Implementing FOUNDATION Fieldbus™ H1 Networks in Hazardous Areas

Many Engineers today find themselves questioning which bus technology to implement in their facility. As if that topic isn't difficult enough to resolve, the subject is further complicated by implementing your chosen bus in a hazardous area. This classification alone adds a layer of complexity to the design and implementation of your control system. If you choose to implement networks such as Foundation fieldbus into your control system, the task may seem overwhelming. We were challenged with that task when we decided to implement Foundation fieldbus at Boehringer Ingelheim Chemicals, Inc. (www.boehringer-ingelheim.com). The purpose of this white paper is to provide some insight into the process for safely implementing Foundation fieldbus in a classified area of your facility.

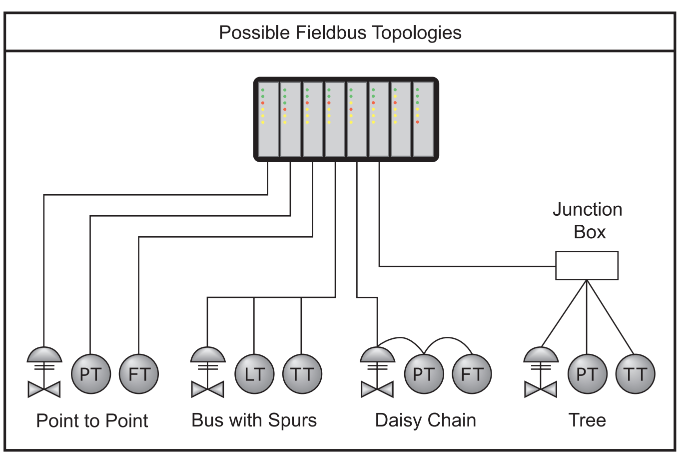
Production areas at Boehringer Ingelheim Chemicals plant in Petersburg, VA, are deemed hazardous, requiring an intrinsically safe fieldbus installation.

FOUNDATION Fieldbus H1 Primer

The Foundation fieldbus specification is open and internationally accepted as well as driven by the Fieldbus Foundation. There are two basic flavors of Foundation fieldbus: H1 and HSE. This paper will focus on H1, which is a 31.25 kBit/s, interoperable, bi-directional, digital, serial, publisher-subscriber communications network interconnecting smart devices that support function blocks executing in the host, the smart device, or a combination of the two.

There are several possible network topologies in Foundation fieldbus (Figure 1), such as point-to-point, bus with spurs, daisy chain, tree or mixed (a combination of all supported topologies). The trunk is the main communication pathway between devices and is typically the power supply for spurs on the segment. The segment is a section that is terminated by terminators and cannot exceed 1,900 m in length, including the main trunk and spurs. A spur is a branch off the trunk and can vary in length between 1 and 120 m.

Figure 1. *Fieldbus topologies include point-to-point, bus with spurs, daisy chain, tree, or combinations thereof.*



The physical components of a standard Foundation fieldbus H1 network consist of a power supply, power conditioner, optional repeater(s), cables, junction box(es), terminators and devices. The power supply provides 19 to 26 VDC to the trunk and must be conditioned using a power conditioner that is either a separate component or an integral component of the power supply. The type of power supply can be a bulk supply or a dedicated supply; however, the power conditioner is not optional. Repeaters can be used to extend a segment which will allow another 1,900 m. The total number of devices on any segment is limited to 32. The total number of devices on a segment may also be limited by logical components of the fieldbus such as the scheduled macrocycle, control system loop configuration and the amount of data communicated to/from a device (links and VCRs).

Individual shielded twisted pair cable defined as Type A cable in the IEC/ISA Physical Layer Standard is the preferred cable. The maximum segment length of 1,900 m will have to be reduced if another type of cable is selected or if cable types are mixed. Table 1 summarizes the maximum lengths of different types of cables.

Table 1. *Maximum Length of Cables.*

Cable Type	Description	Size	Max. Length
A	Twisted-pair w/shield	#18 AWG	1,900 m
B	Multi-twisted pair w/shield	#22 AWG	1,200 m
C	Multi-twisted pair w/o shield	#26 AWG	400 m
D	Multi-core w/o twisted pairs and having an overall shield	#16 AWG	200 m

Junction boxes with terminal blocks are one method for connecting several devices to the segment at a single location as well as providing an installation point for the segment terminator. Pre-manufactured junction box systems designed for Foundation fieldbus are readily available. A terminator is an impedance matching device located at both ends of the segment that consists of a 100 ohm resistor in series with a 1 μF capacitor.

