Application Note

Determining Maximum Cable Lengths

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Introduction

This article describes how to determine the maximum line length possible when using ICP accelerometers, particularly with on-line systems. The cables that connect sensors to an on-line system inherently limit both the maximum observable frequency and the cable length. These limitations are due to the cable's impedance, which is a function of both frequency and capacitance.

The maximum sustainable frequency for a given cable is determined by the following three parameters:

- The total line capacitance
- The sensor current
- The desired maximum signal amplitude

The basic formula that ties these all together is usually stated as:

- $F_{max} = I / (2\pi\, C_t\, A)$

Where:

- F_{max} = Maximum permissible sensor frequency in Hz
- I = Sensor bias current in Amperes
- π = Universal constant, pi = 3,14159
- C_t = Total line capacitance, in Farads
- A = Signal strength in Volts rms

To use this equation effectively, we need to know what cable is being used and what its capacitance per foot rating is. This value is typically given on the cable specification sheet from the manufacturer.

If we want to solve for maximum line length, we would rewrite the equation as follows:

- $C_t = I / (2 * \pi * A * F_{max})$

Figure 1. The SKF Reliability Systems Condition Monitoring Unit (CMU).

And then use the following equation:

- $L_{max} = C_t / C$

Where:

- L_{max} = Maximum line length
- C = Capacitance per unit length rating (pF/ft.) or (pF/m)

Note that Enveloper Band 4 has a cut off frequency as high as 40 kHz and therefore if Band 4 measurements are required for that particular sensor, the cable length and capacitance should match this requirement. Keep in mind that all enveloper bands collect energy beyond their set cut off frequency, with a 12 dB/oct roll off. It is therefore good to keep a safety margin of roughly two times the band's high cut off frequency in order to maximize energy collection. Thus, use 80 kHz for Band 4 calculations, 20 kHz for Band 3, etc.

Example Calculations

The following examples illustrate how to use the previous equations. It should be pointed out that these calculations pertain to ideal environmental situations, and the actual results may slightly vary. Noise and site-specific conditions such as poor grounding may impose further limitations, and thus having extra margin is recommended to help ensure desired performance.

Example 1: Using a Condition Monitoring Unit (CMU) On-Line System, find F_{max}

An SKF CMSS 9100 cable is 600 ft. long has a capacitance of 27 pF/ft. Calculate the maximum frequency if the desired maximum signal strength is 1 Vp (10 g for a 100 mV/g sensor). The sensor is connected to the CMU, which has a fixed bias current of 4 mA.

Solution:

- $F_{max} = 0{,}004\text{A} / (2 \times 3{,}14159 \times 600 \text{ ft.} \times (27 \times 10^{-12} \times 1 \text{ Vp}))$
  $= 39{,}297 \text{ kHz}$

Notice that if the signal strength is increased to 20 g, F_{max} comes down linearly to 19,648 kHz!

Example 2: Using a Condition Monitoring Unit (CMU) On-Line System, find L_{max}

With a cable capacitance of 33 pF/ft. and a sensor bias current of 4 mA, calculate the maximum line length if frequencies as high as 15 kHz need to be observed. The desired maximum signal strength is 0,5 Vp (5 g for a 100 mV/g sensor).

Solution:

Step 1: Calculate the total line capacitance, C_t. Use the following formula:

- $C_t = I / (2 \times \pi \times A \times F_{max})$
- $C_t = 0{,}004 \text{ A} / (2 \times 3{,}14159 \times (5 \text{ g} \times 0{,}1 \text{ V/g}) \times 15\,000 \text{ Hz}))$
  $= 84{,}9\text{nF}$

Step 2: Calculate L_{max}.

- $L_{max} = C_t / C$
- $L_{max} = 84{,}9 \text{ nF} / 33 \text{ pF}$
  $= 2\,572 \text{ ft.}$

Figure 2. Vibration accelerometer sensors from SKF Reliability Systems.

Example 3: Using a Machine Condition Transmitter (MCT) On-Line System

This example applies to a Machine Condition Transmitter. Let's assume the application requires a line length equal to 2 000 ft., and the cable being used has a capacitance rating equal to 400 nf/km. For this example, let's use F_{max} = 10 kHz for our maximum frequency range of interest, and let's use an ICP current = 4,4 mA = 0,0044 A.

The accelerometer being used has a sensitivity of 100 mV/g and the application requires a full-scale range of 0 to 50g.

Given these parameters, let's figure out if we can meet the 2 000 ft. requirement.

Solution:

Step 1: Calculate total cable capacitance.

- $C_t = I / (2 \times \pi \times A \times F_{max})$
  $= 0{,}0044\ A / (2 \times 3{,}14159 \times (50\ g \times 0{,}1V/g) \times 10\ 000\ Hz)$
  $= 14\ nF$

Step 2: Convert C from nF/km to nF/ft.

- $C = (400\ nF / km) \times (1\ km / 3\ 281\ ft.)$
  $= 0{,}1219\ nF/ft.$

Step 3: Solve for L_{max}.

- $L_{max} = C_t\ [nF] / C\ [nF/ft.]$
  $= 14\ nF / (0{,}1219\ nF/ft.)$
  $= 114{,}85\ ft.$

This is not long enough to meet our 2 000 feet requirement! However, we might be able to make some adjustments:

1 Assume a lower A, or in other words, a lower full-scale range.
2 Use a lower F_{max} (depends on the Machine Condition Transmitter type being used, i.e., acceleration enveloping, band, etc.).
3 Use a better cable if possible. The capacitance per foot rating for this cable is actually pretty high, and it is not uncommon to find cable capacitances between 20 and 35 pF per foot.

- If we reduce A to 15g maximum, we can more than double the range, i.e., L_{max} = 383 ft.
- If we lower the cable capacitance to 20 pF/ft., we come up with L_{max} = 700 ft.
- If we do both of these, we get L_{max} = 2 335 ft. = 711 m, which more than meets the requirement.

Figure 3. The SKF Reliability Systems Machine Condition Transmitters (MCT).

Useful Tips

- 1 nF = 1×10^{-9} F
- 1 km = 3 281 ft.
- 1 pF = 1×10^{-12} F
- 1 ft. = 0,3048 m

Conclusion

This article outlines the approach used to calculate the ideal maximum possible cable length for a given frequency and voltage range, and a known cable capacitance. The relationship between these parameters was also given, along with sample calculations. The last example illustrates that a few iterations may be required to reach a solution. If the first solution will not work, then try different application parameters, if possible, to meet installation requirements.

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