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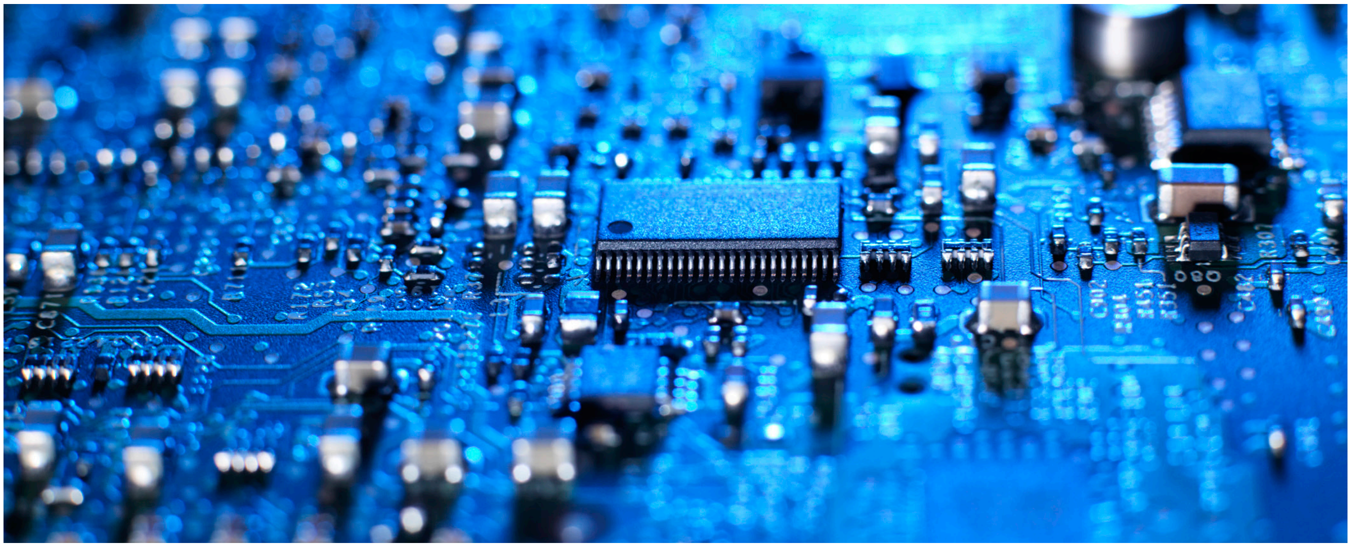

TN-32

How Impedance Relationships Influence Measurement Results

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How Impedance Relationships Influence Measurement Results

Impedance is the measure of the total opposition to current flow in an AC circuit and it plays an important role in most electronic systems. Measurement chains that include an ICP® signal conditioner are no exception. The relationship between the output impedance of an ICP® signal conditioner and the input impedance of a readout device is a critical point in the measurement chain. These impedance values can influence both frequency and amplitude measurement results.

ICP® signal conditioners have two different output types:

1. Unbuffered output: The output impedance of the conditioner is set by a series capacitor and a shunt resistor. This resistor forms a parallel circuit with the input impedance of the readout device (see Figure 1).
2. Buffered output: The output impedance of the conditioner is set by an operational amplifier located after the output resistor in the signal conditioner. In this configuration, the output resistor does not set the output impedance of the conditioner, and does not form a parallel circuit with the input impedance of the readout device (see Figure 2).

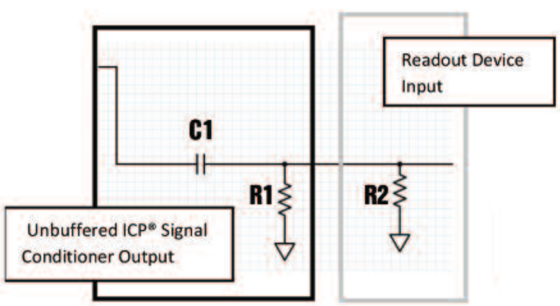

Figure 1 - Unbuffered Circuit Schematic

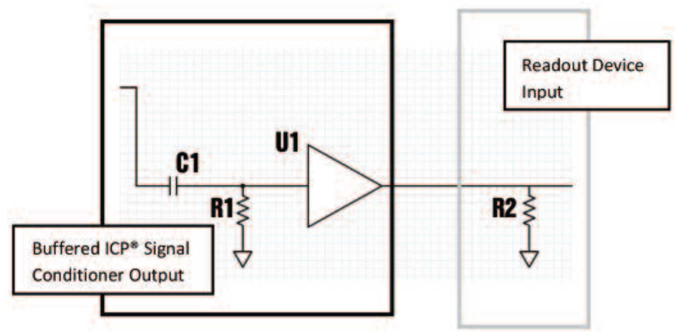

Figure 2 - Buffered Circuit Schematic

Key for Figures 1 and 2

C1 = Signal conditioner output coupling capacitor
R1 (in Figure 1) = Output resistor that sets the output impedance of signal conditioner
R1 (in Figure 2) = Output resistor of signal conditioner
R2 = Input impedance of readout device
U1 = Operational amplifier [buffer]

