Considerations When Using Extended Field Wiring Lengths with Bently Nevada Transducers

[Editor's Note: This article is an abbreviated version of Bently Nevada Applications Note 178454. Due to space limitations, all available graphs, tables, and sample calculations have not been reprinted here from that Note. The interested reader is encouraged to download the full Note from the electronic version of our Reader Service Card for this issue of ORBIT, available at www.orbit-magazine.com.]

The standard maximum cable run for Bently Nevada* transducers has been specified for many years in our product manuals and datasheets as 1000 feet (305 meters). In some cases, however, users have found this limitation to be inconvenient and are interested in running field wiring over extended distances to suit their needs. Longer lengths can be accomplished, provided the user understands the engineering principles involved and is able to properly quantify the effects of longer cable lengths and assess the impact on their particular application. This article discusses the key issues with extended field wiring by showing how wiring length and construction effects capacitance and frequency response, by discussing the types of applications that are particularly dependent upon high-frequency signal content, and by discussing the concept of capacitance limits and its relationship to hazardous area installation requirements.

The origin of the 1000 foot limit

For many years, the field wiring for Bently Nevada transducers has been recommended as 18 AWG. Depending on the transducer type, either 2-conductor or 3-conductor cable is used. Although lighter gauges can also be used (such as 22 AWG), experience has shown that lighter gauges have a greater tendency to break when connecting to terminals on the monitor and transducer. One of the limitations inherent with heavier gauge wire is that it represents greater capacitance per unit length, which in turn affects both the frequency response and suitability for hazardous areas where strict limits on total circuit capacitance are in effect.

Thus, along with our recommendation for 18 AWG wire came a recommendation to limit the length to no more than 1000 feet (305 m) in non-hazardous areas. This length was chosen both because it easy to remember and because it introduces only minimal signal degradation, allowing the full 10 kHz frequency response of our typical transducers to pass with little attenuation. However, as will be discussed in this article, this limit does not hold for all applications. Hazardous area applications and/or those for which the frequency response requirements differ from 0–10 kHz will require the designer to carefully consider the field wiring's effects on stored energy and signal attenuation. This article, and its companion Applications Note, serve as primers on the subject, familiarizing installation designers with the engineering considerations and calculations involved.

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Cable Capacitance

The frequency response of cable is affected by resistance, capacitance, and inductance. However, capacitance will usually be the first to cause problems. In addition, installations into areas with hazardous classifications usually limit the capacitive load allowed. In either case, the total cable capacitance must be calculated and evaluated against the pertinent limits.

The total cable capacitance is a function of the following factors:

- Cable length
- Number of Conductors
  In most cases, field wiring will have two or three conductors, depending upon the type of transducer being used. Proximity transducers always use a three-conductor system (power, signal, common) while other transducers either may not require external power or may share the power/signal wire; consequently, they use a two-conductor system.
- Cable Specifications
  The relevant values for field wiring analysis are the cable capacitance per unit length and the total capacitive load. The data sheet for cable will typically lists its capacitance per unit length. If you cannot find this value, you can usually calculate it from other datasheet values as explained below.

Capacitance values for the field wiring provided by GE for use with Bently Nevada transducers are shown in Table 1.

Table 1 – Cable Capacitance for field wiring provided by GE for use with Bently Nevada transducers

Part Number	Description	Capacitance
02173006	18 AWG two-conductor cable	98 pF/meter
02120015	18 AWG three-conductor cable	289 pF/meter

When using cable from another supplier, consult their datasheet or contact the manufacturer to obtain capacitive values. When this is not possible or practical, it will be necessary to determine these values yourself using the following equations:

- **For two-wire circuits**
  Total capacitance = capacitance core to core + capacitance core to screen.
  $C_{total} = C_{core\text{-}to\text{-}core} + C_{core\text{-}to\text{-}screen}$
- **For three-wire circuits**
  Total capacitance = (2 X capacitance core to core) + capacitance core to screen.
  $C_{total} = (2 * C_{core\text{-}to\text{-}core}) + C_{core\text{-}to\text{-}screen}$

The goal is to determine the total capacitive load for a given length of cable. To find this, multiply the cable capacitance per unit length by the total cable length. As has previously been noted, this total capacitive load must be taken into account when considering the hazardous area and signal integrity issues.