Hazardous Area Classification Primer

The *National Electrical Code* defines classified or hazardous locations as those areas "where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings." The NEC recognizes class and zone as two methods for electrically classifying an area as hazardous. The class method is the primary method utilized in the U.S. and will be the focus of this paper. It is worth noting that the zone method typically yields a more flexible classification. There are three components to the hazardous area classification.

Table 2. *Explosive Atmosphere Classification.*

Explosive Atmosphere Classification	
Class 1	Flammable gases, vapor or liquid
Class 2	Combustible dusts
Class 3	Ignitable fibers and flyings
Reference NEC Chapter 5 - Special Occupancies	

The ***class*** term separates fuels into families and is summarized in Table 2. The three classes are Class 1, Class 2 and Class 3, which signify an environment of flammable gases, vapor or liquids; Combustible dusts; or Ignitable fibers and flyings, respectively.

The ***division*** term separates the area into two parts based on the probability that an explosive fuel and air mixture will be present and is summarized in Table 3. The two divisions are Division 1 and Division 2, which signify that ignitable concentrations of fuel can exist all of the time or some of the time under normal operating conditions; or ignitable concentrations of fuels are not likely to exist under normal operating conditions, respectively.

The ***group*** term categorizes materials with similar explosive properties and is summarized in Table 4. The group categories are A, B, C, D, E, F and G, which signify Acetylene; Hydrogen; Ethylene; Propane; Metal Dust; Coal Dust and Grain Dust, respectively.

Table 3. *Likelihood of Atmosphere Classification.*

Likelihood of Atmosphere Classification	
Division 1	**Zone**
Division 1 Ignitable concentrations of flammable gases, vapors or liquids can exist all of the time or some of the time under normal operating conditions.	Zone 0 Ignitable concentrations of flammable gases, vapors or liquids are present continuously or for long periods of time under normal operating conditions.
	Zone 1 Ignitable concentrations of flammable gases, vapors or liquids are likely to exist under normal operating conditions.
Division 2 Ignitable concentrations of flammable gases, vapors or liquids are not likely to exist under normal operating conditions.	Zone 2 Ignitable concentrations of flammable gases, vapors or liquids are not likely to exist under normal operating conditions.
Reference NEC Chapter 5 - Special Occupancies	

Table 4. *Group Classification (Ease of Ignition).*

Explosive Atmosphere Classification	
Division 1 and 2	**Zone 0, 1 and 2**
A-Acetylene	IIC-Acetylene and Hydrogen
B-Hydrogen	
C-Ethylene	IIB-Ethylene
D-Propane	IIA-Propane
E-Metal Dust	
F-Coal Dust	
G-Grain Dust	
Reference NEC Chapter 5 - Special Occupancies	

In addition to classifying the area based on the explosive atmospheric conditions, there is also a maximum temperature category and is summarized in Table 5. If the maximum operating temperature of a device is greater than 85 °C (T6), the device must be marked with the proper temperature category.

Table 5. *Temperature Classification.*

Temperature Classification	
Division 1 and 2	**Zone 0, 1 and 2**
T1<=450°C	T1<=450°C
T2<=300°C	T2<=300°C
T2A<=280°C, T2B<=260°C T2C<=230°C, T2D<=215°C	N/A
T3<=200°C	T3<=200°C
T3A<=2180°C, T3B<=165°C T3C<=160°C	N/A
T4<=135°C	T4<=135°C
T4A<=120°C	N/A
T5<=105°C	T5<=105°C
T6<=85°C	T6<=85°C
Reference NEC Chapter 5 - Special Occupancies	

A familiar area classification for a chemical plant might be Class 1 Division 2 Group C/D T3C. This classification defines an environment of flammable gases, vapor or liquids with similar explosive properties to ethylene and propane having ignitable concentrations that are not likely to exist under normal operating conditions. The T3C temperature classification signifies that the surface temperature of any equipment installed in this area cannot exceed 160° C. For more information regarding hazardous area classifications reference the NEC Chapter 5 - Special Occupancies.

