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Technical Report

Intrinsically Safe System Assessment Using the Entity Concept

ISA-TR12.2, Intrinsically Safe System Assessment Using the Entity Concept

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The SP12.2 committee wishes to give special recognition to Mr. Brad Larson for his outstanding contribution to the development of this document.

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1 Introduction

When electrical equipment is used in locations where fire or explosion hazards may exist due to flammable gases or vapors, flammable liquids, combustible dust, or ignitible fibers or flyings, the *National Electrical Code (NEC)®*, NFPA 70, requires special precautions to be taken in equipment construction and installation to ensure safe performance. There are several protection techniques in common use, each of which has its own set of advantages and disadvantages.

2 The intrinsic safety protection technique

For low-power applications in Division 1 hazardous (classified) locations, the safest and most easily implemented protection technique is intrinsic safety. Intrinsic safety is the use of equipment and wiring that is incapable of releasing sufficient electrical or thermal energy under normal or abnormal conditions to cause ignition of a specific hazardous atmospheric mixture in its most easily ignited concentration. This is achieved by limiting the energy available to, and stored or generated by, the electrical equipment in the hazardous (classified) location to a level below that which can ignite the hazardous atmosphere.

3 Intrinsically safe systems

Article 504 of the *NEC®* defines an intrinsically safe system as "an assembly of interconnected intrinsically safe apparatus, associated apparatus, and interconnecting cables in which those parts of the system that may be used in hazardous (classified) locations are intrinsically safe circuits." Intrinsically safe apparatus is defined in Article 504 as electrical equipment "in which all the circuits are intrinsically safe." A common example of an intrinsically safe apparatus is a 4-20 mA process transmitter that has been specially designed to be intrinsically safe.

Unless completely self-contained, as is the case with some battery-operated devices, intrinsically safe apparatus must be connected to associated apparatus. Associated apparatus is defined in Article 504 as "apparatus in which the circuits are not necessarily intrinsically safe themselves, but that affect the energy in the intrinsically safe circuits and are relied upon to maintain intrinsic safety." Associated apparatus must be installed in a location not classified as hazardous unless it has an alternative type of protection that allows it to be installed in a hazardous (classified) location.

The most common form of associated apparatus is the intrinsic safety barrier, a device designed to limit the energy available to the intrinsically safe apparatus. Intrinsic safety barriers usually are installed in locations not classified as hazardous and are connected between the intrinsically safe apparatus and other non-intrinsically safe equipment.

4 Intrinsically safe system control drawings

To ensure an intrinsically safe system, intrinsically safe apparatus and associated apparatus must be installed in accordance with the installation requirements specified on control drawings. Article 504 defines a control drawing as "a drawing or other document provided by the manufacturer of the intrinsically safe or associated apparatus that details the allowed interconnections between the intrinsically safe apparatus and associated apparatus."

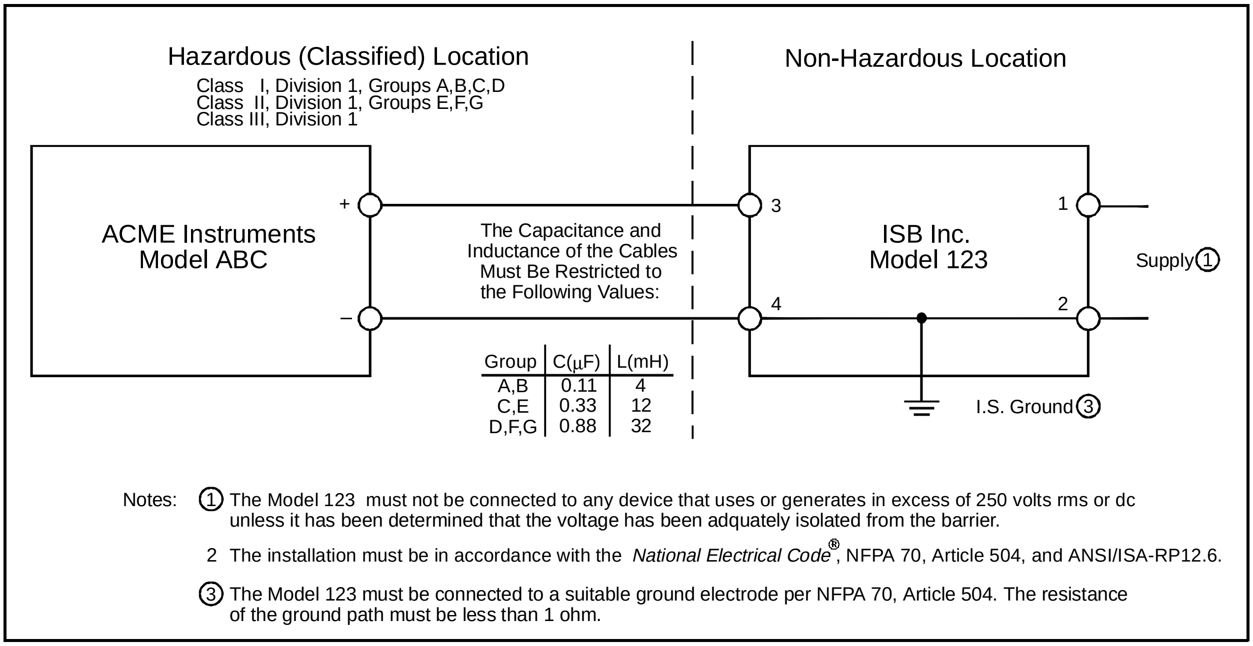


Figure 1 — Example of a typical control drawing

Figure 1 is an example of a typical control drawing that illustrates the interconnection of an intrinsically safe apparatus and an associated apparatus, based on a system examination in which each piece of apparatus has been specifically examined in combination with the other. Although the application of this system approach is straightforward and requires minimal additional examination by the user, it is not very flexible. Given the large and increasing number of possible combinations, it is difficult for the manufacturers of intrinsically safe and associated apparatus to list them all on control drawings.

5 Entity concept

Another approach, known as the entity concept, provides more flexibility in selecting equipment for an intrinsically safe system. The entity concept allows the user to identify acceptable combinations of intrinsically safe apparatus and associated apparatus that have not been examined as a system.

