APPLICATION NOTE 503

HOW TO EVALUATE AND SELECT A DATA ACQUISITION & CONTROL SYSTEM FOR YOUR APPLICATION

Objective evaluation and subsequent selection of a computer-based data acquisition system is complicated by both the lack of industry standards regarding performance specifications the myriad of options available from the different manufacturers. Since most systems today have built-in intelligence, an inordinate amount of emphasis is placed on the system's "bells and whistles" further complicating the evaluation. However, because the system's primary function is to make measurements, the emphasis ultimately must be placed on those system attributes that directly influence the system's ability to perform this function. These include measurement accuracy, bandwidth and sensor compatibility. Regarding this, what criteria are meaningful in evaluating a system's performance? How can the engineer be assured that the comparison between manufacturers or products is fair? Are there other non-technical criteria that should be considered in selecting a data system?

Our intent with this document is to identify criteria and to establish guidelines that can be used to objectively compare the performance of different data acquisition systems. Because there are numerous options available which affect both cost and performance, the decision as to which system is best suited for a given application must be made by the end user. In Section 2 we discuss equipment specifications and present an interpretation of manufacturer's standard specifications as either fixed or variable errors. A technique is presented which can be used to predict total integrated performance based on a combination of these elemental errors. Section 3 describes a technique whereby the relationship between sampling rate and anti-alias filter can be quantified to establish a required bandwidth at a specified distortion level. Section 4 discusses flexibility issues from the viewpoint of analog and digital input capabilities and presents a system requirement checklist for several of the more commonly encountered analog inputs. Section 5 presents a cost-to-performance worksheet that can be used for comparing data acquisition systems.

SECTION 2
STATIC MEASUREMENT ACCURACY

2.1 INTRODUCTION

Measurement systems today consist of various subsystems such as sensors, signal conditioners, multiplexers, analog-to-digital converters, etc. To predict the total integrated measurement performance of a system comprised of several subsystems, the manufacturer's specifications for each of the subsystems are used. Error sources are identified, classified as either fixed or variable, quantified using the different manufacturer's specifications, and mathematically combined to establish a parameter termed *measurement uncertainty*.

Consider Figure 2.1 which illustrates a measurement chain consisting of n subsystems. As shown, each subsystem has various elemental errors denoted $e_{i,j}$. The classical method for computing the measurement uncertainty consists of the following:

1. Classify elemental errors e_i,j as fixed or variable;

2. For each subsystem, quantify the fixed component of uncertainty, $B_{i,j}$, using he Root-Sum-Square (RSS) technique:

$$Bj = \left[\Sigma\, e_{j,k}^{2} \right]^{1/2}$$

3. Establish total system fixed error component as:

$$B = \left[\Sigma\, e_{j,k}^{2} \right]^{1/2}$$

4. For each subsystem, quantify the variable component of uncertainty, S_j, using the RSS technique:

$$S_j = \left[\Sigma\, e_{j,k}^{2} \right]^{1/2}$$

5. Establish total system variable error component as:

$$S = \left[\Sigma\, s_j^{2} \right]^{1/2}$$

6. Compute uncertainty, U, based on the desired confidence level as:

$$U = \pm \left[B + t_{\alpha} S \right]$$

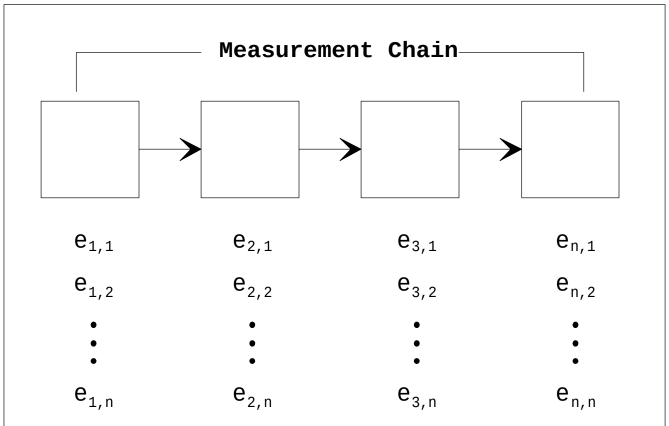


Figure 2.1 Measurement System Consists of Different Subsystems

Notes: *For 95% confidence, $t_a = 2$. For 99.7% confidence, $t_a = 3$.*

Whereas establishing the variable component S using the RSS technique is commonly practiced, quantifying bias is an engineering judgement. Depending upon the application, methods such as using the largest absolute value may be preferable.