Specific installations often run field wiring cable with lower capacitance than that offered by GE to mitigate long field wire lengths. This is successful when proper engineering practices are applied to quantify the performance.

Applications

Certain applications and measurements are known to generate high-frequency content and are particularly dependent upon field wiring that preserves the full spectral integrity of the signal. This typically occurs when the machine itself runs at very high rotational speeds and/or when the nature of the vibration tends to generate a number of harmonics. Some common applications and their dependence upon high-frequency signal content are noted below.

- **Applications more dependent upon high-frequency signals**

  Gearboxes, turbine blade pass, rolling element bearing signatures, high-speed machines (e.g., turbo expanders and the high speed stages of centrifugal air compressors), speed-sensing applications with the sensor observing a toothed wheel.

- **Applications less dependent upon high-frequency signals**

  Non-vibration measurements (e.g., thrust position, differential expansion, case expansion), low-speed machines (e.g., hydro turbine/generators, reciprocating compressors).

The above is intended only as a general guideline. Each application must be evaluated on its own merits by considering the construction of the machine, the frequencies it is likely to generate under normal operating conditions (blade pass, gear mesh, ball pass, etc.) and the frequencies it is likely to generate under malfunction conditions (cavitation, structural resonances, rough load zone, etc.).

Signal Quality

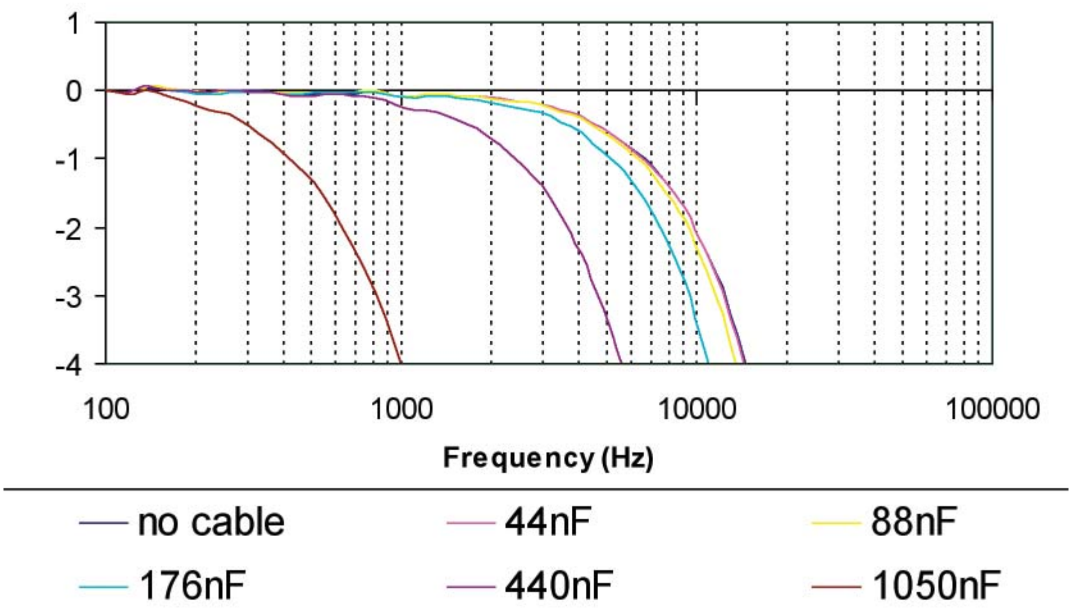
Driving a large capacitive load can be problematic as large loads can attenuate higher frequencies. What is considered 'too large' will depend of the type of transducer being used and the frequencies of interest. Table 2 shows the frequency response of numerous Bently Nevada vibration transducers along with notes regarding cable lengths. Obviously, as long as the field wiring provides a frequency response as good or better than the transducer itself, there will be no degradation of high-frequency content introduced by the field wiring. However, the total capacitance may exceed the allowable limits for hazardous area applications. Thus, when applicable, the designer must carefully consider both before deciding upon an allowable maximum cable length.

Table 2 – Field wiring and signal quality considerations for typical Bently Nevada transducers.