6 Entity parameters

Each apparatus is examined separately by a nationally recognized test laboratory (NRTL) and assigned a set of parameters, known as entity parameters.

Intrinsically safe apparatus is assigned the following parameters:

- V_{max} = Maximum voltage that may be applied safely to the intrinsically safe apparatus;
- I_{max} = Maximum current that may be applied safely to the intrinsically safe apparatus;
- C_i = Internal unprotected capacitance of the intrinsically safe apparatus; and
- L_i = Internal unprotected inductance of the intrinsically safe apparatus.

Each channel of associated apparatus is assigned the following parameters:

- V_{oc} = Maximum open-circuit voltage that can appear across the intrinsically safe connections of the associated apparatus under fault conditions;
- I_{sc} = Maximum short-circuit current that can be drawn from the intrinsically safe connections of the associated apparatus under fault conditions;
- C_a = Maximum capacitance that can be connected safely to the associated apparatus; and
- L_a = Maximum inductance that can be connected safely to the associated apparatus.

6.1 Entity parameter specification

V_{max} and I_{max} are specified by the manufacturer of the intrinsically safe apparatus.They are used for comparison to associated apparatus parameters that have been determined under specified fault conditions. Thus, the values of V_{max} and I_{max} do not necessarily bear any relationship to the normal operating voltage and current of the intrinsically safe apparatus.

For the parameters to be useful, values high enough to allow interconnection with appropriate associated apparatus must be selected. The values of V_{max} and I_{max} are limited only to the maximum voltage and current that the intrinsically safe apparatus can receive and remain intrinsically safe, based on stored energy and thermal considerations.

The V_{max} and I_{max} values specified for a given intrinsically safe apparatus, taken together and compared to the ignition curves (Reference: ANSI/UL913), may fall in the ignition-capable area of the curve. This is not a problem, since any NRTL-approved associated apparatus to which the intrinsically safe apparatus might be connected will always have V_{oc} and I_{sc} parameters that are not ignition capable. For example, an intrinsically safe apparatus with low C_i and L_i values and properly rated components could realistically have a V_{max} of 45 volts and an I_{max} of 350 mA. At 45 volts, 350 mA is well into the ignition-capable area of the ignition curve. However, based on the ignition curve for Groups A and B, an associated apparatus with a V_{oc} of 45 volts would have an I_{sc} of no more than 45 mA, and an associated apparatus with an I_{sc} of 350 mA would have a V_{oc} of no more than 19 volts. The connection of either associated apparatus to the intrinsically safe apparatus would form an intrinsically safe system, since in both cases $V_{max} \geq V_{oc}$ and $I_{max} \geq I_{sc}$.

An additional parameter that optionally may be assigned to either the intrinsically safe apparatus or associated apparatus is P_{max}. When assigned to the intrinsically safe apparatus, P_{max} is the maximum power that may be applied safely to the intrinsically safe apparatus. When assigned to the associated apparatus, P_{max} is the maximum power that can be delivered under specified fault conditions by the associated apparatus.

The use of the P_{max} parameter can provide additional flexibility in the use of the entity concept. For example, when P_{max} is specified for the intrinsically safe apparatus, the NRTL examination of thermal effects in the intrinsically safe apparatus is conducted using the value of P_{max}. In this case V_{max} and I_{max} are not limited by thermal effects, only by stored energy, and thus may have considerably higher limits. When P_{max} is not specified, the V_{max} and I_{max} parameters will be used in the examination of thermal effects. This may have the effect of limiting the value of V_{max} and I_{max} to values that do not allow interconnection with the desired associated apparatus. When P_{max} is specified for an intrinsically safe apparatus, it must be connected to an associated apparatus that has an equal or lower P_{max}.

7 Entity concept control drawings

Entity parameters may be found on the control drawing supplied by the apparatus manufacturer, along with other pertinent information regarding proper connections, conditions of use, etc. Figure 2 is an example of a control drawing for an intrinsically safe apparatus. Figure 3 is an example of a control drawing for an associated apparatus.

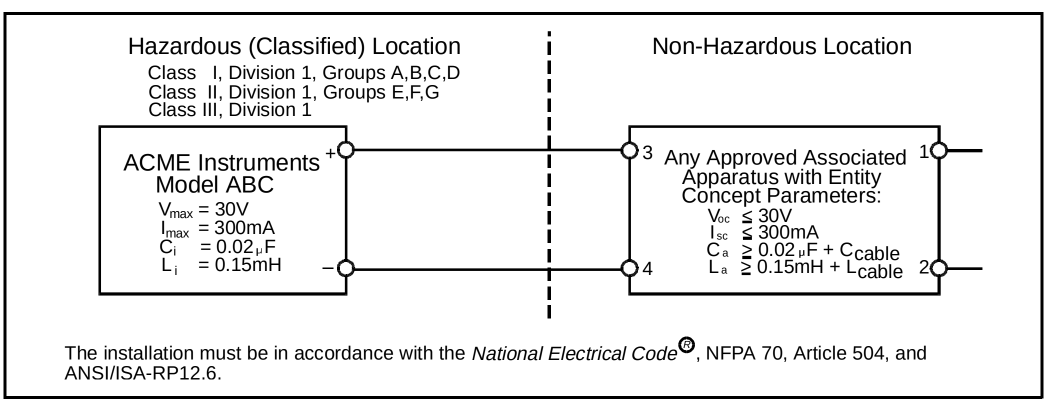


Figure 2 — Control drawing for an intrinsically safe apparatus examined under the entity concept