Engineering and Installation in Hazardous Areas

Several accepted engineering and installation methods can be implemented to reduce the risk of an explosion. Some of these methods are explosion proof, purging, oil immersion, encapsulation, intrinsically safe and nonincendive. Regardless of which method is chosen, the basic concept for each is to eliminate at least one of the three parts of the combustion triangle (fuel, oxygen and heat). We will focus on the three that apply to fieldbus: explosion proof, intrinsically safe and nonincendive. All three methods reduce the risk of ignition by limiting the amount of energy that can be released or present in the environment but each accomplishes this differently.

Explosion proof designs are not as they may seem and do not mean an explosion or ignition is impossible. An explosion proof design and installation requires that if a fuel were ignited inside the device enclosure, the enclosure would contain the energy of ignition and disperse it into the classified area at a level low enough to prevent a secondary ignition from occurring outside the enclosure. Explosion proof designs require special installation methods, as well as requiring the electrical devices and enclosures to be rated explosion-proof (NEMA 7/9) for the proper area classification. This type of system cannot be worked on while energized without a gas clearance certificate commonly referred to as a hot work permit.

Intrinsically safe circuit designs limit the electrical energy at the device to a level below the explosive limits of the environment and remain safe with a component failure. An intrinsically safe circuit, as defined by the NEC, is "a circuit in which any spark or any thermal effect is incapable of causing ignition of a mixture of flammable or combustible material in air under prescribed test conditions." An IS circuit uses a safety device such as a safety barrier to limit the power in the hazardous environment based on the ignition curves of a given gas family and its related minimum ignition energy. Intrinsically safe designs have less stringent installation methods and allow more standard (NEMA 4) enclosures instead of explosion proof (NEMA 7/9) enclosures. The two IS standards in use today are "ia" and "ib," where safety is maintained with up to two faults or one fault, respectively. The "ia" standard is acceptable in Zone 0 classifications and "ib" standard is acceptable in Zone 1, Zone 2, Division 1 and Division 2 classifications. This type of circuit can be worked on while energized without a hot work permit.

Nonincendive circuit designs are similar to IS circuit designs. A nonincendive circuit, as defined by the NEC, is "a circuit, other than field wiring, in which any arc or thermal effect produced under intended operating conditions of the equipment is not capable, under specified test conditions, of igniting the flammable gas-air, vapor-air or dust-air mixture." Nonincendive circuit designs do not take component failure into consideration thereby offering a reduced level of safety by comparison to the intrinsically safe circuit design. Depending on the design, this type of circuit can be worked on while energized without a hot work permit.

Do not confuse nonincendive equipment with nonincendive circuits. Nonincendive equipment, as defined by the NEC, is "equipment having electrical/electronic circuitry that is incapable, under normal operating conditions, of causing ignition of a specified flammable gas-air, vapor-air, or dust-air mixture due to arcing or thermal means." The power rating of a nonincendive device may require that the energy level in the interconnecting wiring exceed the ignition curves of the rated area; therefore, this type of design cannot be worked on while energized without a hot work permit and requires that the device cover not be capable of removal without a tool. Nonincendive requirements and specifications can be ambiguous to the system designer and for this reason intrinsically safe circuit designs are often chosen over nonincendive designs. Nonincendive energy limited means that the energy within the circuit is within safe limits for the area and can be worked on 'live'; nonincendive non-arcing cannot be worked on 'live'—knowing which is important!

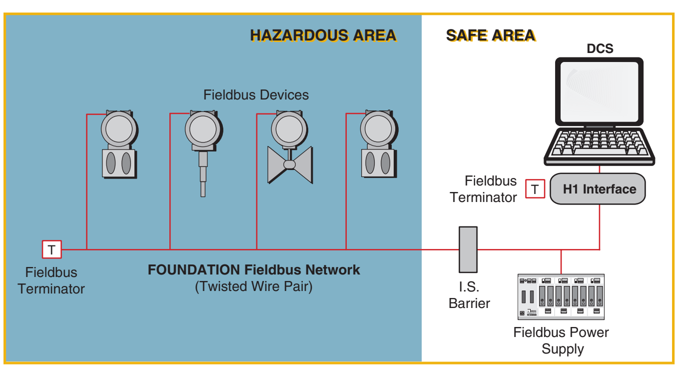
Since intrinsically safe and nonincendive circuit designs keep the energy level in the classified area below ignition points, a number of details must be considered during the engineering process. The overall system design of these circuits must include ENTITY parameter evaluation for the safety apparatus and devices; interconnecting cable/wire inductance and capacitance; safety grounding; vendor provided control drawings; device testing agency approvals; device ratings and markings appropriate for the area; and cabinet layout for wire routing (per NEC IS, and nonincendive wiring must be separated from standard wiring).