Transducer	Frequency Response	Notes
3300XL 8mm and NSv Proximitor* Sensor	0 - 10 kHz	Extended field wire lengths can attenuate relevant high-frequency content and affect measurement integrity.
3300XL 11mm Proximitor Sensor	0 – 8 kHz	Extended field wire lengths can attenuate relevant high-frequency content and affect measurement integrity.
3300XL 25mm Proximitor Sensor	0 – 2.7 kHz	Extended field wire lengths will rarely be an issue for frequency response considerations.
3300XL 50mm Proximitor Sensor	0 - 50Hz	Extended field wire lengths will rarely be an issue for frequency response considerations.
XL Radiation Resistant Proximitor Sensor	15 ft. system: 0 – 10 kHz 40 ft. system: 0 – 9 kHz 110 ft system: 0 – 5 kHz	Extended field wire lengths can attenuate relevant high-frequency content and affect measurement integrity.
LVDT	n/a	Extended field wiring lengths are not recommended under any circumstance due to the LVDT's sensitivity to resistance.
Velomitors	Varies depending on model. See pertinent transducer datasheet.	Extended field wire lengths can attenuate relevant high-frequency content and affect measurement integrity, depending on transducer frequency response.
Accelerometers	Varies depending on model. See pertinent transducer datasheet	Extended field wire lengths can attenuate relevant high-frequency content and affect measurement integrity.
Thermocouples and RTDs	n/a	Extended field wiring lengths are not recommended under any circumstances due to the sensor's sensitivity to resistance.

The manual for each transducer will typically provide a graph similar to Figure 1, showing the affect of total cable capacitance on frequency response.

Figure 1 – Effect of field wiring total capacitance on frequency response for 3300 XL 8mm Proximity Transducer System (5 meter system length, no I.S. barriers)



Frequency Response Calculation Examples

Example 1

Goal

Determine the frequency response attenuation that will occur for a 3300 XL 8mm proximity transducer system (5 meter system length, no barriers) when 1500 m of GE's standard 18 AWG 3-conductor field wiring is used.

Solution

Using the value of 289 pF/m from Table 1 for 3-conductor field wiring, the total cable capacitance for 1500 m is found simply as:

289 pF/m x 1500 m = 433,500 pF = 433.5 nF

Since this value is very close to the 440 nF curve of Figure 1, we will use that curve for estimation purposes. When computing signal strength, it is customary to use the -3db point as the so-called cut-off frequency (–3dB represents a signal that has only one-half of the original amplitude). The –3dB point for 440nF of total field wiring capacitance is approximately 5 kHz. Thus, by introducing 1500 meters of field wiring, we have reduced the 10 kHz frequency response of the transducer system to approximately 5 kHz.

Example 2

Goal

Determine whether the transducer installation of example 1 would be acceptable for a speed-indication application using a 60-tooth wheel on a turbine running at 6200 rpm.

Solution

A proximity transducer observing a 60-tooth wheel turning at 6200 rpm will generated a square-wave type pulse with nominal frequency of:

60 teeth/rev × 1 pulse/tooth × 6200 rev/min = 372,000 pulses per min = 6200 pulses/sec = 6.2 kHz.

Clearly, the cable length introduces too much attenuation at this frequency, particularly since a "clean" square wave signal is necessary for a tachometer to trigger reliably. At this frequency (6200 Hz), even the fundamental (1X) component of the square wave will be attenuated by more than 4 dB as noted in Figure 1. The user would either need to shorten the field wiring length or choose field wiring with a lower capacitance-per-meter rating.

Hazardous Area Considerations

Another extremely important issue with extended length field wiring is the need to remain compliant with hazardous area classifications when applicable. Today, the most common methods of complying with hazardous area classifications are through the use of designs that are either intrinsically safe (in the case of Zone 0/1 areas) or nonincendive (in the case of Zone 2 areas). The principle behind such designs is to limit the amount of available energy such that a flammable atmosphere cannot be ignited under the appropriate conditions.

Nonincendive (N.I.)

The apparatus is incapable of releasing sufficient electrical or thermal energy under normal operating conditions to cause ignition of a specific flammable atmosphere.

Intrinsically Safe (I.S.)

The apparatus is incapable of releasing sufficient electrical or thermal energy under normal and abnormal operating conditions to cause ignition of a specific flammable atmosphere.

