Quality Information from a Quality Supplier

This technical white paper utilizes Pepperl+Fuchs’ expertise and knowledge to provide a clear insight into the many new technological and application issues you may face with a fieldbus installation. It corresponds to our way of working and thinking: combining state-of-the-art technologies with years of research and innovation to simplify planning, installation and commissioning, operation, and plant upkeep.

Our promise is to simplify your work processes with fieldbus: You can stay focused on your day-to-day business with a reliable FieldConnex® fieldbus infrastructure. It ensures the connection between DCS and instruments, fully digital with explosion protection for any hazardous area. We are driven to provide innovation with proven reliability for process automation practitioners:

- FieldConnex is robust, reliable, and the first choice of many well-known end users worldwide.
- Advanced physical layer diagnostics reach down to spurs, accessories, and instruments; interpret data, and provide detailed fault analysis. Water ingress and worn-out surge protectors are identified without manual inspection.
- The High-Power Trunk concept allows long cable runs and high device counts and is now an industry standard. DART Fieldbus makes the High-Power Trunk intrinsically safe.

If the content of this paper sparks comments or questions, we invite you to contact your Pepperl+Fuchs office or representative to get in touch with the experts. We are glad to share our expertise with you for your business success.
Abstract

Fieldbus systems are well established in process automation, namely FOUNDATION fieldbus H1 and PROFIBUS PA. Their main attributes contributing to their success are: long cable runs, power and data on a single twisted pair and easy-to-implement explosion protection.

Planning and design lays the cornerstone for successful implementation, and proper planning will invariably lead to savings during installation and more importantly commissioning and plant start-up. Poor planning on the other hand will cause the opposite.

This paper details steps and decisions made during planning of the fieldbus physical layer. It serves as a reference with examples and cookbook recipes leading planners to decision criteria important to success with fieldbus. Steps described here will ensure a working fieldbus infrastructure before the first cable is installed.

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Contents

1 Motivation and introduction ........................................................................................................................... 2
2 Segment planning for the safe area ...................................................................................................................... 2
   2.1 Steps for planning a fieldbus segment ......................................................................................................... 3
   2.2 Calculating electrical values ....................................................................................................................... 6
   2.3 Documenting segment design ..................................................................................................................... 6
   2.4 Topology – A case study ............................................................................................................................ 7
      2.4.1 Specification ........................................................................................................................................ 7
      2.4.2 Hardware chosen for the fieldbus infrastructure .................................................................................. 7
      2.4.3 Validation and results ......................................................................................................................... 8
      2.4.4 Calculations for validation example .................................................................................................... 9
   2.5 Additional considerations – grounding, shielding, surge ....................................................................... 9
3 Fieldbus in hazardous areas ............................................................................................................................ 11
   3.1 Explosion protection methods .................................................................................................................... 11
      3.1.1 Entity ................................................................................................................................................. 12
      3.1.2 FISCO – Fieldbus Intrinsically Safe Concept ....................................................................................... 13
      3.1.3 The High-Power Trunk Concept .......................................................................................................... 13
      3.1.4 The High-Power Trunk Concept with DART ...................................................................................... 14
      3.1.5 Explosion-proof housing ..................................................................................................................... 14
      3.1.6 Flameproof installation - Ex d-rated wiring interfaces ....................................................................... 14
   3.2 Performance comparison ............................................................................................................................. 15
   3.3 Case study showing cable lengths and device count ................................................................................. 16
   3.4 Comparison of actual values ..................................................................................................................... 16
   3.5 Summary of comparison ............................................................................................................................ 17
      3.5.1 Cable run ............................................................................................................................................ 17
      3.5.2 Energy limitation for the entire segment .............................................................................................. 17
      3.5.3 High-Power Trunk Concept ................................................................................................................ 17
   3.6 General considerations for fieldbus in hazardous areas ........................................................................... 17
4 Safety applications up to SIL 3 ........................................................................................................................ 18
   4.1 Reliability required ..................................................................................................................................... 18
   4.2 Designing for highest availability ............................................................................................................. 19
5 Conclusions and summary ............................................................................................................................. 20
1 Motivation and introduction

Bus systems are well established in process automation. They realize savings in wiring and engineering and enable remote configuration and parameterization. The main savings potential is by enabling predictive maintenance strategies. Potential sources for faults can be detected and repaired, before an unwanted plant shutdown occurs.

In process automation, the object to be automated is often located in the hazardous area. This means that installation technology and field devices need to have a life span of 20 years; they also need to be usable in the most hazardous areas with respect to their zones or divisions. To enable plants to run continuously, it must be possible to work on and maintain devices while the plant is in operation; thus, energy-limiting methods for explosion protection are preferred.

An advantage of fieldbus is the fact that many participants can be connected to a single electrical network. This makes validation of intrinsic safety with fieldbus more difficult. While 4…20 mA technology employs simple-to-calculate point-to-point connections, fieldbus utilizes connections in parallel. In the course of the years new concepts have been developed and existing concepts improved simplifying validation of intrinsic safety in fieldbus systems – for example, as of 2002 all calculations have been dropped for validation when intrinsic safety is employed according to the FISCO model, thus making fieldbus even more profitable in the hazardous area.

Fieldbus for the process industry typically must not only meet the IEC standard for fieldbus, IEC 61158-2, but also the standards for explosion protection, IEC 60079. This guideline first describes the requirements according to IEC 61158-2 regarding the planning of a fieldbus topology and respective constraints. Expanding upon it, the tighter constraints of explosion protection are described.