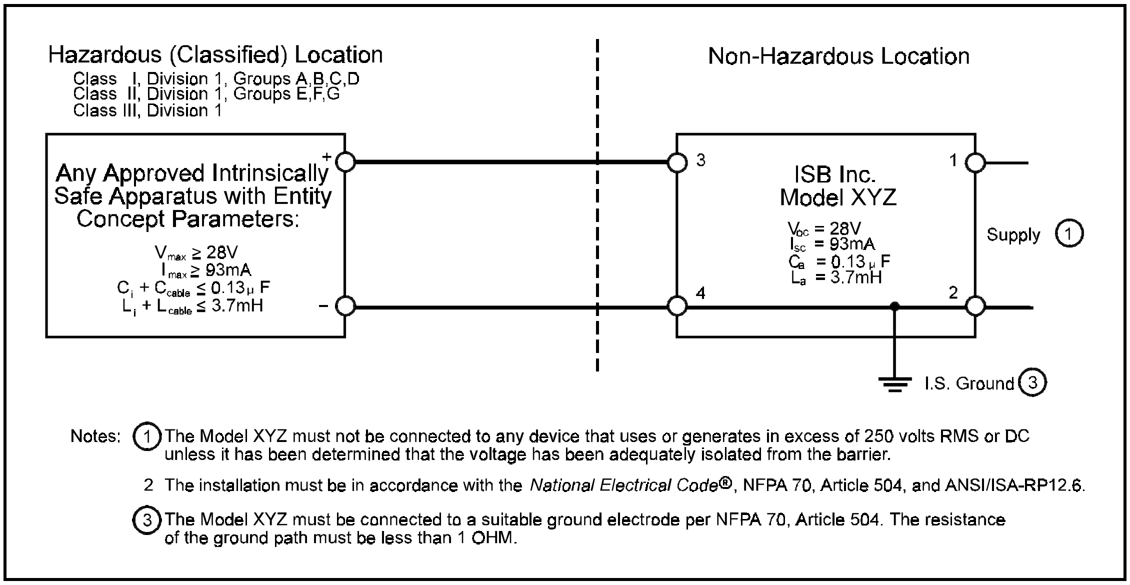


Figure 3 — Control drawing for an associated apparatus examined under the entity concept

8 Assessing the intrinsic safety of simple loops

The interconnection of the apparatus depicted in Figures 2 and 3 is a two-wire loop with grounded return—i.e., a transmitter with single-channel grounded zener barrier. This is an example of the simplest and most easily understood combination. Assessing the intrinsic safety of this system is a matter of comparing the entity parameters as follows:

V_{max}	must be greater than or equal to	V_{oc};
I_{max}	must be greater than or equal to	I_{sc};
$C_i + C_{cable}$	must be less than or equal to	C_a; and
$L_i + L_{cable}$	must be less than or equal to	L_a.

Note that the capacitance and inductance of the cable must be added to that of the intrinsically safe apparatus. If the actual cable capacitance and inductance values are known, they may be used. If unknown, ANSI/ISA-RP12.6 recommends the following default values:

Cable capacitance - 60 pF/foot; and

Cable inductance - 0.20 µH/foot.

Inserting the values from Figures 2 and 3, the above conditions are met as follows:

V_{max}	(30 Volts)	must be greater than or equal to	V_{oc} (28 Volts);
I_{max}	(300 mA)	must be greater than or equal to	I_{sc} (93 mA);
C_i	(0.02 µF)	is less than	C_a (0.13 µF) by 0.11 µF; and
L_i	(0.15 mH)	is less than	L_a (3.7 mH) by 3.55 mH.

A maximum of 1,833 feet of cable (0.11 µF/60 pF per foot) can be used due to capacitance limitations and a maximum of 17,750 feet of cable (3.55 mH/0.20 µH per foot) can be used due to inductance limitations. The shorter length (1,833 feet) can be used. Therefore, the interconnection of these two devices is intrinsically safe with as much as 1,833 feet of cable.

9 Loop operation considerations

The comparison of entity parameters assures only that the interconnection of the intrinsically safe apparatus and associated apparatus is intrinsically safe. Nothing can be inferred from a successful entity parameter match about the operational suitability of the interconnection. The user still must evaluate the operating specifications of each apparatus to ensure that the combination will operate as desired.

10 Special considerations for multi-channel associated apparatus loops

There are many intrinsically safe installations for which a single-channel associated apparatus with grounded return is not appropriate. An example of this is when it is not desirable to connect either conductor in a two-wire loop to ground, as is often the case with low-level analog signals, or in which the intrinsically safe apparatus has multiple connections. In these cases it is necessary to limit the total energy from any combination of conductors entering the hazardous location to an intrinsically safe level. Figures 4 and 5 depict a two-wire loop with neither conductor connected to intrinsic safety ground. Figure 4 uses two, single-channel associated apparatus, and Figure 5 uses one, two-channel associated apparatus.

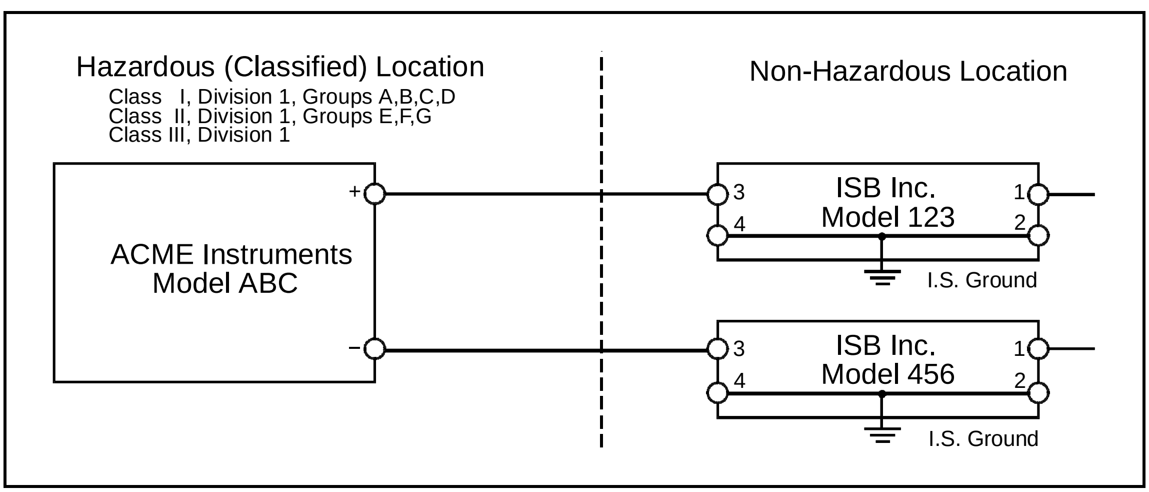


Figure 4 — Two-wire loop with neither conductor connected to ground using two single-channel associated apparatus

