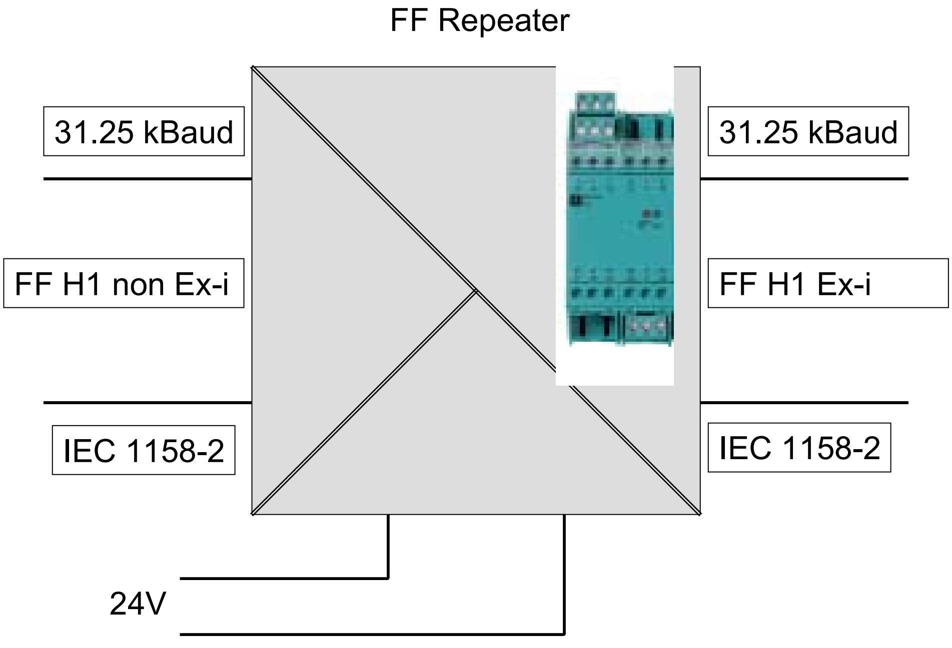

Fig 7. FF Repeater (Pepperl + Fuchs, 1999)

8. Summary

The FISCO model for intrinsically safe IEC 1158-2 field bus configurations allows easy Ex-i conformity, independence from fieldbus cable length and provides enough Ex-i power to feed up to 10 Ex-i field devices for ia or ib power supplies and gas group IIC.

These major advantages led to an increased acceptance of the FISCO model for intrinsic safety evaluation in IEC 1158-2 Ex-i fieldbus applications.

FISCO compliant repeaters and segment couplers are approved by FM for the US market and by PTB for the use in Europe. A significant number of Foundation Fieldbus and Profibus PA field instruments is approved for the use in conjunction with FISCO compliant power supplies.

Several working groups in both Profibus User Organization and Foundation Fieldbus Association are working on a continuous improvement of the acceptance of the FISCO model. The FISCO model was an integral part of the PROFUBUS PA definition while the Fieldbus Foundation is currently working on the introduction of the FISCO model into the existing specification. Six documents will be amended. The release of these documents is expected after the review of the membership before end of 2001.

At the same time the FISCO model will be published as an IEC standard that specifies the aspects of intrinsic safety and ensures interoperability between FISCO power supply units and field instruments. The committee draft will be published before the end of 2001.

Meanwhile the approval status for FISCO model power supplies and standardisation efforts are leading to an increased resonance of the model as such and the incorporation of FISCO models in repeaters, power supplies and field devices.

Pech, A., "*Kommunikationsmodelle*", 8 – 16, Schnell, G., "*Bussysteme in der Automatisierungstechnik*", Vieweg-Verlag, Wiesbaden, (1996).

Pfleger, J., "*Kommunikation in der Leittechnik*", 48. NAMUR-Hauptsitzung, Lahnstein, (1985).

Schmitz, A. „Beispiele aufgeführter Bussysteme“, 174 – 180, Schnell, G., "*Bussysteme in der Automatisierungstechnik*", Vieweg-Verlag, Wiesbaden, (1996).

Schnell, G., „Datensicherung“, 28 – 30, Schnell, G. "*Bussysteme in der Automatisierungstechnik*", Vieweg-Verlag, Wiebaden, (1996).

Johannsmeyer, U., " Investigations into the Intrinsic Safety of field bus systems", *PTB-Bericht W-53e*, Braunschweig, (1994).

Johannsmeyer, U., H.-D. Göldner, I. Schebsdat and H. Storck, "Zusammenschaltung nichtlinearer und linearer eigensicherer Stromkreise", *PTB-Bericht W39*, Brauchschweig, (1989).

Pepperl + Fuchs GmbH, "Data Sheet KLD2-PR-Ex1.IEC1", Mannheim, (1999).