2 Segment planning for the safe area

Chapter 12 of IEC 61158-2 describes all requirements that must be met for proper operation of a network for FOUNDATION fieldbus H1 or PROFIBUS PA (MBP). Most requirements relate to interface design. Those details relevant for planning are described here for convenience with tips from practice for successful implementation of fieldbus segments.

A carefully planned fieldbus segment is the basis for reliable operation. Getting the segment design right the first time is an important step that will allow significant time savings during commissioning compared to classic interface technology. The following extra steps described here, save significant time in comparison to fixing issues later in the field.

If your total desired cable length is more than 1900 m, (the sum of the trunk line and all spur lines) you must find alternate ways to design the fieldbus infrastructure in order to bring the total cable length to less than 1900 m. This may include running communications via fiber optics or by other means such as repeaters. This chapter focuses on H1-bus, bus-powered fieldbus infrastructure only, which is provided by FOUNDATION fieldbus H1 and PROFIBUS PA (MBP).

The basic design steps are listed below and explained in greater detail in the next chapter:

- Specify environmental conditions
- Design typical loops for control and monitoring
- Calculate or specify the required bus cycle times
- Verify longest cable distances
- Choose the segment topology
- Select the cable to be used
- Choose power supply and wiring interfaces
- Determine the number of devices connectable to the typical loops
- Verify that required trunk and spur length is possible based on number of devices connected
The good news first: After making some basic engineering decisions, software tools – most of them freeware – take care of calculating all electrical values and automate the process of validating the segment design on the fly, reassuring the planner that the actual design will work. Even change requests and red lining is easy to document with the help of these software tools.

2.1 Steps for planning a fieldbus segment

Environmental conditions
Ambient temperature is an important aspect for planning segments as high temperatures can have a negative influence on achievable cable lengths. The following aspects influence selection of components, however without influence on segment design:

- Shock/vibration
- Corrosion ratings/requirements
- Type of enclosure
- IP-class and NEMA ratings of enclosures

Typical loops
Because many variables are not yet known at this point, planners will design typical loops that fulfill the highest demands or constraints on the fieldbus infrastructure. The following table lists data to be considered for typical loops:

- Longest cable length from the control room into the field
- Current consumption of field devices used
- Maximum bus cycle time acceptable

There are two typical loops to be considered:

1. Control loops with a demand for shorter response times and thus shorter bus cycle time
2. Monitoring loops where a longer bus cycle is satisfactory

Bus cycle time
The bus cycle time of control and monitoring loops is an important ingredient in planning a fieldbus segment because it influences the overall system responsiveness. There are many factors influencing bus cycle time that are often determined with software available from DCS system vendors.

The bus cycle time is determined from the following aspects that influence the number of devices per segment and must also be considered when planning a segment. It is recommended that the bus cycle time is determined and the maximum possible number of devices calculated.

- Fieldbus system used (i.e. FOUNDATION fieldbus H1 or PROFIBUS PA)
- DCS system used
- Number of devices on the segment
- Amount of data to be transmitted
- Time required for acyclic data exchange (e.g., configuration and diagnostic data)

The topology
Next the planner chooses the topology. Though the planner is free to choose any topology, the trunk-and-spur and tree topologies are recommended as they fulfill the following demands:

- Usable for all segments of the plant
- Easy to understand and thus easy to work with and maintain
- Enable short-circuit protection for the trunk allowing live work on field devices

These topologies have been adopted as de facto standard in most process plants today; they will be considered in the examples below. Typically the power supply is installed at one end of the trunk in a cabinet in the control room. The trunk is the longest part of the segment, it requires a fieldbus terminator installed at each end. See Figure 1.
Planning fieldbus segments in safe and hazardous areas

Segment planning for the safe area

04 / 21 www.pepperl-fuchs.com

Figure 1: Trunk and Spur Topology. Easy to install and maintain. Also referred to as tree topology when all fieldbus couplers are mounted in one place.

Fieldbus distributors – Protecting the trunk
For the safe area, distribution units with simple terminators and connectors are permissible. Simple junction boxes, also known as wiring bricks, or wiring blocks are installed near the field instruments with a layout following the selected topology. Good working practice then demands that the cable inside the junction box is detached first. Only then are the terminals inside the field instrument disconnected. However, this type of installation is seldom used in practice.

Live work on an instrument in the field almost always causes intermittent short circuits, which would cause the entire segment to fail. A wiring interface named Segment Protector features short-circuit protection at each spur and protects the trunk from unintended faults caused when live work is performed on a field device. Since current-limiting wiring interfaces may have a non-linear behavior it is recommended to use a planning tool, where this load characteristic is considered and calculated.

Figure 2: Segment Protector Principle Diagram: Each spur connection is equipped with short-circuit protection. Operation of the segment remains undisturbed from live work on the field device
Considerations for power supply – current and voltage reserves

The maximum current provided by the power supply determines the maximum number of field devices and wiring interfaces. The standard prescribes a minimum current consumption of 10 mA per field device. Current consumption of most devices is between 10…20 mA.

A reserve of minimum 20% per segment is typically specified enabling later additions and expansions. Additionally, current consumption stated in datasheets has differed from actual values. This reserve protects from mishaps that may be discovered very late during commissioning and then cause a significant unexpected increase in cost to fix the issue in the field – e.g., having to install additional segments.

At least one short-circuit condition has to be considered when adding up current consumption. This is due to the fact that live work on field instrumentation is a “normal” mode of operation and will most likely cause intermittent short circuits.

Device libraries are available for Segment Checker that detail load conditions for many field instruments of many manufacturers. Additionally, devices can be added to custom libraries manually allowing exact planning of load conditions.

