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Kulite TD 1011
Maintaining High-Frequency Signal Transmission for Pressure Systems

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Silicon on Insulator (SOI) pressure sensors manufactured by Kulite are capable of measuring pressure over a very wide bandwidth. The transducer packaging and mounting will ultimately determine the highest usable bandwidth for a given installation.[1] However, the output of high-impedance transducers may only permit the transmission of the higher frequency signal content over relatively short cable runs. It is often necessary to transform the output resistance of a transducer to a low-impedance voltage source capable of low-noise, high-frequency transmission.[2] The system design engineer or test engineer must evaluate the complete signal chain with the measurement conditions and performance requirements in mind while planning any test requiring the high-speed measurement of pressures.

The two most important parameters to control when high-bandwidth transmission is required are the capacitance of the extension cable and the output resistance of the pressure transducer. See Equation 1 below for the formula used to estimate the pressure signal transmission bandwidth. The room temperature transducer resistance is typically reported as R_{OUT} on the calibration certificate. This value increases with temperature at a rate of about 10%/100° F for unamplified SOI transducers.

Equation 1:
$$-3\ dB\ (Hz) = \frac{1}{2\pi\ (C_{TOTAL})[(R_{OUT})+(R_{CABLE})]}$$

Nominal cable resistance is reported as the DC resistance at room temperature in ohms per 1000 feet on the cable technical specification sheet. Since the signal is transmitted via two conductors, the total resistance must account for the full loop resistance (R_{CABLE}) plus R_{OUT}. Larger conductors, that would lower the cable resistance, provide little improvement in bandwidth performance when the nominal output impedance of a transducer is 1,000 ohms and higher. Also, the temperature-induced resistance changes of the cable may be disregarded when estimating system bandwidth in all except a very few instances.

Capacitance is the most important performance specification of multi-pair instrumentation cable. The distributed cable capacitance is typically expressed in picofarads per foot (pF/ft) on the cable technical specification sheet. Many people use the conductor-to-conductor capacitance multiplied by the cable length to estimate the total capacitance of a cable as a simplified 1st-order approximation. Fortunately, the 1st-order approximation is usually within a few percent of the measured response for multi-pair cable and the initial estimate of transmission capability may be made with some confidence (-3 dB, ±10%). A typical installation example is presented later in this technical document.

In critical applications a more thorough analysis may be warranted. For multi-conductor cables, the conductor-to-conductor and the conductor-to-shield capacitance for every conductor and shield should also be included in the estimation. It is very important to dedicate each pair of conductors in the cable to each primary function (signal, excitation, and sense) to minimize noise pickup and to control the distributed capacitance and resistance of each balanced, differential signal.[3] The cable resistance estimation is also non-trivial as its distributed nature creates an apparent resistance that is considerably lower than the lumped resistance total. A full treatment of the methodology for estimating the total capacitance and resistance is presented in the technical paper developed by Precision Filters, Inc. of Ithaca, NY.[4]

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Using the 1st-order estimate, we will determine the -3 dB bandwidth of a typical wind tunnel installation using a 2-pair, shielded and twisted #24 AWG instrumentation cable with the following specifications. R_{OUT}, as measured across the green-white pair is 1200 Ω (at operating temperature). The overall cable length (test article to amplifier) is 150 feet. The nominal DC conductor resistance is 24.1 ohms per 1000 feet. The conductor-to-conductor capacitance is 25 picofarads per foot.

(R_{CABLE}) is estimated as 7 Ω resulting in a total resistance estimate of 1207 Ω. The total capacitance estimate is 3.75 nF. Completing the calculation of Equation 1 results in a -3 dB bandwidth estimation of approximately 35 kHz. It is important to keep in mind the -3 dB frequency signifies an attenuation of nearly 30% over the steady-state response and should be used primarily as a figure of merit. The magnitude of any frequency, also known as gain, transmitted by the pressure transducer may be estimated using Equation 2. As with similar RC passive circuitry, this value will be one at steady-state conditions with a gradual attenuation over increasing frequency. The process for converting this value to logarithmic gain in decibels (dB) is to calculate the base 10 logarithm of V_{OUT} and multiply by twenty.

Equation 2: $$V_{out} = \frac{1}{\sqrt{(1+(2\pi f R_{Total} C_{Total})^2}}$$

Kulite personnel are available to assist in the transducer/cable bandwidth estimation when the capacitance values are not available and can provide instructions and references to empirically measure the frequency response of a given installation.

Conclusion

A cost analysis of higher quality cabling versus local amplification may be in order if the installation bandwidth is deemed insufficient. Premium-quality cable may be an expensive proposition, especially for temporary installations, but installing cabling with lower overall capacitance is an option. Greater improvements are to be gained by dramatically lowering the source resistance than by incrementally lowering the cable capacitance. The output impedance of locally amplified transducers typically ranges from 10 to 200 ohms. The addition of an in-line amplifier such as the Kulite KEA Series (available at the time of order from Kulite) or relocating the stand-alone signal conditioner/amplifier system near the test section is the usual recommended practice for decreasing the attenuation of the dynamic pressure signal at higher frequency. It may be seen that increasing the usable bandwidth to a minimum of 100 kHz is accomplished in most instances by using local amplification.

References

[1] A.M. Hurst, et. al, "An Experimental Frequency Response Characterization of MEMS Piezoresistive Pressure Transducers," GT2014-27159, ASME Turbo Expo 2014, Düsseldorf, Germany June 2014

[2] "The Importance of Quality Signal Conditioning for Pressure Measurements," Kulite Semiconductor Products Technical Document TD-1008, 2020

[3] "Selecting the Appropriate Analog Output for Pressure Applications," Kulite Semiconductor Products Technical Document TD-1010, 2020

[4] A.R. Szary, et. al, "Methods and Procedures for Predicting Cable Roll-off in Sensor Measurements, Part 1: Full Bridge Measurements" Precision Filters, Inc., 2021

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