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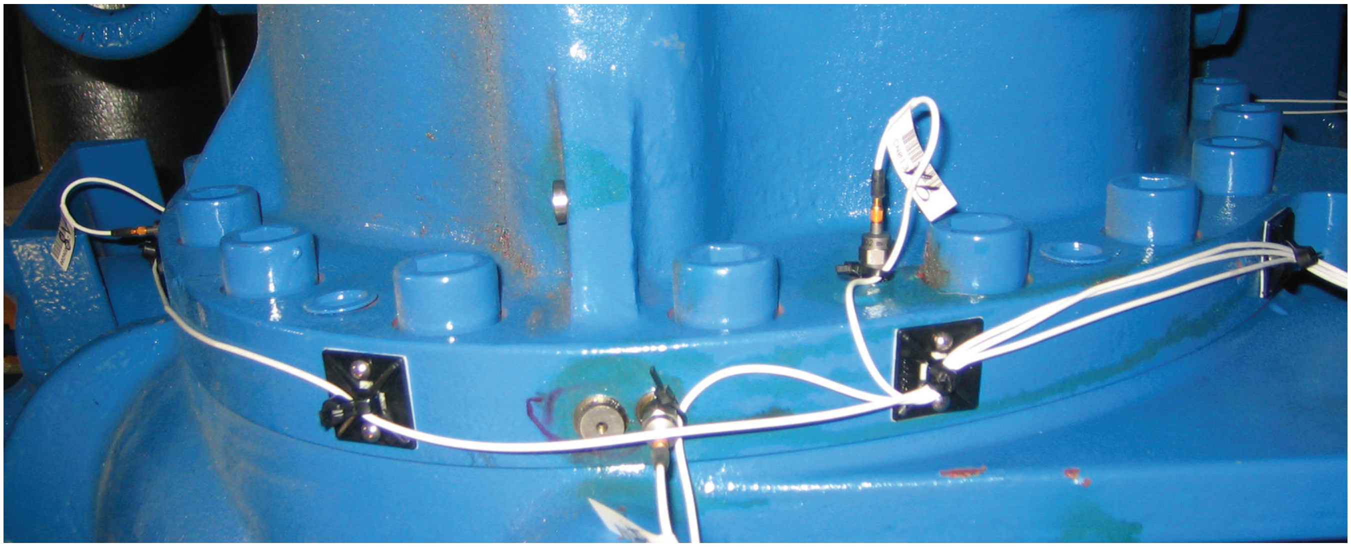

Signal Transmission on Long Cable Lengths With ICP® Sensors

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IMI Sensors produces two broad categories of sensors- charge sensors (pC/unit) and ICP® sensors (mV/unit). Charge sensors do not include a built-in amplifier and have a high-impedance output signal while ICP® sensors include a built-in amplifier and have a low-impedance output signal.

Low-impedance output signals are well-suited for transmission over long cable lengths as they are generally not susceptible to noise distortion when transmitted long distances. However, caution does need to be taken with cable runs longer than 100ft. as signal filtering of high frequency outputs (greater than 10,000 Hz) could occur as a result of cable capacitance.

What is Cable Capacitance?

Cable capacitance is a type of stray or parasitic capacitance that is unwanted and yet unavoidable. It occurs when two insulated conductors within a coaxial cable are at different electric potentials. See Figure 1. A polarizing electric field develops across the non-conductive insulator (dielectric) as positive charge collects on one conductor and negative charge collects on the other conductor.