The maximum voltage of the power supply together with the load current determines maximum cable runs, due to the voltage drop on the cable. This is influenced by the cable type, load, and topology. The standard prescribes a minimum voltage of 9 V available at the field device. Planners will typically ask for 10% reserve or minimum of 10 V at every field device.

Finally: State-of-the-art power supplies provide galvanic isolation between the segment and the bulk power supply.

Cable Type – Trunk and Spur lengths

Four cable types with respective values are defined for fieldbus use. IEC 61158-2. They can be specified or purchased as type “A”… “D”. They include single twisted pair and multi-core versions. The type and wire gauge of the cable influences the maximum reachable cable distance.

Table 1 shows the maximum achievable cable lengths by cable type at 25 °C. This is the sum of the trunk line and all spur lines. Longest cable lengths of 1900 m are reached when Type A cable is applied. Lower limits apply to the other types. Additionally the achievable cable length depends on the ambient temperature and wire cross section.

From these requirements the planning software will help to determine the maximum number of devices that can be connected to the segment for the desired cable runs. The number of devices connected to a segment dictates the maximum permitted length of the spur as shown in Table 2.

With the data in Table 2 it becomes evident that the limitation in spur lengths is the reason why planners choose a number of participants of 24 or smaller. The number of participants includes the field instruments and the host system. The host system has a count of two where redundant hosts are used.

NB: Different limits apply for number of devices and spur length when hazardous locations are considered. These are discussed further below.
2.2 Calculating electrical values

All data collected from the considerations above is entered into a segment planning tool such as Segment Checker, (www.segmentchecker.com) the fieldbus planning tool created by Pepperl+Fuchs. The planning tool assists in calculating voltage drops and current consumption and verifies the validity of segment design immediately.

Segment Checker is a tool provided and maintained by Pepperl+Fuchs for planning and design of fieldbus systems. Segment Checker supports the layout and documentation of any fieldbus architecture, topology, and design. It compares the topology entered against specifications of the fieldbus standard IEC 61158-2 and highlights errors and potential problems with error messages and color-coding. Current consumption and voltage levels are shown at every point in the electrical system. A comprehensive set of libraries with field instruments can be easily loaded and a device editor allows simple addition of devices.

Planning a fieldbus segment: Easy to use with the ability to drag and drop devices. The software immediately validates the configuration and highlights conditions that violate the minimum requirements.

2.3 Documenting segment design

The planning software, Segment Checker, has an export function including documentation text, lists and graphic representation.

Drawing and engineering packages can be used to create connection diagrams. However, some planners reduce the amount of documentation to a simple spreadsheet that outlines the tag numbers of all equipment installed. This saves on documentation while at the same time simplifying all work steps with fieldbus.
2.4 Topology – A case study

2.4.1 Specification
The following requirements may constitute a real-life example based on the discussion above. Segment design must meet the specifications as follows:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Value or Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature</td>
<td>55 °C</td>
</tr>
<tr>
<td>Trunk length</td>
<td>min. 600 m</td>
</tr>
<tr>
<td>Topology</td>
<td>Tree</td>
</tr>
<tr>
<td>Cable</td>
<td>Cross section 0.8 mm, AWG 18, 44 Ω/km</td>
</tr>
<tr>
<td>Current consumption per field device</td>
<td>20 mA average: based on calculation of actual current consumption of devices planned to be used.</td>
</tr>
<tr>
<td>Short-circuit protection</td>
<td>Yes</td>
</tr>
<tr>
<td>Host-redundancy</td>
<td>Yes</td>
</tr>
<tr>
<td>Host spur length</td>
<td>5 m</td>
</tr>
<tr>
<td>Power supply load</td>
<td>20% reserve</td>
</tr>
<tr>
<td>Field device spur length minimum</td>
<td>70 m</td>
</tr>
<tr>
<td>Number of instruments per segment</td>
<td>10</td>
</tr>
</tbody>
</table>

2.4.2 Hardware chosen for the fieldbus infrastructure
Power Supply: 25 V / 360 mA, e.g., HD2-FBPS-1.25.360
Segment Protector: R2-SP-N12. All field instruments are connected to one Segment Protector installed at the end of the trunk cable.

Standard fieldbus cable, type A.

The segment topology looks as follows:

Figure 3: The topology as shown in Segment Checker. Simple mouse clicks result in a fully validated structure.
### 2.4.3 Validation and results

This design is valid for implementation in the safe area. Segment Checker automatically validates conformity of all data according to IEC 61158-2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Actual</th>
<th>Limit</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cable length</td>
<td>1505 m</td>
<td>Min. 1900 m</td>
<td>Meets limit of IEC 61158-2</td>
</tr>
<tr>
<td>Spur length</td>
<td>70 m</td>
<td>Max. 90 m</td>
<td>Meets limit of IEC 61158-2 for up to 14 participants</td>
</tr>
<tr>
<td>Load of power supply</td>
<td>229 mA</td>
<td>Max. 288 mA</td>
<td>Meets 20% reserve of max. power supply current</td>
</tr>
<tr>
<td>Voltage at Segment Protector</td>
<td>19.1 V</td>
<td>9…31 V</td>
<td>Meets limit of IEC 61158-2 including 10% reserve</td>
</tr>
<tr>
<td>Voltage at field instrument</td>
<td>18.5 V</td>
<td>Min. 9.9 V</td>
<td>Meets limit of IEC 61158-2 including 10% reserve</td>
</tr>
</tbody>
</table>

This segment is a good design that follows all design rules and provides for enough reserve for good function and future expansions. For the purpose of showing the calculation steps to be carried out the example is validated “on foot” below:

### Cables: Length: Overall, trunk and spurs

Overall cable length is 1505 m, which is less than 1900 m according to IEC 61158-2. Calculation.

\[
I_{\text{Tot}} = \sum I_{\text{Spur}} + I_{\text{Trunk}}
\]

*Formula 1: Total cable length is the sum of all spur lengths + the trunk length*

Spur length specified as 70 m is less than 90 m, the maximum according to IEC 61158-2. According to Table 2 a spur length of up to 90 m is permitted with up to 14 participants. In this segment, consisting of 10 field instruments plus 2 host connections the spur length of 90 m is therefore OK. Two extra field instruments are permissible as reserve per segment while keeping the exact same planning.