You may also need to contact your insurance carrier to discuss your design because some carriers such as Factory Mutual (FM) may require that the devices used in your design be FM approved. Not all devices manufactured today carry approvals from all of the testing agencies. It is the responsibility of the user to select, integrate and implement the components into a safe system per the vendor provided control drawing and this type of design is referred to as an ENTITY based system.

Safe FOUNDATION Fieldbus

Like traditional 4-20 mA circuit designs (Figure 2), Foundation fieldbus can be implemented in hazardous locations using explosion proof, intrinsically safe and nonincendive designs. Explosion proof designs are not practical for fieldbus implementations due to the cost,

Figure 2. *In traditional intrinsically safe system, a barrier in the safe area limits the amount of electrical energy that can enter a hazardous area. FISCO-based IS systems use a barrier which limits the segment to six devices in a IIC hazardous area.*



bulky enclosure size and inability to work on the network while energized without a hot work permit.

The concept of intrinsically safe systems was developed in the early 1900s as a result of a mine explosion that killed 439 people. In the early days, IS systems were used mainly when there was no other method available. As time progressed, IS systems became an accepted standard in Europe. In 1965, the ISA published RP 12.2 "Intrinsically Safe and Non-Incendive Electrical Instruments." In the years to follow, many standards and approval agencies around the world became more aligned in regard to IS systems (ISA, IEC, NFPA, CENELC, UL, FM, OSHA and many more), allowing North America to take advantage of all of the products being used in Europe.

Intrinsically safe and nonincendive devices or apparatus are approved by either an ENTITY or SYSTEM method. The ENTITY method requires that devices be certified individually as an intrinsically safe device or apparatus. It becomes the responsibility of the user to select and integrate the individual components into a system using the device's ENTITY parameters and the vendor control drawing.

The SYSTEM method requires that the manufacturer combine its individual components into a system that is certified. The manufacturer must also provide a control drawing that depicts the system as well as any constraints, such as maximum cable capacitance and inductance, which would violate the certification/approval.

The early barriers used in IS fieldbus implementation limited the available bus current to about 80 mA per segment. If you use 20 mA per device as the load, that equates to four devices per segment without taking into account any losses due to barriers or cable lengths. This does not realize a cost savings in comparison to traditional 4-20 mA IS circuits, nor does it demonstrate any of the benefits of bus technology. As stated earlier, in this design the end user is responsible for integrating the components into a safe system based on vendor control drawing(s).

In an effort to reduce end user engineering and increase the bus current available, two standards were created specifically for Foundation fieldbus implementation in hazardous areas. One is based on the intrinsically safe circuit concept and the other is based on the nonincendive circuit concept. The standards are FISCO and FNICO, respectively.

The **F**ieldbus **I**ntrinsically Safe **CO**ncept (FISCO) is a standard that considers IS fieldbus as a system that allows the end user to specify FISCO certified devices and simply integrate them without the engineering requirements of the ENTITY approach. The standard was based on work done by Physikalisch-Technische Bundesanstalt (PTB), the national metrology institute in Germany, and involved theoretical and experimental techniques. The first edition of the standard was published in April 2005 as IEC 60079-27. FISCO simplified the design calculations required in the traditional ENTITY approach by requiring all fieldbus components to be tested and certified to a set of standards defined by the specification.

By certifying the devices to a standard and using cable that falls into the limits of the experimental data (see Table 6), the design calculations were simplified to Ohm's law and inductance/capacitance ENTITY parameters were no longer components in the calculations. This also allowed FISCO power supplies to generate up to 120 mA in a IIC (A/B) gas group and 265 mA in IIB (C/D) gas group, which theoretically equates to 6 devices and 13 devices respectively. Reduced engineering and an increased number of devices are two obvious advantages for considering FISCO over ENTITY. Disadvantages include an impact on unit MTTF through the complexity of the individual product designs and an overall reduction in allowable segment (Division 1) and spur length by about 50%.