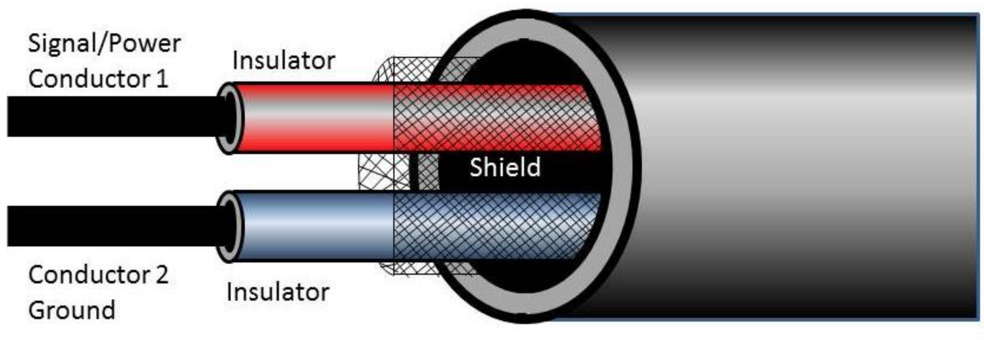

Figure 1: Illustration of Two-Conductor Cable for ICP® Sensor

The differential charge between the two conductors allows the storage of energy (ie. voltage) in the electric field, which typically resists a change in voltage. When there is no change in voltage, there will be no current. Each time the voltage changes, the electric field draws or supplies current to charge or discharge the electric field. If the charging of the electric field is restricted by a low sensor constant excitation current, the field cannot be charged fast enough in order to provide adequate voltage to the sensor amplifier in order to maintain its slew rate (ie. the ability of the amplifier to effectively maintain output). See Figure 2 for slew rate equation. As a result, a low pass filter that clips the waveform of signals with a frequency greater than approximately 10,000 Hz.

$$SR = 2 \times \pi \times f \times V$$

SR = amplifier slew rate (V/µs)
f = sensor maximum frequency (Hz)
V = maximum peak output from sensor (Volts)

Figure 2: Calculating Slew Rate of ICP® Sensor Built-In Amplifier

Cable capacitance (measured in picofarads) can be affected by distance between the two conductors, type/amount of insulation between the two conductors or amount of conductor surface area. Conductor surface area increases as cable length increases with cable capacitance typically being determined by multiplying capacitance per foot of cable times the total length of the cable.

Two Methodologies for Determining the Maximum Frequency Signal for a Given Cable Length

As referenced above, the maximum frequency that can be transmitted over a given cable length is a function of both the cable capacitance and the output impedance (ratio of the peak signal voltage to the current available from the signal conditioner). There are two methodologies to determine the maximum frequency signal for a given cable length.

The first methodology is the use of the equation provided in Figure 2. The equation shows that a greater constant current is required to drive a signal as the length of cable, peak voltage output or maximum frequency increases. The total current supplied to the ICP® sensor is reduced by 1 mA to compensate for powering the internal electronics of the IMI Sensors' ICP® sensor.

$$f_{max} = \frac{10^9}{2\pi CV/(I_c - 1)}$$

f_{max} = maximum frequency (Hz)
C = cable capacitance (pF)
V = maximum peak output from sensor (Volts)
I_c = constant current from signal conditioner (mA)
10^9 = scaling factor to equate units

Figure 3: Calculating Maximum Frequency Transmitted on Given Cable Length

The second methodology is the use of a nomograph. The nomograph in Figure 3 provides a simple, graphical method for obtaining the expected maximum frequency capability of an ICP® sensor. The maximum peak signal voltage amplitude, cable capacitance and supplied constant current must be known or presumed.