### Load Condition of the power supply

Load conditions at power supply is 229 mA, which is more than 20% less than 360 mA.

\[
I_{\text{Seg}} = \sum I_{\text{Dev}} + \sum I_{\text{S.P.}} + I_{\text{Host}}
\]

*Formula 2: Total load of the power supply (I_{\text{Seg}}) is the sum of all device currents, plus load current of segment protectors and the host current.*

### Available Voltage at Segment Protector and Field Instruments

Additionally, the voltage available at wiring interfaces and field devices must meet minimum criteria:

\[
R_{\text{Cable}} = R_{20} \times (1 + \alpha_{20} (T - 20^\circ C))
\]

\[
U_{SP} - U_{PS} - I_{\text{Seg}} \times R_{\text{Cable}}
\]

\[
U_{\text{DEV}} = U_{SP} - U_{\Delta SP} - I_{\text{DEV}} \times R_{\text{Cable}}
\]

*Formula 3: Resistance and voltage drop calculated for Segment Protector (SP) and field device (DEV). Available voltage is lower with higher ambient temperature.*

Voltage at the Segment Protector is 19.0 V and the voltage at the field instruments is 18.4 V, which are both larger than 9 V min according to IEC 61158-2 and within the range specified as 9…31 V.
2.4.4 Calculations for validation example

Total cable length

<table>
<thead>
<tr>
<th>Component</th>
<th>Length 1</th>
<th>Length 2</th>
<th>Length 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trunk length</td>
<td>600 m</td>
<td>600 m</td>
<td></td>
<td>1200 m</td>
</tr>
<tr>
<td>Spur length</td>
<td>90 m</td>
<td>90 m</td>
<td></td>
<td>180 m</td>
</tr>
<tr>
<td>Host connection length</td>
<td>5 m</td>
<td></td>
<td></td>
<td>5 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1505 m</td>
</tr>
</tbody>
</table>

Load current on trunk cable

- Field instrument load current: 20 mA
- Segment Protector, load current: 9 mA

Load of power supply

- Load current on trunk cable: 209 mA
- Load current from host system: 20 mA
- Load of power supply: 229 mA

Maximum load of power supply: 288 mA

Cable resistance calculations

- Temperature Coefficient: 0.0039 Ohms/mK
- Difference to ambient temperature: 35 K

Coefficient for temperature at 55 °C: 1.1365

- Cable resistance at 20 °C: 44 Ohms/km
- Cable resistance at 55 °C: 50,006 Ohms/km

- Trunk length and resistance: 600 m, 30,0036 Ohms
- Spur length and resistance: 90 m, 4,50054 Ohms

Voltage Drop on the Trunk Cable

- Load current on trunk cable: 209 mA
- Resistance of trunk cable: 30.0 Ohms

Voltage drop on the trunk cable: 6.3 V

Voltage at Input of Segment Protector

- Output voltage of power supply: 25.3 V
- Voltage drop on the trunk cable: 6.3 V

Voltage at Segment Protector: 19.0 V

Voltage Drop on Spur Cable

- Load current on spur cable: 20.0 mA
- Resistance of spur cable: 4.5 Ohm

Voltage drop on spur cable: 0.1 V

Voltage at Input of Field Instrument

- Voltage at Segment Protector: 19.0 V
- Voltage drop inside Segment Protector: 0.5 V

Voltage at field instrument: 18.4 V

2.5 Additional considerations – grounding, shielding, surge

Grounding and shielding is important for immunity to noise of the fieldbus segment. A common method should be chosen for fieldbus that matches the grounding and shielding philosophy of the plant. Great care should be taken to ensure proper grounding shielding; this should be checked during planning.

The potential difference between the two leads (+/-) carries the communication signal. Thus, neither of the two leads should be connected to ground or shield. Additional communication stability and protection from faults can be achieved through use of galvanic isolation in the power supplies:

Galvanic isolation of the power supply

While in the past simple power conditioners only provided the required impedance matching and overload protection, they neither provided voltage regulation nor galvanic isolation between the segments and the bulk power supply. Galvanic isolation in the fieldbus power supply protects the segment from signal distortion. Figure 4 shows a fault scenario with a ground fault. The system will continue to run, however distorted signals on Segment 2 and unknown effects on segment 1 such as
cross talk are consequences of a single ground fault. Additionally a second ground fault in another segment on the other lead (e.g. ‘+’ lead) will cause a short circuit on two segments.

Figure 4: Without galvanic isolation two ground faults can cause a distortion in the segment with unknown effects such as crosstalk on other segments.

Power conditioners without galvanic isolation should only be used where galvanic isolation is provided in the FieldBarrier or in the bulk power supply and when neither of the fieldbus leads are grounded. In principle, the fieldbus power supply should have galvanic isolation, which reflects state-of-the-art technology.