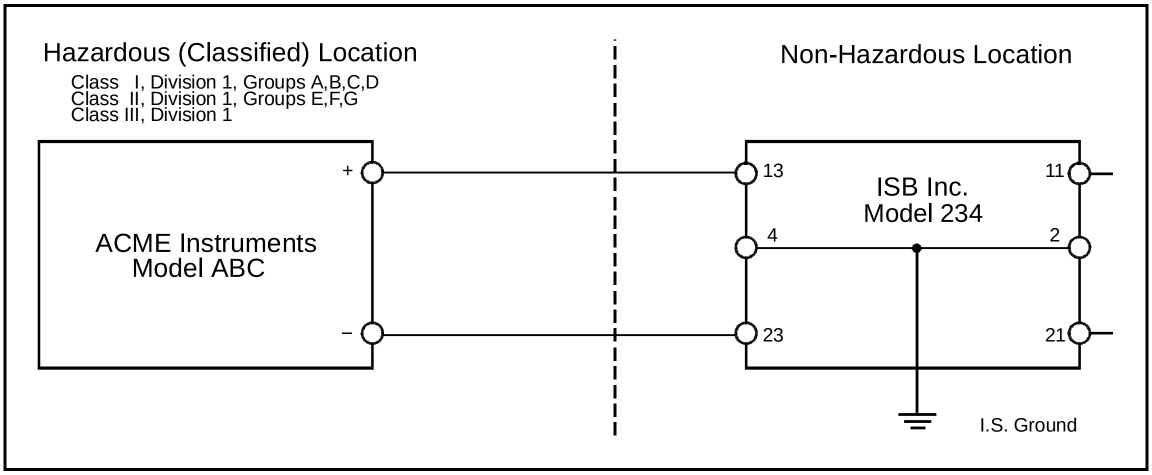


Figure 5 — Two-wire loop with neither conductor connected to ground using one dual-channel associated apparatus

The intrinsic safety of the system cannot be assessed if: (1) only the entity parameters of each associated apparatus in Figure 4 are known, or (2) only the entity parameters of each channel of the associated apparatus in Figure 5 are known. An assessment cannot be made because the individual V_{oc} parameters address only the maximum voltage of each conductor with respect to ground. The maximum voltage between the two conductors is not known and cannot be derived from the individual V_{max} parameters. Therefore, it is necessary for the manufacturer of the associated apparatus to provide a control drawing giving the entity parameters for the specific connection.

One NRTL, Factory Mutual Research Corporation, uses the parameter V_t to describe the maximum voltage between any two channels, and the parameter I_t to describe the sum of the currents from all channels of the given combination. Other NRTLs continue to use V_{oc} and I_{sc} and assure that the control drawing is clear as to which combination of terminals each parameter applies. In any case, the user must assure that the entity parameters used are taken from control drawings that correctly describe the loop configuration.

Once this is done, the entity concept assessment of the intrinsic safety of the loop is performed in exactly the same manner as previously described. When the maximum voltage and current of the apparatus (as shown in Figure 6) are indicated on the control drawing by V_t and I_t, these values should be used in the parameter comparison in lieu of V_{oc} and I_{sc}.

However, the V_t and I_t parameters are independent from each other and cannot be used to determine the maximum power (P_{max}) that can be delivered by the combination of channels. The entity parameter comparisons for the loop shown in Figure 5 are correctly made using the values from Figures 2 and 6, as follows:

V_{max} (30 V)	is greater than	V_t (29.2 V);
I_{max} (300 mA)	is greater than	I_t (287 mA);
C_i (0.02 µF)	is less than	C_a (0.11 µF) by 0.09 µF; and
L_i (0.15 mH)	is less than	L_a (0.48 mH) by 0.33 mH.

The connection is intrinsically safe with as much as 1,500 feet of cable using the default cable parameter of 60 pF/foot (0.09 µF/60 pF per foot = 1,500 feet).

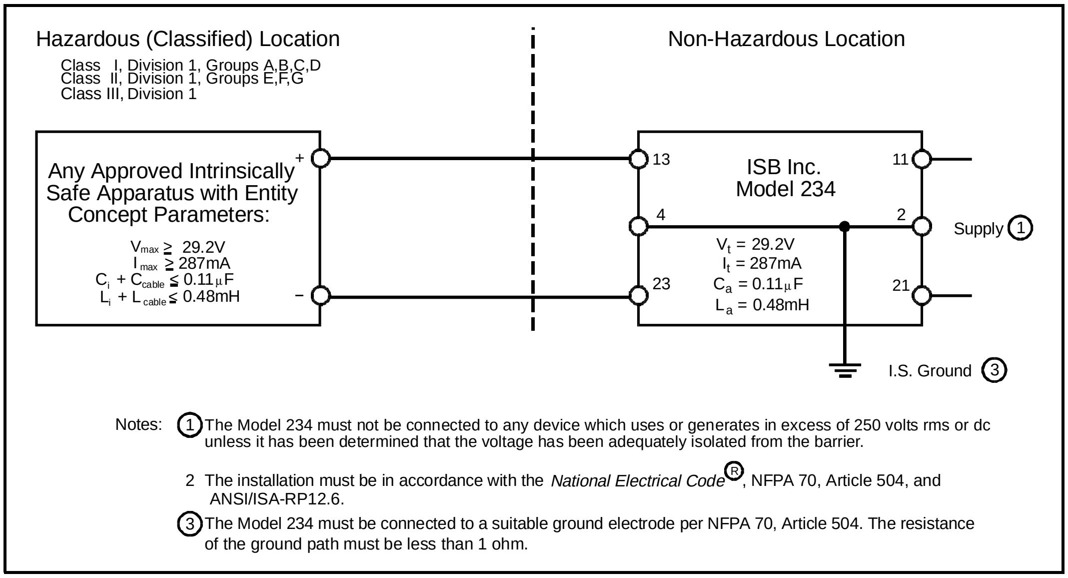


Figure 6 — Control drawing for two-channel associated apparatus with V_t and I_t parameters

11 Assessing the intrinsic safety of complex loops

The intrinsic safety of more complex loops can be assessed using the entity concept, but its use may be quite restrictive and may result in no possible functional combinations. In these cases a system examination is less restrictive and may provide a functional intrinsically safe system. However, for complex loops that operate at sufficiently low power, the entity concept still may be appropriate. Figure 7 is an example of a complex loop that has two pieces of intrinsically safe apparatus and three pieces of associated apparatus. Each associated apparatus has two channels, and one piece of intrinsically safe apparatus has three circuits.