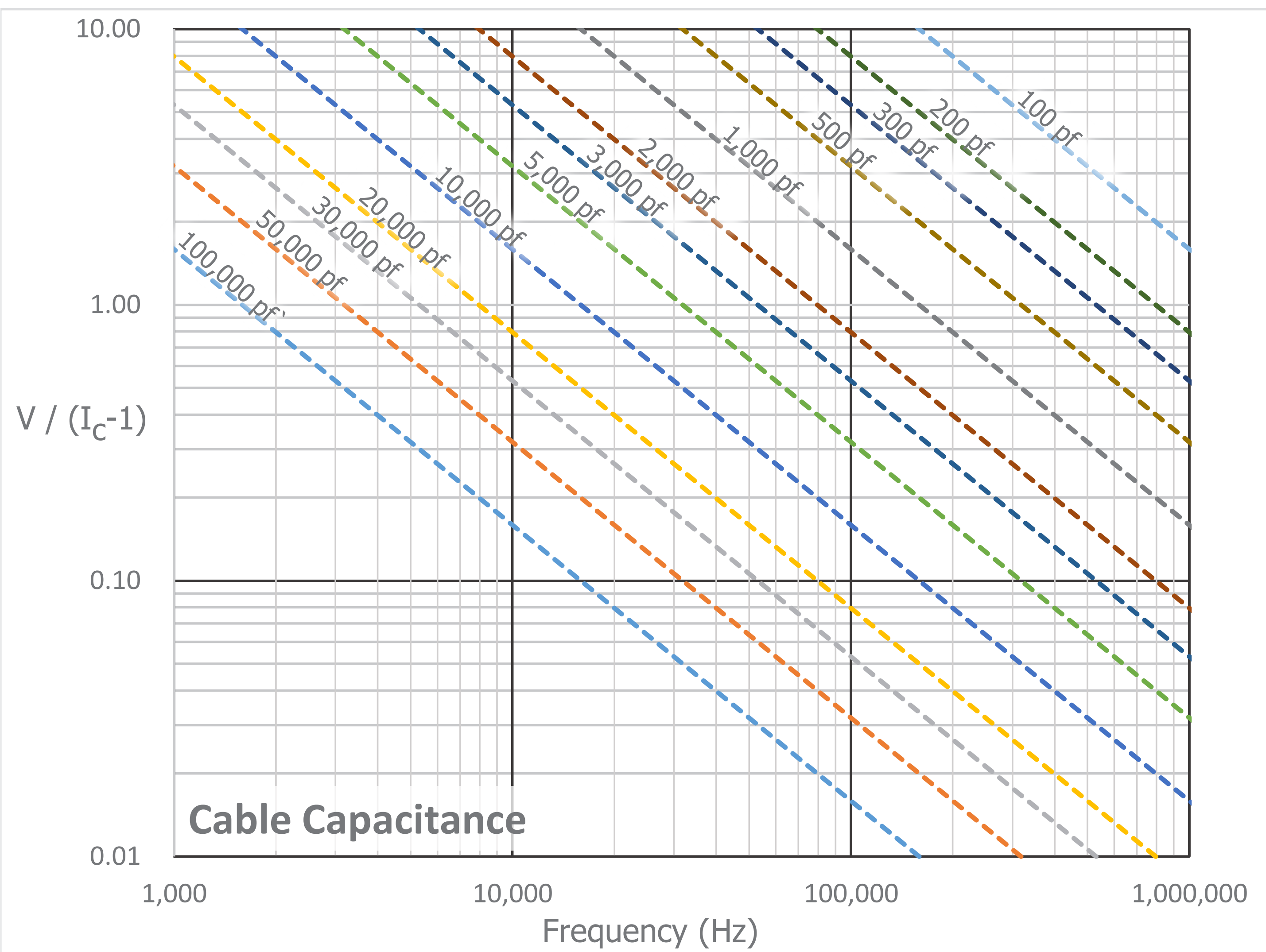

Figure 4: Cable Driving Nomograph

Below is an example:

- Step 1: You have 100 ft. cable with a capacitance of 30 pF/ft = 3000 pF. Find the corresponding diagonal line.
- Step 2: You have a maximum sensor output range of 5 V and a signal conditioner constant current of 2 mA. You calculate that $V/(I_c-1) = 5/(2-1) = 5$. Find the corresponding value on the vertical axis.
- Step 3: Trace horizontally from the vertical axis position determined in Step 2 to an intersection with the diagonal line determined in Step 1. The highest possible frequency output = approximately 10.2 kHz.

The nomograph does not indicate whether the frequency amplitude response at a point is flat, rising or falling. It is good practice to increase the constant current (if possible) to the sensor (within its maximum limit) so that the frequency determined from the nomograph is approximately 1.5 to 2 times greater than the maximum frequency of interest. Note that higher current levels will deplete battery-powered signal conditioners at a faster rate. Also, any current not used by the cable goes directly to power the internal electronics and will create heat. This may cause the sensor to exceed its maximum temperature specification. For this reason, do not supply excessive current over short cable runs or when testing at elevated temperatures.