Surge Protection
The effects of a lightning strike, even at a distance of 500 m, can endanger electric equipment. A risk analysis based on the location of the fieldbus systems and its dimension and version, decides on the use of surge protection. High-grade fieldbus components contain a protective diode between the pair of signal wires that already protects against surges and small amounts of energy. For high surges, external protection components are used. They permit the flow of large stray surge current against earth potential without being destroyed in the process.
3 Fieldbus in hazardous areas

All calculations and reasoning shown for fieldbus in safe areas are based on the fieldbus standard IEC 61158-2. This standard defines the maximum dimensions for a fieldbus segment. In hazardous areas additional constraints apply for explosion protection defined in IEC 60079. Here we show only the differences or extra work steps required to layout and plan a fieldbus segment in the hazardous area.

Note: As of this edit of the document, the ignition protection method “Ex nL” is no longer a valid standard for new plants. This guideline will continue to reference Ex nL to support those users that continue to operate their plants with this method of protection. For new plants, in any case Ex ic should be used in hazardous areas applies to plants with classifications as Zone 2 or Class I/Div. 2.

The same general steps for planning fieldbus segments in safe areas apply to hazardous areas. The choice of topology is essentially the same as in safe areas. The general work steps are:

- Specify environmental conditions
- Design typical loops for control and monitoring
- Calculate or specify the required bus cycle times
- Verify longest cable distances
- Choose the segment topology
- Select appropriate method(s) for explosion protection (NEW)
- Select the cable to be used
- Choose power supply and wiring interfaces
- Determine the number of devices connectable to the typical loops
- Verify that required trunk and spur length is possible based on number of devices connected
- Validate explosion protection (NEW)

The only additions are the choice of explosion protection and its validation. A case study shows how achievable cable lengths and number of field devices per segment are influenced by the method of explosion protection. This case study is intended to serve as a guide for selection criteria.

The good news is: Solutions such as the High-Power Trunk Concept (HTPC) allow the same topology to be used in the hazardous area as in the safe area while preserving the ability to allow work on field devices without hot work permit. (See chapter 3.1.3) The HPTC is implemented with energy-limiting fieldbus couplers (e.g., Segment Protector or FieldBarrier). Additionally, the HPTC actually simplifies the validation of explosion protection according to the way it is implemented. This chapter explains how.

More good news: Segment Checker will actually allow selection of power supplies and wiring interfaces for any hazardous area with their respective input and output values allowing the same easy steps to ensure that the fieldbus segment will work as planned. Segment Checker, however, will only validate power, voltage, and current levels. It remains the responsibility of the segment designer to validate and document explosion protection parameters.

3.1 Explosion protection methods

This is a summary of explosion protection methods and their impact on fieldbus planning, most importantly, the available power. This chapter is provided as a general reference leading to decision criteria for the method that best meets the demands of the process automation system to be implemented.

Particularly when work on field devices must be possible without hot work permit, energy-limiting explosion protection methods such as intrinsic safety (Ex i) and Non-incendive (Ex nL) are preferred. However, these methods have the significant disadvantage that they place significant constraints on cable lengths and/or number of field devices.

Energy-limiting methods for explosion protection are used where live work on field instrumentation is specified without requiring a hot work permit. Where long distances must be bridged and higher
power levels are required, mechanical methods of explosion protection methods are applied. These are shown in Table 4 and Table 5.

<table>
<thead>
<tr>
<th>Hazardous area</th>
<th>Explosion protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 0</td>
<td>Ex ia</td>
</tr>
<tr>
<td>Zone 1</td>
<td>Ex ib</td>
</tr>
<tr>
<td>Zone 2</td>
<td>Ex ic or Ex nL</td>
</tr>
<tr>
<td>Division 1</td>
<td>Ex ia</td>
</tr>
<tr>
<td>Division 2</td>
<td>Ex nL or nonincendive field wiring</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazardous area</th>
<th>Explosion protection</th>
<th>Available power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 0 / 1 / 2</td>
<td>Flameproof installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Protected wiring</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flameproof enclosures (Ex d)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pressurized enclosures (Ex p)</td>
<td></td>
</tr>
<tr>
<td>Division 1 / Division 2</td>
<td>Div. 2 wiring method</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explosion-proof installation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amorced cable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Purge for enclosures</td>
<td></td>
</tr>
</tbody>
</table>

3.1.1 Entity

The Entity model is defined in IEC 60079-11 and NEC 515. It is a method of validating an installation of intrinsically safe and associated apparatus through the use of intrinsically safe parameters. It is easy to use in a point-to-point connection; however, calculations become cumbersome when a network with multiple devices has to be considered. In addition to the devices’ parameters, the cable capacitance and inductance have to be considered as well. Simplifications for fieldbus were not considered within this specification and planners had no other option than to accept the complex and time-consuming calculation efforts to validate an installation.

The first initiative to broadly define standardized IS parameters for fieldbus was started by the release of the FOUNDATION fieldbus FF-816 Physical Layer Profile. Based on the conservative Entity model, this document recommended safety parameters of $U_o = 24 \text{ V}$, $I_o = 250 \text{ mA}$ and $P_o = 1.2 \text{ W}$ for power supplies used for gas group IIC (group A,B) applications.

Gases of group IIB (group C) need more energy to ignite. In an attempt to overcome the 1.2 W limitation one manufacturer introduced a IIB Entity power supply. Wiring blocks further limited the energy for IIC Entity field devices. Wiring had to be located in a IIB location even for IIC applications.