The entity concept assessment for a loop, as shown in Figure 7, is performed in much the same manner as for simple loops. The main difference is that when there is more than one piece of intrinsically safe apparatus, the entity parameter comparisons are made as follows:

V_{max} of each intrinsically safe apparatus must be greater than V_t of the associated apparatus;

I_{max} of each intrinsically safe apparatus must be greater than I_t of the associated apparatus;

The sum of all C_i parameters and the capacity of the cable must be less than C_a of the associated apparatus; and

The sum of all L_i parameters and the inductance of the cable must be less than L_a of the associated apparatus.

Figures 8, 9, and 10 are examples of the control drawings necessary to complete the assessment of the loop shown in Figure 7.

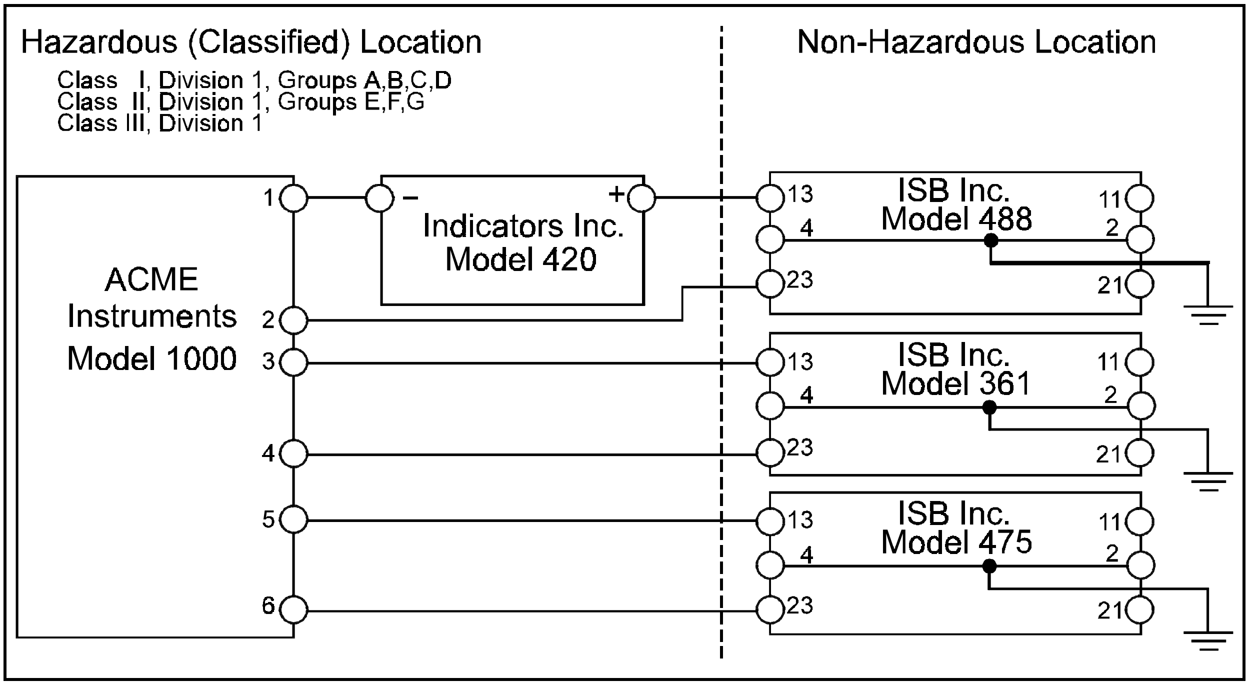
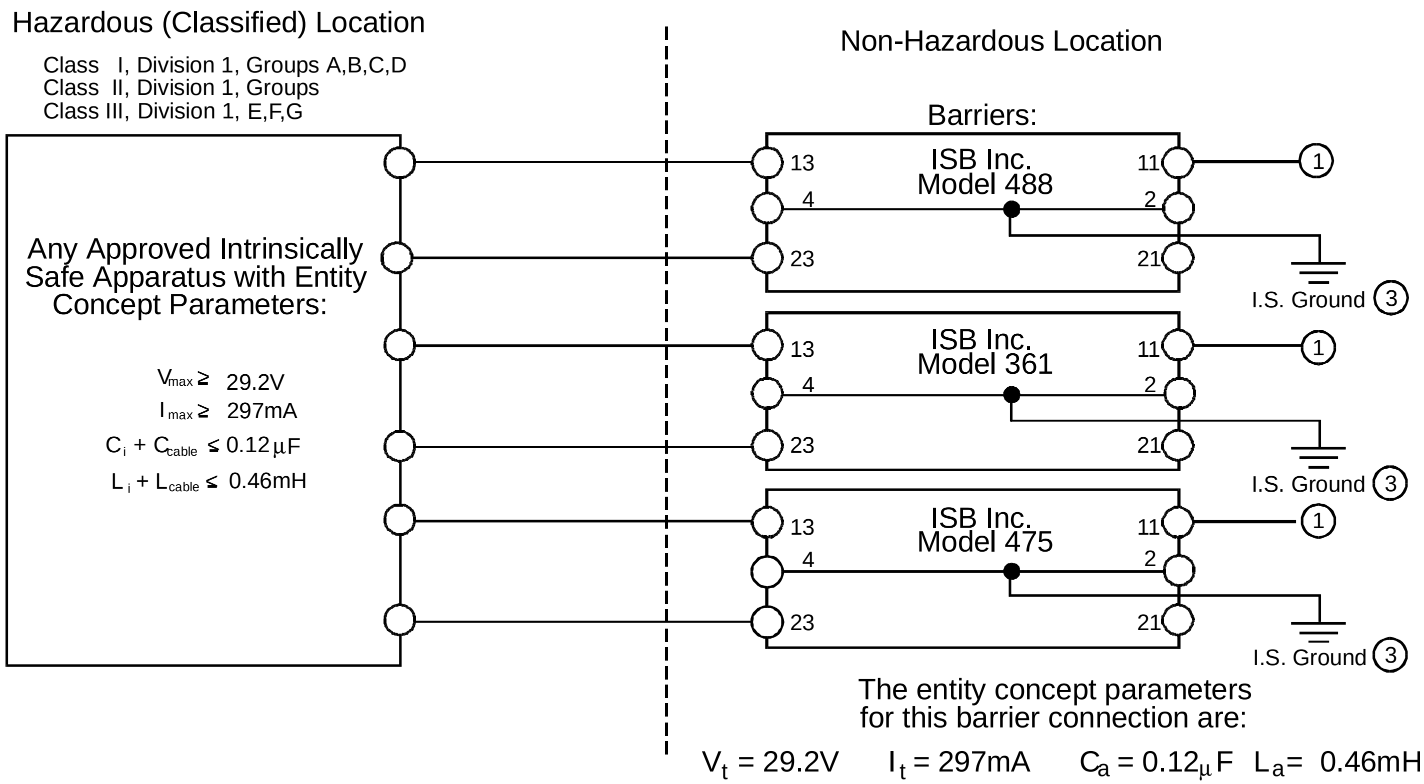