As can be seen, I.S. is a more stringent requirement, requiring a design that limits the energy under both normal and abnormal operating conditions. Consequently, designers will find that the maximum capacitance allowed for I.S. installations is more restrictive than for N.I. installations. Also, although both inductors and capacitors can store energy, the energy stored in the capacitance of the field wiring is much larger than that stored by the wiring's inductance for our transducer/monitor applications. Agency approvals work on the basis of "most restrictive." In other words, the designer looks at the cable lengths that will result in either excessive capacitive energy or excessive inductive energy, and uses the more restrictive constraint. Invariably, as noted, capacitance turns out to be the limiting factor for our applications. Consequently, the discussion here confines itself only to capacitance. However, be aware that with other electrical or electronic apparatus you encounter, inductance may be the limiting factor. The astute designer will know when an installation will need to be concerned with capacitive constraints instead of inductive constraints, and vice-versa.

I.S. installations rely on special current/voltage limiting devices, such as galvanic isolators or so-called I.S. barriers. Although each uses different principles of operation, the idea of an energy-limiting circuit is the same. When external barriers are used, a small voltage drop occurs across the resistance of the barrier. Bently Nevada monitoring systems designed for use with external barriers allow the user to compensate for this small voltage drop. Systems that are available with internal barriers, such as 3300 and 3500, provide this compensation automatically; it is transparent to the user.

When considering the allowable maximum length of field wiring, the designer consults the appropriate tables and specifications for the particular zone, atmosphere, and Bently Nevada hardware type, allowing the maximum capacitance available for field wiring to be determined. One the maximum capacitance has been determined, the maximum field wiring length can be readily ascertained. Similar calculations are also performed to determine the maximum field wiring length while retaining the necessary frequency response for the application. Finally, the designer chooses the more restrictive of these two constraints (frequency response or hazardous area) and this becomes the governing criteria for the maximum cable length.

Several examples follow that demonstrate these concepts for typical monitoring system hardware.

[Editor's Note: Due to space limitations, only selected tables from the Applications Note have been provided here, allowing the reader to perform the sample calculations below.]

Hazardous Area Calculation Examples

Example 3

Goal

Determine the maximum cable length L_{max} allowed in a Zone 2 area with atmosphere type IIC for a channel using a 3500/42M monitor with Prox/Vel I/O module and a 3300 XL 8mm Proximity Probe (5 meter system length). Assume the use of field wiring with Bently Nevada part number 02120015.

Solution

Using Table 3, it can be seen that the maximum allowable connected capacitance C_o for a 3500/42 monitor with a Prox/Vel I/O module (p/n 140471-XX) is 0.2 μF (200 nF) regardless of atmosphere (gas) type. Next, per the published specifications in the 3300XL 8mm proximity transducer system datasheet, the input capacitance C_i of the Proximitor module is 5.7 nF, which we round off to 6 nF. This allows us to determine the maximum allowable total capacitance of the field wiring, C_{cable}, as follows:

$$C_{total} = C_{cable} + C_i \leq 0.2\mu F$$

$$C_{total} = C_{cable} + C_i \leq 200nF$$

$$C_{cable} + 6nF \leq 200nF$$

$$C_{cable} \leq 194nF$$

$$C_{cable} \leq 194{,}000pF$$

Now, since we have found the maximum total cable capacitance C_{cable}, the maximum allowable length is simply C_{cable} divided by the capacitance per unit length (which is found in Table 1):

$$L_{max} = \frac{C_{cable}}{289pF/m} = \frac{194{,}000pF}{289pF/m}$$

$$L_{max} = 671m$$

It is worth noting that while up to 671 m of this field wiring would allow the system to remain within hazardous area constraints, it introduces 194 nF of total capacitance which affects the frequency response adversely. Referring again to Figure 1 (we will use the curve for 176 nF since it is close to the actual value of 194 nF), it can be seen that the –3dB point is now less than 10 kHz (somewhere between 8 and 8.5 kHz). Thus, for applications that require the full 10 kHz frequency response of the proximity transducer, the field wiring would have to be shortened until the attenuation was within acceptable limits.

Project Services

Although many customers will feel comfortable performing these calculations themselves and managing the installation of transducers, monitors, and associated field wiring, other customers prefer to use GE's project services capabilities. These services can be provided for selected portions of a project, such as field wiring calculations; or, they can be provided as part of a broader scope, such as preparation of drawings, supervision of subcontractors, and field machining services to retrofit or upgrade instrumentation on existing machinery.