The specified input impedance value of data acquisition systems can vary. High impedance inputs, greater than 1MΩ, are not a concern for either type of conditioner output, unbuffered or buffered. Low impedance inputs, approximately 50Ω, are a concern for both types of conditioner outputs and each will be negatively impacted. For an unbuffered output the discharge time constant will get shorter, which impacts the low frequency response of the system. For a buffered output the amplitude of the signal decreases. This is further quantified in the following examples and equations.

Unbuffered Output

The discharge time constant (DTC) is calculated by Equation 1.

$$T = R \times C$$

Equation 1

Where:

T = Discharge time constant in seconds

R = Impedance in ohms

C = Capacitance in farads

C is the capacitance value of the signal conditioner output coupling capacitor. R is not the signal conditioner output impedance. The signal conditioner output impedance and the readout device input impedance are in parallel (Figure 1). This makes R the total parallel impedance of this portion of the circuit. The total R value is dependent on both the impedance value of the signal conditioner and the readout device. This is critical because the R value in the DTC equation is a system impedance. Total parallel impedance is calculated by Equation 2.

$$R_{Total} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Equation 2

Where:

R_1 = Output impedance of the signal conditioner

R_2 = Input impedance of the readout device

R_{Total} = Total parallel impedance

Examples 1 and 2 illustrate how the input impedance of a readout device affects the total impedance value of the parallel circuit when used with an unbuffered ICP® signal conditioner. The examples are based on component values similar to those used in unbuffered PCB® model 482C05.

Example 1.
Recommended – High input impedance on readout device

$R_1 = 357k\Omega$, $R_2 = 1M\Omega$, $C_1 = 47\mu F$

$$R_{Total} = \frac{357k\Omega \times 1M\Omega}{357k\Omega + 1M\Omega} = 263k\Omega$$

$T = R_{Total} \times C = 263k\Omega \times 47\mu F = 12.36s$

Example 2.
Not Recommended – Low input impedance on readout device

$R_1 = 357k\Omega$, $R_2 = 50\Omega$, $C_1 = 47\mu F$

$$R_{Total} = \frac{357k\Omega \times 50\Omega}{357k\Omega + 50\Omega} = 49.99\Omega$$

$T = R_{Total} \times C = 49.99\Omega \times 47\mu F = .00235s$

The specification of model 482C05 lists a discharge time constant of greater than 5 seconds with a 1MΩ load. Example 1 confirms that a very high input impedance [1MΩ] on the readout device will maintain the signal conditioner discharge time constant. Example 2 indicates that a very low input impedance [50Ω] on the readout device reduces the discharge time constant significantly to the point where it no longer meets the stated specification.

The discharge time constant establishes the low frequency response of the system. The R-C network of the signal conditioner and the readout device is a high pass filter that attenuates low frequency signals. Figure 3 is a plot of the typical low frequency and phase response. The theoretical lower corner frequency (F_0) will move lower or higher in frequency depending on the value of the discharge time constant. Figure 4 is a low frequency response table that includes some typical DTC values and their corresponding frequency amplitude points. Equations 3, 4 and 5 show the relationship between the DTC and frequency.

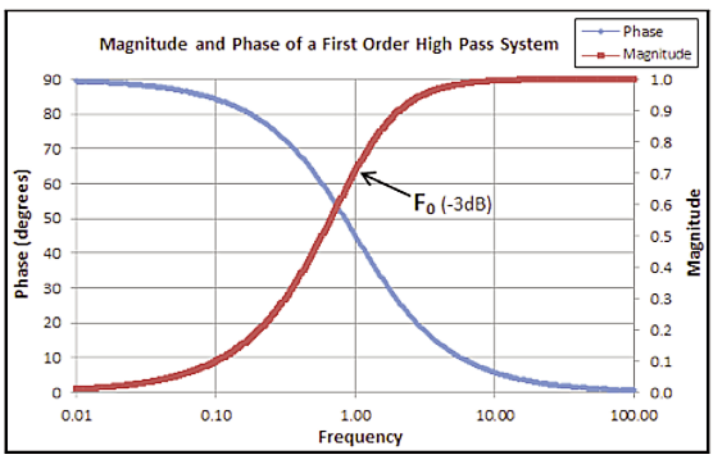

Figure 3 – Low Frequency Plot

DTC (sec)	Frequency (Hz)		
	-5%	-10%	-3 dB
.1	5	3.4	1.6
.5	1	.68	.32
1	.5	.34	.16
5	.1	.07	.03
10	.05	.03	.016