Applying the Entity model to fieldbus in practical applications is rather rare; there are only a few power supplies conforming to the Entity model available today. Typically, they provide 10…12 V and 70…100 mA, which is just enough to operate 2…3 field devices per segment (gas group IIC). In the end, Entity:

- Provides power for segments with up to 3 instruments
- Requires a significant calculation effort to validate intrinsic safety
- IIB solution offers more power; however, it is not suitable where many applications require group IIC
- Does not support redundant power
3.1.2 FISCO – Fieldbus Intrinsically Safe Concept

Initially published as an IEC technical specification created by the Physikalisch Technische Bundesanstalt (PTB), Germany FISCO is now defined in IEC 60079-11 and -25 for Ex ia, Ex ib and Ex ic. Triggered by preliminary experiments conducted by PTB the very conservative approach of Entity with concentrated cable inductances and capacitances was re-evaluated with the following objectives:

- Increase available power
- Standardize the installation parameters and limits
- Simplify system calculations, validation, and documentation

FISCO prescribes that only one power supply is permitted per fieldbus segment and that all other devices are power drains with measures in place to prevent unintentional power feedback to the cable. For the first time, a standard placed actual restrictions on cable and electric apparatus with regards to parasitic capacity and inductance. Instruments and power supplies require certification through a notified body. Cables are documented through a declaration by the manufacturer.

With the constraint of only a single power supply permitted per network, power supply redundancy is not possible. Available solutions are implemented as hot-standby redundancy.

Without requiring any calculations, FISCO offers the easiest method for validation of explosion protection, which explains its popularity. It shifts the bulk of the responsibility for sound electric design from the planner and operator of process plants to the equipment manufacturers. Under real-life conditions, it is suitable for small applications with very short cable lengths and 4…8 devices per segment depending on the gas group.

3.1.3 The High-Power Trunk Concept

The High-Power Trunk Concept (HPTC) removes the limitations with regards to segment length and number of devices. HPTC was developed and introduced by Pepperl+Fuchs in 2002.

The principle idea of the HPTC is to deliver unlimited energy on the fieldbus trunk by means of mechanical methods of explosion protection into the hazardous area. Within the hazardous area it is distributed via energy-limiting wiring interfaces to its final destination, the field instrument. The trunk is installed utilizing protected installation and is, therefore, protected from mechanical damage and effects such as unintentional disconnect, corrosion, etc.

![Diagram of High-Power Trunk](image)

Figure 5: High-Power Trunk for any hazardous area Segment Protectors provide short-circuit protection and non-incendive energy limitation (Ex nL) as well as intrinsic safety Ex ic. FieldBarriers provide intrinsic safety (Ex ia).
Standard power supplies are applied for the HPTC, which are much simpler by design and available at a lower price. For Zone 1/0 (Div. 1) applications the wiring interface, typically called FieldBarrier, is used and acts as distribution interface providing galvanically isolated outputs with intrinsically safe energy limitation (Ex ia IIC). Each output of the FieldBarrier acts as an independent FISCO or Entity power supply. Up to four FieldBarriers may be operated on one segment, allowing up to 16 intrinsically safe field devices and an overall maximum cable length of up to 1900 m.

The HPTC enables higher availability of the fieldbus segment as the power supplies may be operated in redundant configuration. The same topology used in the safe area can be used for all hazardous areas: Zone 0, 1 and 2 and Class 1 / Divisions 1 and 2.

3.1.4 The High-Power Trunk Concept with DART
Dynamic Arc Recognition and Termination (DART) is the latest advancement in energy limitation utilizing dynamically acting power supplies and equipment. A spark is detected as it occurs and shuts off before the energy released in the spark becomes incendive. DART realizes long cable runs and many devices while removing the need for protected installation of the trunk cable. DART essentially realizes the intrinsically safe High-Power Trunk Concept.

3.1.5 Explosion-proof housing
Applicable in countries governed by NEC standards: As part of the NEC article 500 explosion-proof is a protection method that can be used in hazardous locations. An explosion proof housing contains a spark and limits venting of the ionized gases in such a way that the energy released into the hazardous area cannot cause an explosion. An explosion-proof enclosure houses ordinary equipment. It also requires the use of rigid metal conduit with poured seals at each end in order to run cabling from the hazardous area into the safe area. Explosion-proof is costly to install and maintain compared to other hazardous location protection methods and it does not allow live work of any of the involved fieldbus components without a hot work permit. It is, therefore, not used for creating a fieldbus installation.

3.1.6 Flameproof installation - Ex d-rated wiring interfaces
Although energy-limiting installation methods are generally used, there are exceptions where field instruments require higher energy levels and/or come with a flameproof housing. In such cases the fieldbus infrastructure is installed using Segment Protectors with an Ex d rating. The rating of the wiring interface permits installation in any junction box in the field.

This method requires “protected installation” of all cable – trunk and spurs. Live work on field instruments requires a hot work permit. Any type of segment planning is done in accordance with that described in Chapter 2 oben as energy is not limited for the purpose of explosion protection.
3.2 Performance comparison

The comparison shown in Table 6 highlights attributes qualitatively. Attributes are defined below and evaluated for their technical and business benefits as positive, neutral or negative. The evaluation criteria shown in the table are:

- **Installation cost and effort**: The cost of parts and labor to install the fieldbus infrastructure.
- **Available power**: The amount of power available for instrument supply.
- **Validation of explosion protection**: Or better the simplicity thereof: This is the amount of calculations and work required to validate the installation for the purpose of explosion protection. I.e. with FISCO even limiting voltages and currents are defined so that no calculations are required and validation is limited to documenting conformity of power supplies, instruments and cable.
- **Power supply redundancy**: Option available to utilize power supply redundancy.
- **Continuous physical layer diagnostics**: Option available to utilize continuous online physical layer diagnostics.
- **Segment design mix**: Possibility to mix and match explosion protection methods. This is often required where a need for a particular method of explosion protection is forced due to availability of field instruments for the method of choice.
- **Cabinet space requirement**: Foot print and heat dissipation leading to cabinet space requirements and cooling inside the cabinet. This may be a significant issue particularly where real estate comes at a significant price such as any type of marine application or underground installations.
- **Power supply initial cost**: The initial cost of intrinsically safe power supplies is typically higher due to higher demands on designs such as built-in redundancies and the requirements for certification.
- **Trunk live working**: Working on the trunk’s electric circuits while the plant is in operation without requiring a hot work permit.
- **Spur live working**: Working on spurs’ and field instruments’ electric circuits while the plant is in operation without requiring a hot work permit.

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Entity Ex I and Ex nL</th>
<th>FISCO (redundant) Ex I and Ex nL</th>
<th>High-Power Trunk</th>
<th>DART</th>
<th>Explosion/Flame proof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installation cost and effort</td>
<td>O</td>
<td>O</td>
<td>+</td>
<td>O</td>
<td>–</td>
</tr>
<tr>
<td>Available power</td>
<td>–</td>
<td>O</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Validation of explosion protection</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>O</td>
</tr>
<tr>
<td>Power supply redundancy</td>
<td>–</td>
<td>– (⁺⁺)</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Continuous physical layer diagnostics</td>
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<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Segment design mix</td>
<td>–</td>
<td>– (––)</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Cabinet space requirement</td>
<td>–</td>
<td>– (––)</td>
<td>+</td>
<td>+</td>
<td>O</td>
</tr>
<tr>
<td>Power supply initial cost</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>O</td>
<td>+</td>
</tr>
<tr>
<td>Trunk live working</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Spur live working</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
</tbody>
</table>

⁺ = positive attribute  
O = neutral attribute  
⁻ = negative attribute
### 3.3 Case study showing cable lengths and device count

In this comparison the primary goal is to maximize spur and trunk cable length and to derive from that the number of devices that can be connected. The results are based on calculations done with Segment Checker.

It is important to note that all parameters specified in Table 7 are parameters for fieldbus design as necessitated by IEC 61158-2. Calculations with Segment Checker then lead to the resulting cable lengths with the reduced values from devices with explosion protection.

| Table 7: Basic values for case study calculation |
|-----------------|-----|
| **Parameter**   | **Value** |
| Ambient temperature | 50°C |
| Instrument average current consumption | 20 mA |
| Minimum available voltage available to instrument 10% above IEC 61158-2 | 10 V |
| Current reserve for future extensions per segment | 20% |
| Power supply load reserve for short-circuit condition | 20 mA |
| Current consumption per wiring interface, where used | 5 mA |
| Cable specification | AWG 18, 50 Ω/km |

### 3.4 Comparison of actual values

The comparison shown in Table 8 illustrates the significant differences in actual available cable length and the number of field instruments for each method of explosion protection. Primarily the voltage level is the constraint for the maximum achievable cable length, while the current value is the constraint for the number of field instruments that can be operated.

Calculation basis is the voltage level a power supply provides under load, which is 10...20% less than the maximum voltage available without load. The effectively available current describes the current available for the field instruments. It is calculated utilizing the 20% current reserve, the subtraction of 20 mA short-circuit current and 5 mA multiplied by the number of distribution units in use.

| Table 8: Values calculated for real-life application |
|-----------------|-----|-----|-----|-----|
| **Performance indicator** | **Entity** | **FISCO** | **High-Power Trunk** | **DART** |
|                  | IIC | IIB | IIC | IIB |            | |
| Maximum output voltage       | 10.9 V | 18.65 V | 14 V | 14.8 V | 30 V | 24 V |
| Output voltage under load    | 10.6 V | 17 V   | 12.4 V | 13.1 V | 28.5 V | 22 V |
| Maximum output current       | 100 mA | 350 mA | 120 mA | 265 mA | 200 mA | 360 mA |
| Effectively available current| 55 mA  | 255 mA | 66 mA  | 177 mA | 500 mA | 360 mA |
| Real-life trunk length       | 180 m (1900 m) | 700 m (1900 m) | 570 m (1000 m) | 290 m (1900 m) | 668 m (1900 m) | 670 m (1000 m) |
| (theoretic trunk length)     |     |       |       |       |       |       |
| Real-life spur length        | 30 m (120 m) | 60 m (120 m) | 60 m (60 m) | 60 m (60 m) | 90 m (120 m) | 100 m (120 m) |
| (theoretic spur length)      |     |       |       |       |       |       |
| Max. number of field devices | 2   | 8   | 4   | 8   | 12  | 12  |
3.5 Summary of comparison

3.5.1 Cable run
Where longer cable runs are required a higher cable cross-section can be used to counteract voltage drop. Another method would be to install repeaters in the field. Repeaters require additional power supply. They refresh the signal received and repeat it while providing galvanic isolation between the two segments.

A repeater creates a new segment for both a fieldbus and explosion protection method. A drawback is the high installation cost that requires a power cable and an explosion-protected housing installed in the field to host the repeater.

3.5.2 Energy limitation for the entire segment
As can be expected, energy limitation applied to the entire segment based on Entity or FISCO places the tightest constraints on cable lengths and number of devices. These methods will also require the highest number of segments to lead into the field.