Figure 7 — Complex loop with two intrinsically safe apparatus and three two-channel associated apparatus



Notes: 1 The barriers must not be connected to any device which uses or generates in excess of 250 volts rms or dc unless it has been determined that the voltage has been adequately isolated from the barrier.

2 The installation must be in accordance with the *National Electrical Code®*, NFPA 70, Article 504, and ANSI/ISA-RP12.6. The resistance of the ground path must be less than 1 ohm.

3 The barrier must be connected to a suitable ground electrode per NFPA 70, Article 504. The resistance of the ground path must be less than 1 ohm.

Figure 8 — Control drawing for three two-channel associated apparatus with V_t and I_t

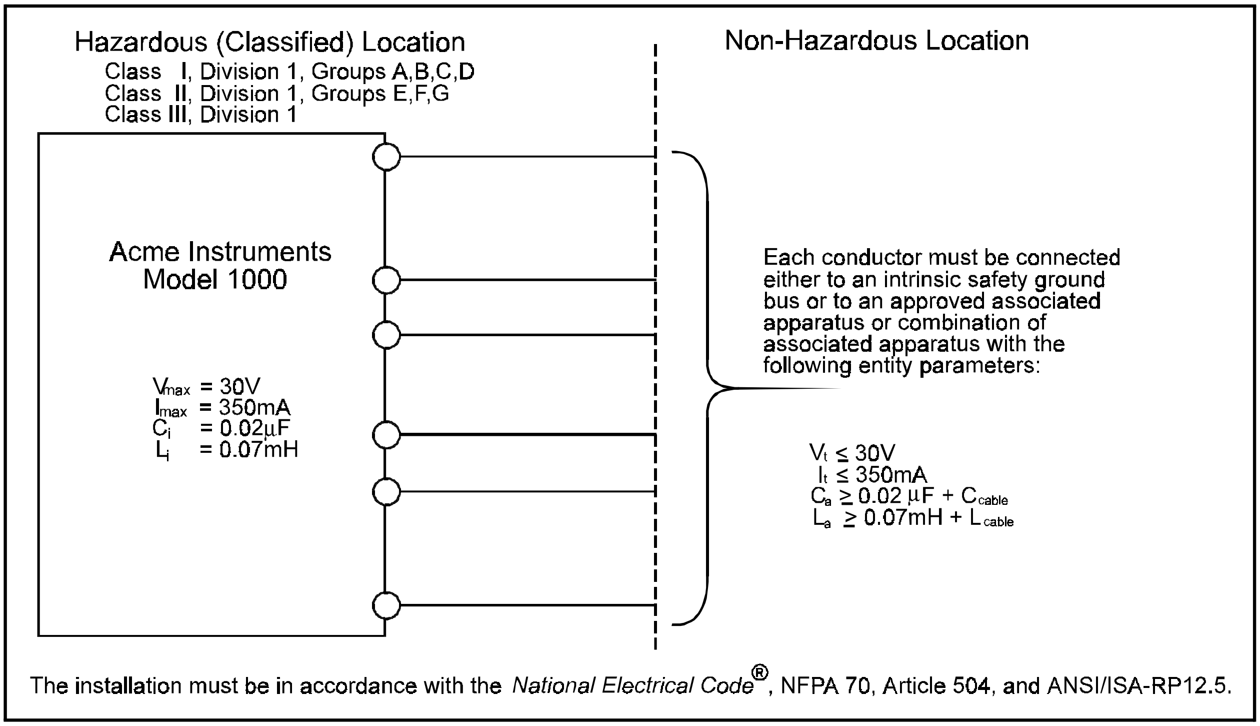


Figure 9 — Control drawing for intrinsically safe apparatus with multiple circuits