Table 3 – Maximum capacitance for 3500 monitoring system I/O modules in Zone 2 hazardous areas for gas group IIA - IIC			
Module Number	**Co by gas group (uF)**		
	IIC	**IIB**	**IIA**
146031-01, 3500/22M-01	1000		
140471-01,-02 3500/25, 3500/4x Prox / Velomitor 3500/64	0.2		
169459-01, -02, 350 0/4x Multimode, Prox/Velom (IT and ET)	0.2		
169715-01, -02, 3500/4x, Multimode Positive Input (IT and ET)	0.1		
125800-01, 3500/25	0.2		
133819-02, 3500/61, Thermocouple and RTD	1.56	10.5	42
133835-02, 3500/61, Isolated Thermocouple	1.56	10.5	42
136491-01, 3500/62, +/- 10Vdc I/O	1.71	1.71	48

Example 4

Goal

Assume the details given in example 3; however, installation constraints now require that the transducer system be located a minimum of 1000m from the monitor system. Find the maximum cable capacitance per unit length that can be used.

Solution

The maximum total cable capacitance C_{cable} is the same as in example 3; namely, 194,000 pF. Here, however, we are given the length and need to find the capacitance per unit length C_{UL}.

$$L_{max} = \frac{C_{cable}}{C_{UL}} \qquad C_{UL} = \frac{194{,}000\text{pF}}{1000\text{m}}$$

$$C_{UL} = \frac{C_{cable}}{L_{max}} \qquad C_{UL} = 194\text{pF/m}$$

Thus, field wiring cable should be chosen with a capacitance per unit length less than or equal to 194 pF/m. Since this value is less than the standard 18 AWG 3-conducter field wiring cable of Table 1, GE's standard cable cannot be used and an alternative cable type meeting the required capacitance per unit length must be employed.

As pointed out in example 3, although the length of field wiring used here will allow the system to remain within the constraints imposed by the hazardous area criteria, it will result in some roll-off of the frequency response. As such, this length of field wiring may or may not be acceptable depending on whether the full 10 kHz frequency response available from the proximity transducer is required or not.

Example 5

Goal

Determine the maximum cable length L_{max} for the channel described in Example 3 except now it must be suitable for a Zone 0 classified area with gas group IIC. Assume that the 3500 monitor uses an I/O module for Prox/Accel with internal barriers. Assume also the same field wiring type as example 3.

Solution

Using Table 4, it can be seen that the maximum allowable connected capacitance C_o for a 3500/42 monitor with an internal barrier Prox/Vel I/O module (p/n 135470-01) is 0.083μF (83 nF). Also, as before, the input capacitance Ci of the Proximitor module is approximately 6 nF. This allows us to determine the maximum allowable total capacitance of the field wiring, C_{cable}, as follows.

Table 4 – Maximum capacitance for 3500 monitoring system I/O modules in Zone 0/1 hazardous areas with gas group IIC atmospheres

Barrier Module Number	C_o by gas group (uF)
135470-01, Proximitor & Accelerometer	0.083
135471-01, Velomitor	0.088
137101-01, Process Variable	0.76
135472-01, Temperature	8.8

$C_{total} = C_{cable} + C_i \leq 0.083\mu F$

$C_{total} = C_{cable} + C_i \leq 83nF$

$C_{cable} + 6nF \leq 83nF$

$C_{cable} \leq 77nF$

$C_{cable} \leq 77{,}000pF$

Finally, the maximum allowable length is found using the same equation as 3.

$$L_{max} = \frac{C_{cable}}{289pF/m} = \frac{77{,}000pF}{289pF/m}$$

$L_{max} = 266m$

Summary

Long field wiring lengths are sometimes required due to the nature of the cable runs and plant layout. This introduces additional capacitance and can affect the integrity of the monitoring system in one or both of the following ways:

- By attenuating high frequencies in the vibration signal
- By allowing too much stored electrical energy, violating hazardous area certification limits

In order to determine the maximum length of field wiring, the designer must therefore understand both the necessary frequency response required by the application and the allowable maximum capacitance for the particular hazardous area classification (when applicable). The calculations allow the designer to determine either the maximum length of standard field wiring cable that can be used, or the maximum capacitance per unit length of alternate field wiring, allowing cable with appropriate specifications to be procured.

*Denotes a trademark of the General Electric Company.