Spares installation requires additional trunk cabling that is typically accounted for during segment design. In practice spares in many parts of the plant remain unused while there are not enough in other parts. This requires additional installation work while the plant is in operation.

3.5.3 High-Power Trunk Concept
The High-Power Trunk Concept has the longest cable runs and enables the connection of the largest number of devices to one segment. It utilizes mechanical and energy-limiting methods of explosion protection. The trunk, installed with armored cable, Div. 2 wiring method, or protected installation is not limited for explosion protection and allows maximum cable runs. Energy is limited at the wiring interface in the field. This enables live work in field instruments without requiring a hot work permit.

From the performance indicator values listed in Table 8, the conclusion can be drawn that the High-Power Trunk Concept enables the longest cable runs and allows a satisfactory number of field devices. DART, however, has the potential to become the alternative once it has been generally accepted, as it provides a completely intrinsically safe solution with the same amount of power for the same number of devices and cable length.

3.6 General considerations for fieldbus in hazardous areas

All considerations for fieldbus in the safe area apply. This includes environmental conditions, required cable length, etc.

Next the explosion protection concept is chosen. This includes the choice of field instruments, where the explosion protection method must be available. For this choice, qualitative aspects, attributes, and constraints of each method of explosion protection must be applied. (See Table 6.)

Then cable distances and power levels are verified using the planning software (e.g., www.segmentchecker.com) and utilizing actual numbers and values of the components available for the explosion concept of choice.

The steps for validating explosion protection are done according to applicable standards. Applying fieldbus in hazardous areas is just that simple.
4 Safety applications up to SIL 3

4.1 Reliability required

PROFIBUS or FOUNDATION fieldbus H1 protocols enable error detection in data transfer via safety mechanisms that recognize these errors and reject data. In the protocol, a cyclic redundancy check is used that recognizes errors with very high probability, but it is insufficient for a safety-related control.

The PROFIsafe and FF-SIF safe fieldbuses use their respective native standard PROFIBUS and FOUNDATION Fieldbus H1 protocols as a transmission basis and secure the data in such a way that transmission errors are noted. Together with safety-relevant performance and control data, additional information is transmitted in the standard protocol data telegram, such as: telegram numbers and a particularly long cyclic redundancy check. One can also talk about a “telegram within a telegram.” (Figure 6). Additionally, the actuator is equipped with functions that bring the plant to a safe condition if communication is interrupted or fails. Details on the safety mechanism are described in another part of this engineers’ guide above.

Figure 6: PROFIBUS PA uses a telegram inside a telegram where regular transmission mechanisms of PROFIBUS PA are used to tunnel safety relevant information as data. This allows connection of standard and safety-related field instruments to the same fieldbus cable.

Through the additional mechanisms of data transfer alone, PROFIsafe and FF-SIF safety protocols enable safe data transfer, which has been certified by the TÜV public testing station as SIL 3. The fieldbus infrastructure, such as power supply, installation components, and its accessories, is excluded from system safety consideration. (Figure 7) This is known as the “black channel,” derived from the “black box” concept.
4.2 Designing for highest availability

Redundancy: Because the fieldbus power supply contains the highest number of electronic components, there are increased needs for availability. Therefore, it is implemented in redundant form.

Availability of the cable is ensured with the High-Power Trunk concept. The HPTC protects the cable from damage or accidental disconnect, often referred to as “protected installation.” The HPTC or an installation with communication cables separated from power cables enables a very high availability of the cable. Where protected installation is NOT required and where there is a particularly high need for availability, the trunk can be designed in redundant form.

The continuous monitoring of the operating parameters of the fieldbus infrastructure is the guarantee for high availability. In the plant asset management system, a fully integrated fieldbus diagnostic system delivers warning and alarm messages to the control system for deviations of parameters from the originally reported optimum value. Maintenance personnel promptly receive maintenance requirements before the fieldbus can lose its communication ability. For highest availability, online physical layer diagnostics should be specified.

Power supply redundancy: Modules individually attachable to a motherboard feed in parallel via a decoupling diode switch. In normal operation, the load between the modules is divided, which increases service life due to a low loading on the components. In the event of an error, a power supply module takes the full load without interruption. This wireless transfer guarantees communication of the field devices without interruption. This is particularly important for the safe fieldbus so as not to unintentionally cause a safety shutdown due to a breakup in communication.
5 Conclusions and summary

This chapter explains the working steps for planning fieldbus segments in safe and hazardous areas. Good planning is an essential step and a small extra effort in professionally applying fieldbus in process automation. Following the planning procedure outlined in this chapter will automatically lead to a fieldbus infrastructure that is applicable to both standard and safety-related fieldbus applications.

Good planning is an investment which pays a good return during installation and more importantly commissioning. Planning tools automate repetitive calculation tasks and ensure that fieldbus segments will work before the first cable is installed. This saves significant time for troubleshooting and even reduces effort compared to classic 4…20 mA installation technology. Users report time savings in complete loop checks of 45 minutes or more per loop.

For hazardous areas the High-Power Trunk concept is established as a de-facto standard. It provides the longest cable runs while ensuring that devices can be maintained during normal operation. While all major vendors now support it, FieldConnex was the first family of fieldbus infrastructure components including power supplies and fieldbus barriers that implement the High-Power Trunk concept.

Finally, after proper planning and installation automated testing procedures check-out the fieldbus infrastructure. They document the quality of the installation and pave the road for smooth loop check.
Your automation, our passion

Explosion protection
- Intrinsically safe barriers
- Signal conditioners
- Fieldbus infrastructure
- Remote I/O systems
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- Proximity sensors
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