Table 6. *FISCO and FNICO Cable Parameters Limits*

FISCO and FNICO Cable Parameters Limits	
Parameter	**Value**
Loop Resistance	15 ohms/km to 150 ohms/km
Loop Inductance	0.4 mH/km to 1 mH/km
Loop Capacitance	45 nF/km to 200nF/km
Maximum Spur Length	60 m in IIC and IIB
Maximum Total Cable Length	1.0 km in IIC and 1.9 km in IIB

Like FISCO, the **F**ieldbus **N**on**I**ncendive **CO**ncept (FNICO) is a specification that considers nonincendive fieldbus as a system. FNICO is a derivative of FISCO and is specifically intended for division 2 classifications. FNICO takes advantage of the less stringent requirements of a nonincendive design. Like FISCO it allows the end user to specify FNICO certified devices and simply integrate them without the engineering requirements of the ENTITY approach. The available bus current is also increased to 180 mA in a IIC (A/B) gas group and 320 mA in IIB (C/D) gas group. Using the 20 mA device as before, that would theoretically equate to 9 devices and 16 devices respectively. For the same reasons, FNICO is an obvious advantage over ENTITY. FNICO is a larger advantage over ENTITY in a division 2 area. Due to the reduced safety factor of nonincendive designs, they are only allowed in division 2 areas.

A hybrid approach known as the **H**igh **P**ower **T**runk (HPT) is also available where the fieldbus trunk is installed nonincendive (non-sparking and not FNICO) and the individual device spurs are installed as intrinsically safe spurs. The trunk and safety barrier is typically installed in either a safe or division 2 area and the spurs can be wired to devices located in either a division 1 or 2 area. The devices can be ENTITY, FISCO, FNICO or a combination. Beware that in the HPT design the trunk cannot be worked on while energized without a hot work permit; however, the spurs can be worked on while energized without a hot work permit.

Application in the Pharmaceutical Industry

Boehringer Ingelheim Chemicals, Inc. is a bulk API (Active Pharmaceutical Ingredient) manufacturing facility located in Petersburg, VA (see page 1 photo). The facility consists of three primary production buildings that have their interiors classified as hazardous areas (Figure 3). The

Figure 3. *The processing areas are deemed Class 1 Division 1 Group C/D hazardous areas. Instruments can be in Group B/C/D areas.*

classification for the buildings is generally Class 1, Divisions 1 and 2 and Groups C/D with a maximum temperature requirement of T3C. Our manufacturing processes are controlled primarily by an Emerson Process Management DeltaV control system.

We installed our first IS fieldbus system in the facility in 2001 as part of our Bay 34 Upgrade Project. We implemented an ENTITY type of IS fieldbus, using barrier/repeaters with a maximum of four devices per segment. Figure 4 is photograph of the inside of a cabinet implementing an ENTITY based IS fieldbus system. This implementation caused our control system cabinets to be large and required a large number of fieldbus segments.

Figure 4. *The original ENTITY-based IS system,installed in 2001, required barriers, large cabinets and many fieldbus segments.*