Figure 4 – Low Frequency Response Table

3dB down: $F_0 = \frac{0.16}{DTC}$

Equation 3

10% down: $F_0 = \frac{0.34}{DTC}$

Equation 4

5% down: $F_0 = \frac{0.5}{DTC}$

Equation 5

Continuing with previous examples 1 and 2, the low frequency responses are:

Example 1) -5% frequency point = $\frac{0.5}{12.36s}$ = .04Hz

Example 2) -5% frequency point = $\frac{0.5}{.00235s}$ = 213Hz

In Example 2, measurements below 213Hz will be attenuated by the high pass filter. The filter roll-off is at a higher frequency than the signal conditioner's specification. PCB® Model 482C05 has a frequency response specified as <0.1Hz. With a low impedance input on the readout device, this specification is no longer met. A 1MΩ readout impedance will guarantee that the low frequency response is maintained.

Buffered Output

A buffered output on an ICP® signal conditioner maintains the discharge time constant and low frequency response regardless of the input impedance of the readout device.

An operational amplifier is placed after the resistor at the output of the signal conditioner (the amplifier is U1 in Figure 2). This amplifier acts as a buffer and isolates the output resistor from the input impedance of the readout device. The resistor that typically sets the output impedance of the conditioner is no longer in parallel with the input impedance of the readout device. The placement of the amplifier negates any impact that the input impedance of the readout device has on the signal conditioner DTC or low frequency response. The DTC equation for the signal conditioner is the same as Equation 1 but R is no longer a system impedance that can be affected by the readout device. R is determined by other resistance values internal to the signal conditioner that are isolated by the amplifier.

A buffered output on an ICP® signal conditioner doesn't eliminate all of the signal transfer problems associated with a low impedance readout device. A low impedance input will still affect the measurement signal by decreasing the voltage amplitude. The operational amplifier acts as an impedance converter and sets the output impedance of the signal conditioner. The output impedance of a buffered PCB® signal conditioner is typically 50Ω or less (much lower than an unbuffered conditioner). This creates a problem because of the impedance and voltage values that make up the voltage transfer equation. Equation 6 shows this relationship:

$$V_{Out} = V_{In}\frac{R_2}{R_1 + R_2}$$

Equation 6

Where:

V_{In} = Voltage of measurement signal from sensor

R_1 = Output impedance of signal conditioner

R_2 = Input impedance of readout device

Examples 3 and 4 illustrate how the input impedance of a readout device affects the measurement signal amplitude when used with a buffered ICP® signal conditioner. These examples are based on the specifications of PCB® model 482C16 and a 5V full scale output from a sensor.

Example 3.
Recommended – High input impedance on readout device

$V_{In} = 5V$, $R_1 = 50\Omega$, $R_2 = 1M\Omega$

$V_{Out} = (5V)\frac{1M\Omega}{50\Omega + 1M\Omega}$ = 4.999V [99.98% signal transfer]

Example 4.
Not Recommended – Low input impedance on readout device

$V_{In} = 5V$, $R_1 = 50\Omega$, $R_2 = 50\Omega$

$V_{Out} = (5V)\frac{50\Omega}{50\Omega + 50\Omega}$ = 2.5V [50% signal transfer]

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Example 3 illustrates excellent signal transfer when the impedance of the readout device is 1MΩ. Example 4 demonstrates how a low impedance input will reduce a 5V signal to 2.5V. The low impedance input degrades the measurement signal and causes inaccurate measurement results. A high impedance value of 1MΩ is recommended for optimum signal transfer because it will ensure that signal amplitude is not decreased.

Signal transfer will be optimized for the majority of applications when a high impedance is selected on the input of the readout device. A high input impedance on the readout device is recommended for both unbuffered and buffered ICP® signal conditioner outputs. Degradation of the frequency response of the system is avoided because the discharge time constant will be kept long. The amplitude of the measurement signals will be maintained at accurate levels. It's important to understand how the input impedance of readout equipment affects the final measurement results. The input impedance of readout equipment should always be checked when setting up for a test. This is a best practice that will help prevent erroneous data and ensures that accurate measurement results will be obtained.

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