Experimentally Testing Long Cables

To more accurately determine the effect of long cables, it is recommended to experimentally determine the high frequency electrical characteristics. See Figure 4 for a suggested methodology.

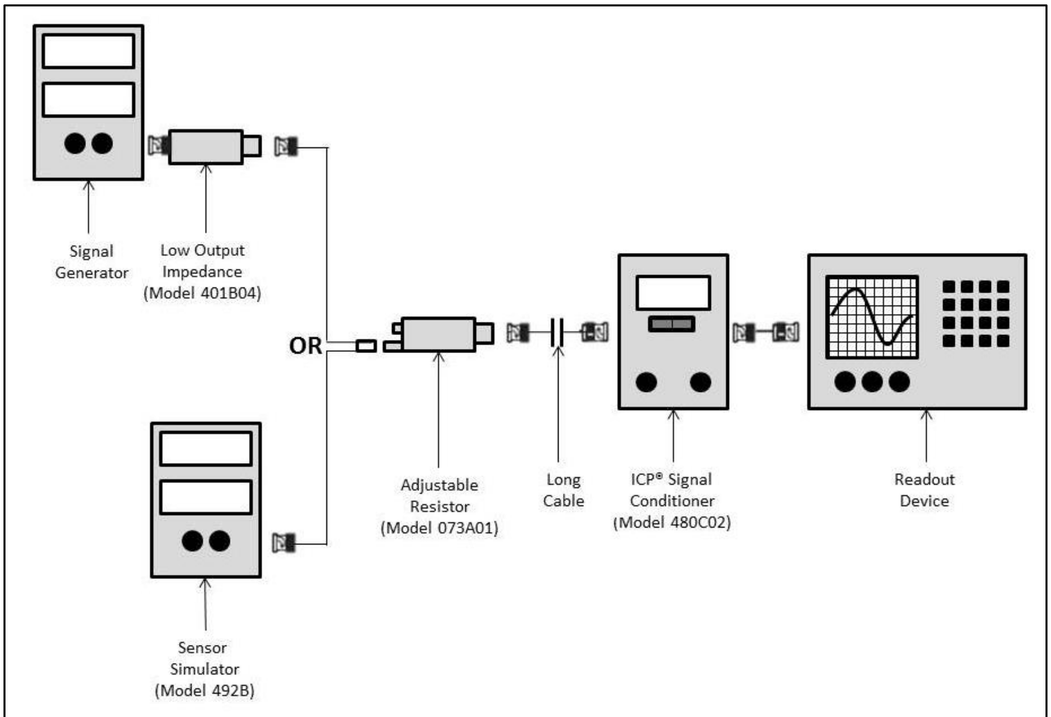

Figure 5: Method for Experimentally Testing Long Cables

The method illustrated involves the use of either a signal generator in conjunction with a unity-gain, low-output impedance (<5 ohm) instrumentation amplifier (Model 401B04) or a sensor simulator (Model 492B). The extremely low output impedance is required to minimize the resistance change when the signal generator/amplifier or sensor simulator is removed from the system.

In order to check the frequency/amplitude response of this system, set the signal generator or sensor simulator to supply the maximum amplitude of the expected measurement signal. Observe the ratio of the amplitude from the signal generator or sensor simulator to that shown on the readout device.

- If the ratio is 1-to-1, the system is adequate for your test.
- If the output signal is rising (ie. 1-to-1.3), add series resistance to attenuate the signal. Use of an adjustable 100 ohm resistor (Model 073A01) will help set the correct resistance more conveniently.
- If the ouput signal is falling (ie. 1-to-0.75), the constant current level must be increased or the cable capacitance must be reduced.

It may be necessary to physically install the cable during cable testing to reflect the actual conditions encountered during data acquisition. This will compensate for potential inductive cable effects that are partially a function of the geometry of the cable route.

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