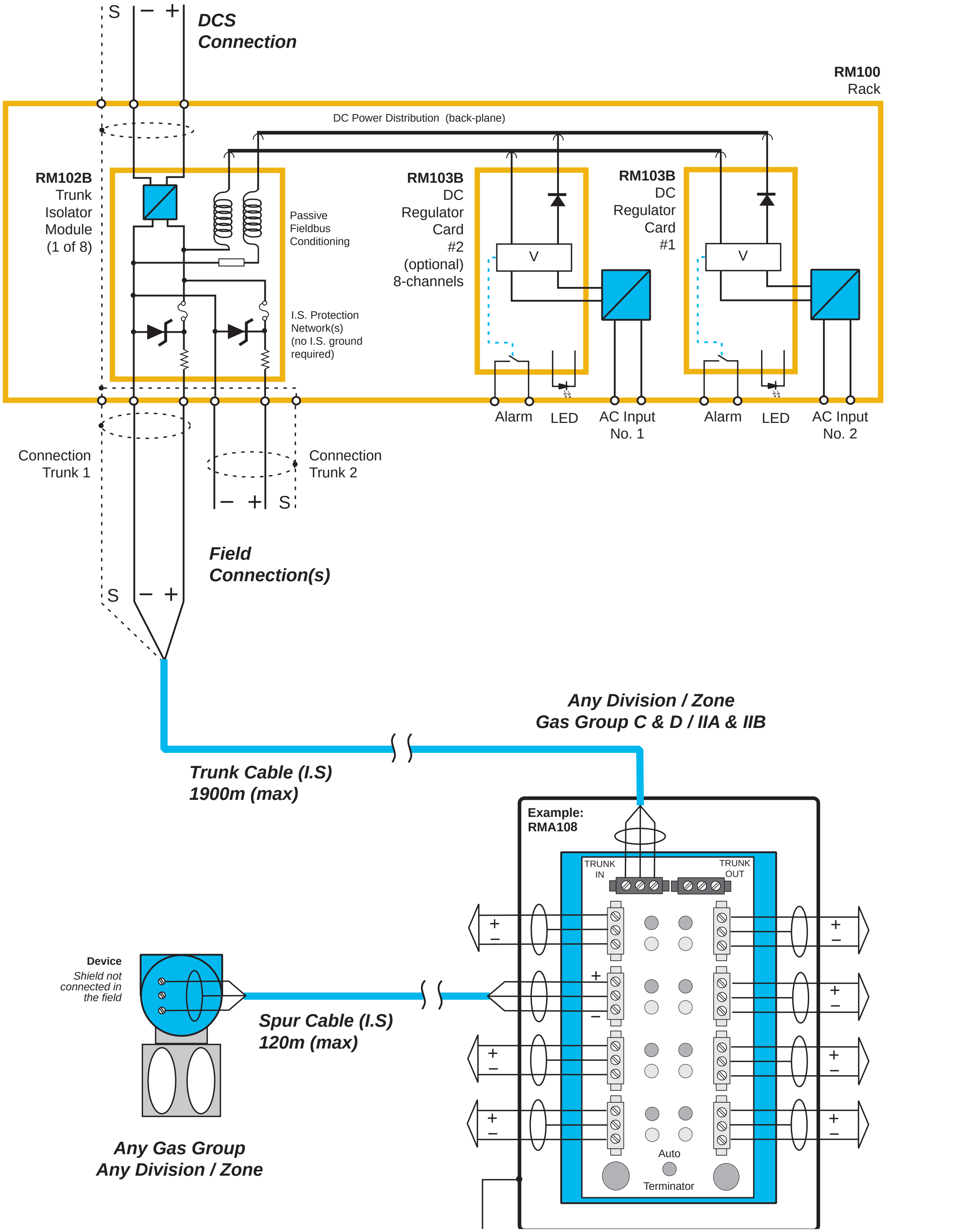
We recently installed an automated solvent distribution system in our S1 production building to accurately deliver organic solvents and raw materials for cleaning and production to approximately 125 end use points. As part of this project, we wanted to install an IS fieldbus infrastructure that would solve our project requirements as well as provide capacity for future growth. Our S1 production building is four stories tall, divided into 10 vertical production bays and electrical rooms located in the north end of the building.

Our IS fieldbus design needed to meet the following requirements:

- Capable of installation in a Class 1 Division 1 Group C/D area.
- Capable of wiring to instruments in a Class 1 Division 1 Group B/C/D area.
- Optimize control performance and minimize segment to segment communications by allowing primary elements and final control elements of a control loop that are physically located on different floors in a bay to be connected to the same segment.
- Maximize the number of devices allowed per segment.
- Trunk/segment must be capable of running across the full length of the S1 building to reach the north end electrical rooms.
- Intrinsically safe system allowing our technicians to troubleshoot and work on the system without needing a hot work permit or having to shut down the process.
- Any replaceable components of the system would need to be hot swappable.
- Provide room for future expansion and growth.