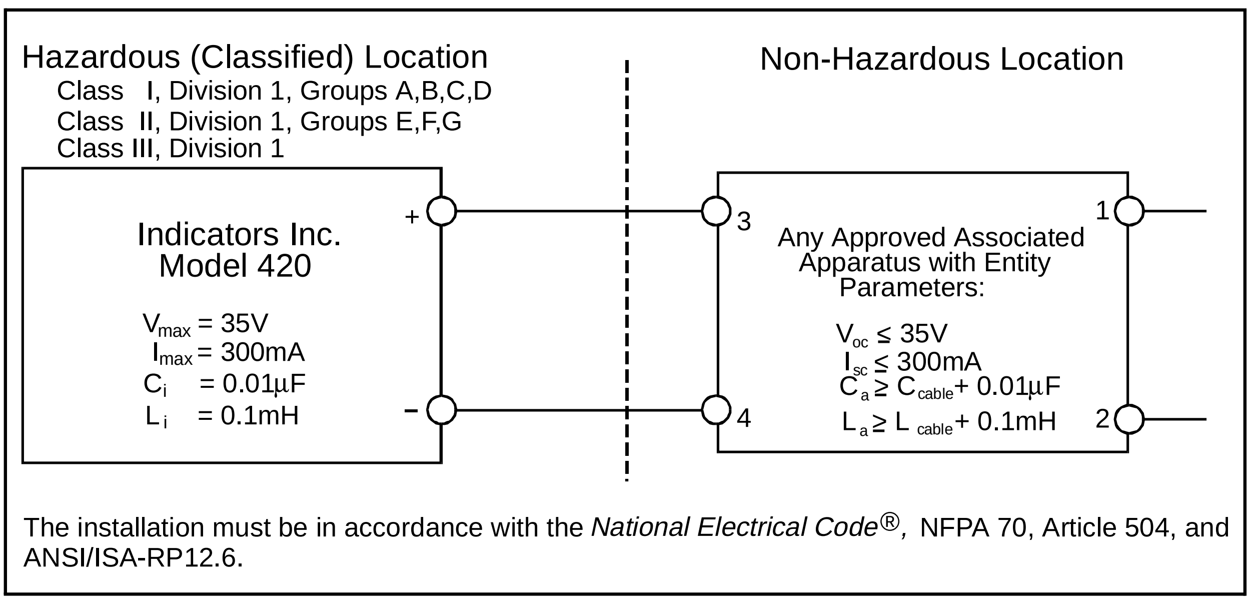


Figure 10 — Control drawing for intrinsically safe apparatus

For the loop in Figure 7, the aforementioned conditions are met as follows:

All V_{max} parameters (30 V and 35 V) are each greater than V_t (29.2 V);

All I_{max} parameters (350 mA and 300 mA) are each greater than I_t (297 mA);

The sum of all C_i parameters (0.02 µF + 0.01 µF = 0.03 µF) is less than C_a (0.12 µF) by 0.09 µF; and

The sum of all L_i parameters (0.07 mH + 0.1 mH = 0.17 mH) is less than L_a (0.46 mH) by 0.29 mH.

The loop is intrinsically safe with up to 1,450 feet of cable using the default cable parameter of 0.20µH/foot (0.29 µH/0.20 µH per foot = 1,450 feet).

12 Intrinsically safe apparatus that adds energy to the loop

In some cases, an intrinsically safe apparatus may add energy to the loop, as well as accept energy from associated apparatus. In this case, the intrinsically safe apparatus will have both input (V_{max}, I_{max}, C_{i1}, L_{i1}) and output (V_{oc}, I_{sc}, C_a, L_a) parameters. (This type of situation is well depicted in Figure 11, which illustrates a typical control drawing for a hand-held communicator.

When using devices that have both input and output entity parameters, careful attention to the instructions on the control drawing is essential. If the communicator were to use a parallel connection (as shown in Figure 11), it is necessary to assure that the sum of the I_{sc} parameters remains intrinsically safe and to calculate a new L_a parameter for the interconnection since introducing the communicator provides an additional current source to the loop. Means to do so are provided on the control drawing. However, if the communicator were connected in series, it would be necessary to assure that the sum of the V_{oc} parameters remains intrinsically safe and to calculate a new C_a parameter for the interconnection since another voltage source would be added to the loop. When using devices that have both input and output entity parameters, careful attention to the instructions on the control drawing is essential.

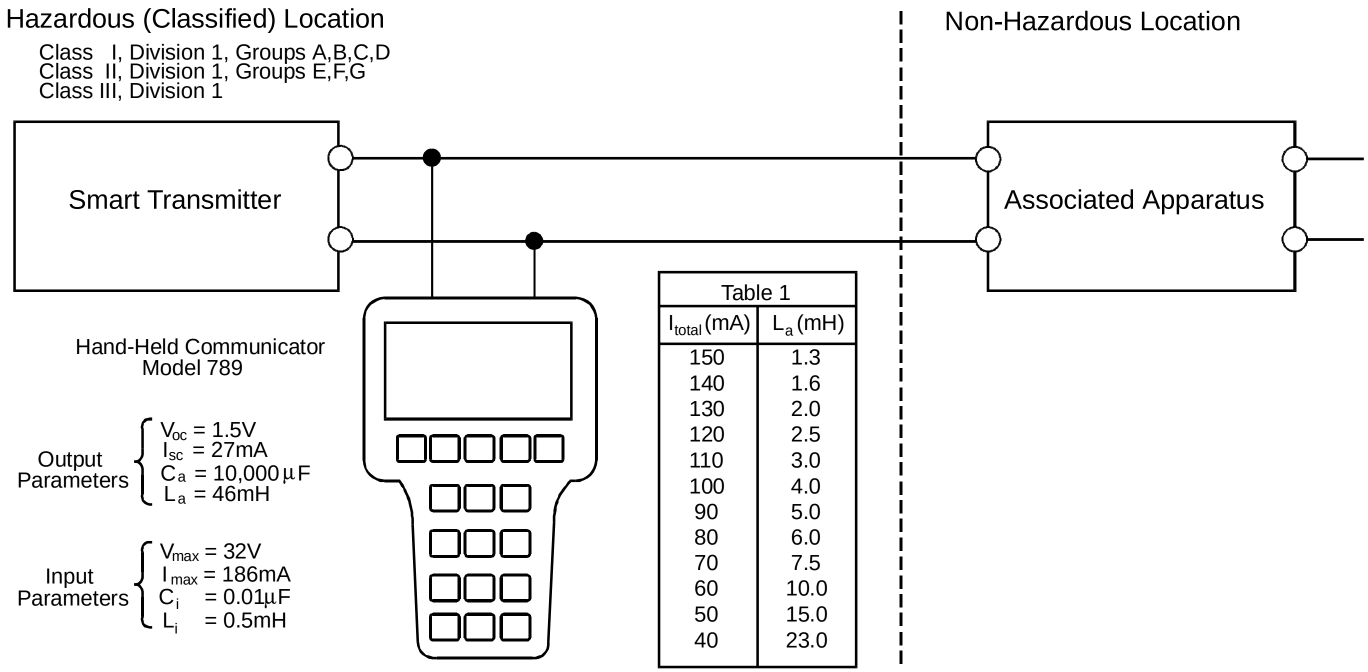


Table 1

I_{total} (mA)	L_a (mH)
150	1.3
140	1.6
130	2.0
120	2.5
110	3.0
100	4.0
90	5.0
80	6.0
70	7.5
60	10.0
50	15.0
40	23.0

Notes:

1- Output parameters: Since current is added to the loop by the communicator, a new L_a value that accounts for the total loop current must be determined. To do this, add the I_{sc} parameter of the associated apparatus to the I_{sc} of the communicator. Find that current in Column 1 of Table 1. Rounding to the next highest value, read the corresponding L_a in Column 2. Since the voltage of the communicator cannot be added to that of the associated apparatus in this configuration, it is not necessary to calculate a new V_{oc} or C_a.

2- The Model 789 communicator may be connected in the hazardous (classified) location as shown if the following conditions are met:

A - The V_{oc} and I_{sc} of the associated apparatus must not exceed the V_{max} and I_{max} of the communicator.

B - The total capacitance connected to the associated apparatus must not exceed the C_a of the associated apparatus. This total consists of the sum of the C_i parameters of all field devices in the loop and the cable capacitance.

C - The total inductance connected to the associated apparatus must not exceed the L_a value calculated using Table 1. This total consists of the sum of the L_i parameters of all field devices in the loop and the cable inductance.

3- The installation must be in accordance with the *National Electrical Code*®, NFPA 70, Article 504, and ANSI/ISA-RP12.6.

Figure 11 — Control drawing for a hand-held communicator

13 Considerations for intrinsically safe bus systems

Bus systems are — by their very nature—complex loops, and they present challenges to the use of the entity concept. The entity concept is very important to bus systems in which interchangeability or interoperability, or both, of bus participants is desired. Without the entity concept, interchangeability would be severely limited because it would be virtually impossible to cover all possible intrinsically safe system combinations on control drawings. (Figure 12 is a typical intrinsically safe bus arrangement.)

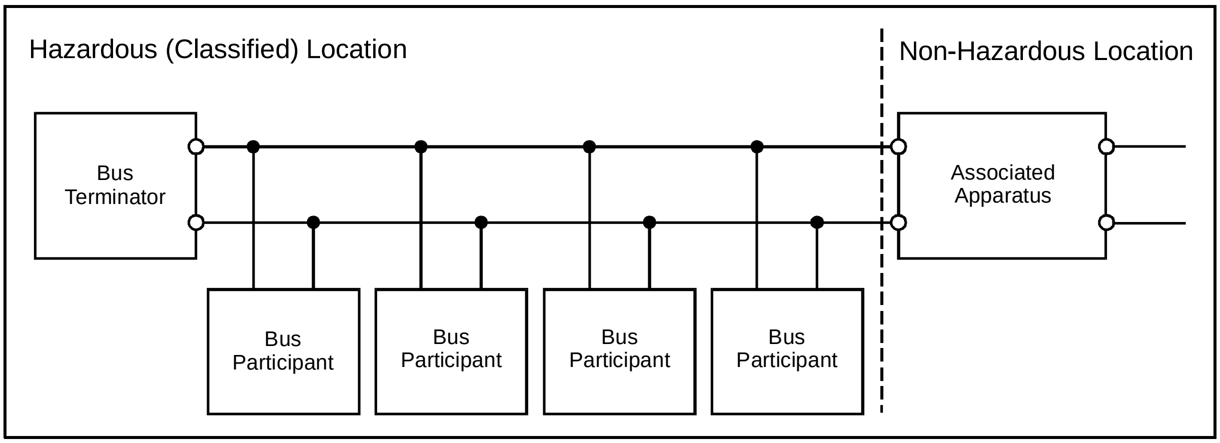


Figure 12 — Typical intrinsically safe bus configuration

The methods of assessing the intrinsic safety of the system illustrated in Figure 12 are identical to those detailed in previous sections for complex loops. However, if a goal of the bus system is to allow the free interchange of equipment, the issue becomes the practical control of a bus loop to ensure that it remains intrinsically safe when equipment is interchanged or portable communicators are momentarily connected.

Most of the organizations involved in the development of bus system standards recognize that such control may be impractical unless several of the following conditions are met by the bus participants:

1) The V_{max} and I_{max} parameters of the intrinsically safe apparatus should be no lower than specified minimum values that are sufficient to accommodate the associated apparatus;

2) The V_{oc} and I_{sc} parameters of the associated apparatus should be no higher than specified maximum values that will accommodate the intrinsically safe apparatus;

3) The C_i and L_i parameters of the intrinsically safe apparatus should be zero or at least very low, relative to the C_a and L_a parameters of the associated apparatus;

4) The intrinsically safe apparatus should not be allowed to add current or voltage to the loop.

The aforementioned conditions are not necessary to assess the intrinsic safety of a given bus system configuration, but they do help simplify the control procedures that are necessary to ensure that the system remains intrinsically safe when equipment interchanges are made.

14 Conclusion

The preceding examples illustrate how the intrinsic safety of a wide variety of loops can be assessed using the entity concept, thus providing greater flexibility in the selection of apparatus. One must simply obtain control drawings that correctly describe the loop configuration, compare the entity parameters as outlined in the examples, and follow any additional instructions given on the control drawings. Performed correctly, this procedure will ensure that a system is intrinsically safe.

15 References

FACTORY MUTUAL RESEARCH CORPORATION (FMRC)

Class No. 3610-1988 — Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and II, Division 1, Hazardous (Classified) Locations

Available from: **FMRC**
1151 Boston-Providence Turnpike
Norwood, MA 02062 (617) 762-4300

ISA

ANSI/ISA-RP12.6-1995 — Wiring Practices for Hazardous (Classified) Locations Instrumentation, Part I: Intrinsic Safety

ISA-S12.1-1991 — Definitions and Information Pertaining to Electrical Instruments in Hazardous (Classified) Locations

Available from: **ISA**
67 Alexander Drive
P.O. Box 12277
Research Triangle Park, NC 27709 Tel: (919) 549-8411

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

ANSI/NFPA 70-1993 — *National Electrical Code®*

Available from: **NFPA**
P.O. Box 9101
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UNDERWRITERS LABORATORIES, INC. (UL)

ANSI/UL 913-1988	Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations

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