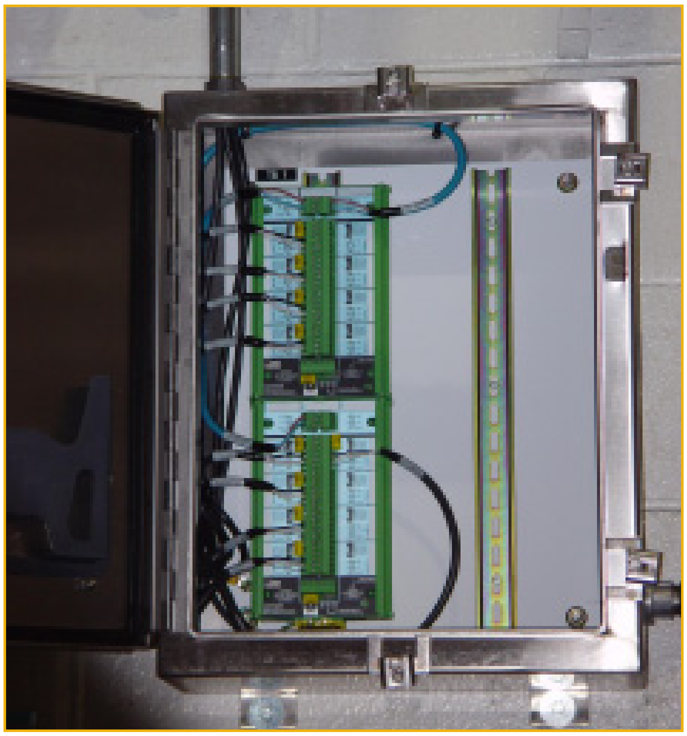
These requirements limited our choices to ENTITY and FISCO methods. After evaluating available technologies, including our existing Bay 34 IS fieldbus system, traditional IS fieldbus systems, and FISCO systems, we chose the ENTITY method. The reason we chose the ENTITY method is because of the MooreHawke ROUTE-MASTER™ product. ROUTE-MASTER systems are based on a split-architecture which separates the barrier into two parts (Figure 5). The first barrier includes a smaller resistance seen at the interface between the safe and hazardous area (high current position) and the second barrier includes a larger resistance seen at the device coupler located in the hazardous area. This design allows for a smaller voltage drop and 350 mA DC on the trunk which theoretically equates to 17 devices.

***Figure 5.** MooreHawke's ENTITY-based IS system uses a split architecture, which separates the barrier into two parts, allowing a H1 segment to have 350 mA and support up to 17 devices in a IIC area, nearly three times as many as a FISCO system.*



The device couplers (Figure 6) are compatible with FF-816 device ENTITY parameters (Vmax. in = 24V, Imax. in = 250mA, Pmax. in = 1.2W) and can be implemented in Class 1 Division 1 Groups C/D with IS connections for Class 1 Division 1 Groups A/B/C/D when they are installed per the appropriate control drawing (HCGFB-902). Since each spur has IS current limiting resistors, that makes each spur an independent IS loop.

Figure 6. *Device couplers, such as these MooreHawke ROUTE-MASTERS, connect multiple fieldbus instruments on spurs to the segment.*



The ROUTE-MASTER system also simplifies the ENTITY parameter calculations by using worst case scenarios, which means reduced engineering to create safety documentation. You calculate the capacitance of a worst case spur, which is 120 m of the chosen cable plus an FF816 device, calculate the L/R ratio for the chosen cable, and document these calculations noting that no current or future spur can be longer than 120 m and no other cable type can utilized. Each spur has electronic auto-resetting short circuit protection which prevents short circuits on one spur causing problems on another spur or the trunk allowing "live work" without the risk of bringing down the entire network.

The ROUTE-MASTER implementation, in conjunction with remote I/O, has allowed us to install four DeltaV controllers in the same amount of cabinet space that we originally used to install one controller. Since the installation, we have had no ROUTE-MASTER component failures and have standardized the fieldbus installations in our facility around the ROUTE-MASTER system.

CONCLUSIONS

In summary, implementing Foundation fieldbus coupled with hazardous area classifications may approach information overload. Believe it or not, with today's technology and product offerings fieldbus is simpler than anytime before to implement (Table 7). Some key elements or questions to ask when considering implementation are listed below:

- **Area classification**. Nonincendive is only allowed in division 2 areas and intrinsically safe concepts are allowed in division 1 and 2 areas.
- **Size and scalability**. How many devices do you plan to implement? What are your future requirements for expansion? How long does the trunk need to be?
- **Technology/product selection**. Does the product provide short circuit protection for the trunk and the spurs? If during maintenance you accidentally short a spur will the trunk be protected? Are the system components "hot swappable"?
- **Safety consideration**. What level of safety or risk are you willing to accept? Intrinsically safe designs take into account component failures and allow maintenance while energized without a hot work permit. Nonincendive designs do not take into account component failures and may not allow maintenance while energized without a hot work permit.
- **Maintenance and downtime**. Can your process be down (fieldbus de-energized) in order to trouble shoot or expand the network? Does your facility have a hot work permit philosophy allowing live work on energized equipment?
- **Engineering consideration**. Will the engineering be done "in-house?" If you are using an engineering firm, interview the proposed staff. Try to use a firm that has experience in hazardous area fieldbus design because this implementation is a hybrid approach for many A&E firms. The design requires knowledge of hazardous area classification, which is primarily an electrical engineering function as well as control systems design, which is primarily a control system engineering function. In many cases these resources may exist in two separate departments (electrical and control systems departments).

- **Control system consideration**. What type of control system will be used? Contact your control system vendor and inquire about technologies and products that have been tested and proven on your control system. Are there any software limitations or "hidden" costs that punish you when utilizing fieldbus on your control system?
- **Acceptance and ownership**. What is the skill set of the maintenance technician(s) that will support this technology? Will training be required?
- **Calibration**. How will the devices be calibrated? Until recently, calibrating fieldbus devices in-house was difficult. In the past couple of years a small number of fieldbus calibration devices have ap peared on the market.

Table 7. *Compares the different implementation methods.*

	Explosion Proof	Intrinsically Safe (ENTITY)	Intrinsically Safe (FISCO)	Intrinsically Safe (ROUTE-MASTER)	Nonincendive (FNICO)	Hybrid (HPT)
Control Drawing	Not Required	Required	Lists of devices only	Required	Lists of devices only	Required
ENTITY Calculations	Not Required	Required	Not required since the cable meets FISCO specification.	Required but only done once for the worst case scenario of the longest spur and the type of cable specified.	Not required since the cable meets FNICO specification.	Required but per spur only since each spur is a separate circuit.
Maximum Current	None	80mA	120mA IIC 265mA IIB	350mA	180mA IIC 320mA IIB	>500mA
Maximum Devices (20mA per device and no losses)	32 (per FFB specifcation)	4	6 in IIC 13 in IIB	17	9 in IIC 16 in IIB	>25
Maximum Segment Length	1900m	1900m	1900m IIB 1000m IIC	1900m	1900m IIB 1000m IIC	1900m
Maximum Spur Length	120m	120m	60m	120m	60m	120m
Allowable Area Classification Implementation	Division 1 and 2	Division 1 and 2	Division 1 and 2	Division 1 and 2	Division 2	Division 2 for the trunk and Division 1 or 2 for the spurs
Hot Work Permit Required to Maintain/ Troubleshoot While Energized	Yes	No	No	No	No	Yes for the trunk No for the spurs

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There are a number of excellent documents on hazardous area classification, intrinsic safety and Foundation fieldbus in the references section of this paper.

REFERENCES

1. Fieldbus Foundation (http://www.foundation.org/)
2. AG-163, "Foundation Fieldbus Application Guide 31.25 kbit/s Intrinsically Safe Systems"
3. AG-140, "Foundation Fieldbus Application Guide 31.25 kbit/s Wiring and Installation"
4. FD-043, "Foundation Fieldbus Technical Overview"
5. IEC 60079-27, "Electrical apparatus for explosive gas atmospheres: Fieldbus intrinsically safe concept (FISCO) and Fieldbus non-incendive concept (FNICO)"
6. NFPA 70- "National Electrical Code (NEC)"
7. NFPA 497 – "Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas"
8. NFPA 499 – "Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas"
9. Factory Mutual, "FM Global Property Loss Prevention Data Sheets 5-1, Electrical Equipment in Hazardous (Classified) Locations"
10. Factory Mutual, "Approval Standard for Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, I, & III, Division 1, and Class I, Zone 0 & 1 Hazardous (Classified) Locations'
11. ANSI/ISA-12.01.01-1999, "Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified) Locations"
12. ANSI/ISA-RP12.06.01-2003, "Recommended Practice for Wiring Methods for Hazardous (Classified) Locations Instrumentation Part 1: Intrinsic Safety"
13. ISA-TR12.2-1995, "Intrinsically Safe System Assessment Using the Entity Concept "
14. Moore-Hawke (http://www.miinet.com/products/sg_fieldbus.shtml)

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