In the following subsection on static measurement accuracy, we key on standard specifications and their classification and interpretation, methods for providing traceability to a standard laboratory and methods for transferring laboratory calibrations to the test facility. Finally, we comment on often overlooked error sources such as common mode and lead line resistance.

2.2 STANDARD SPECIFICATIONS

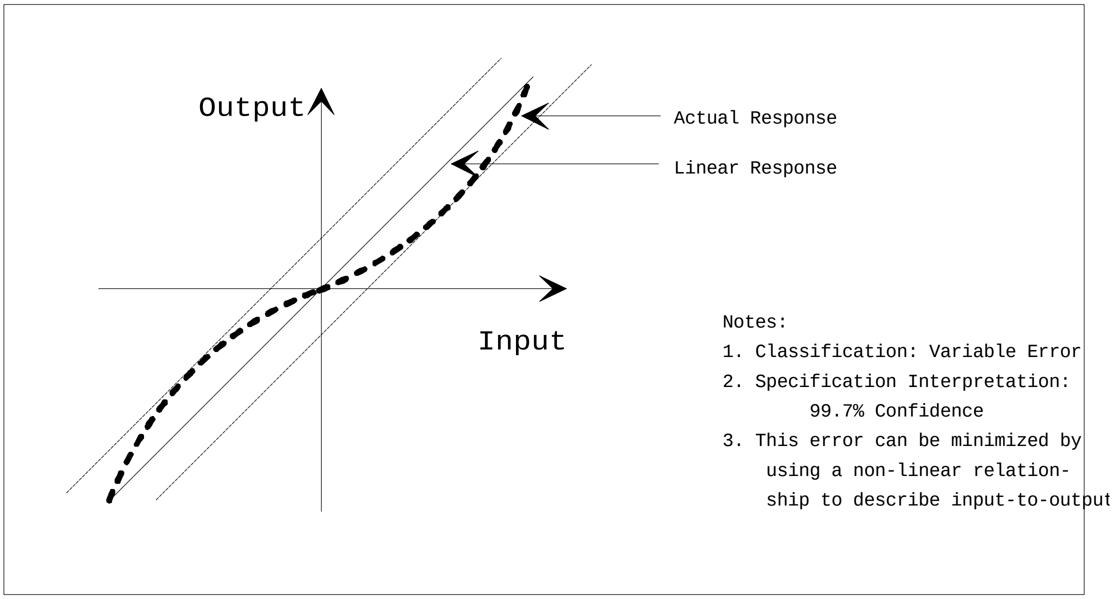
Standard data system specifications relating the performance of active elements include linearity, hysteresis, gain accuracy, offset, noise and drift. Of these, hysteresis, noise, stability and the thermal/time induced errors are considered fixed errors. It is important to note that at a given measurement value each of the non-variable error sources produce a fixed error. However, when each of these fixed error sources is considered over a measurement range, they produce variable errors (i.e., a set of fixed errors, which vary over the range). This distinction is critical if the errors are to be combined and used to compute measurement uncertainty. Several of the different errors are described below.

2.2.1 Linearity

Consider the input/output relationship illustrated by Figure 2.2, which depicts non-linearity as the deviation between the device's actual response and a linear response as established by the terminal points. The maximum deviation can be used to establish a specification for non-linearity over the range. As shown, error attributable to the non-linearity behavior varies over the range from near zero to the maximum value. Since we are confident that the error attributable to non-linearity over the range cannot be greater than this specification, we classify non-linearity as a variable error and interpret the specification as being a 99.7% confidence level specification.

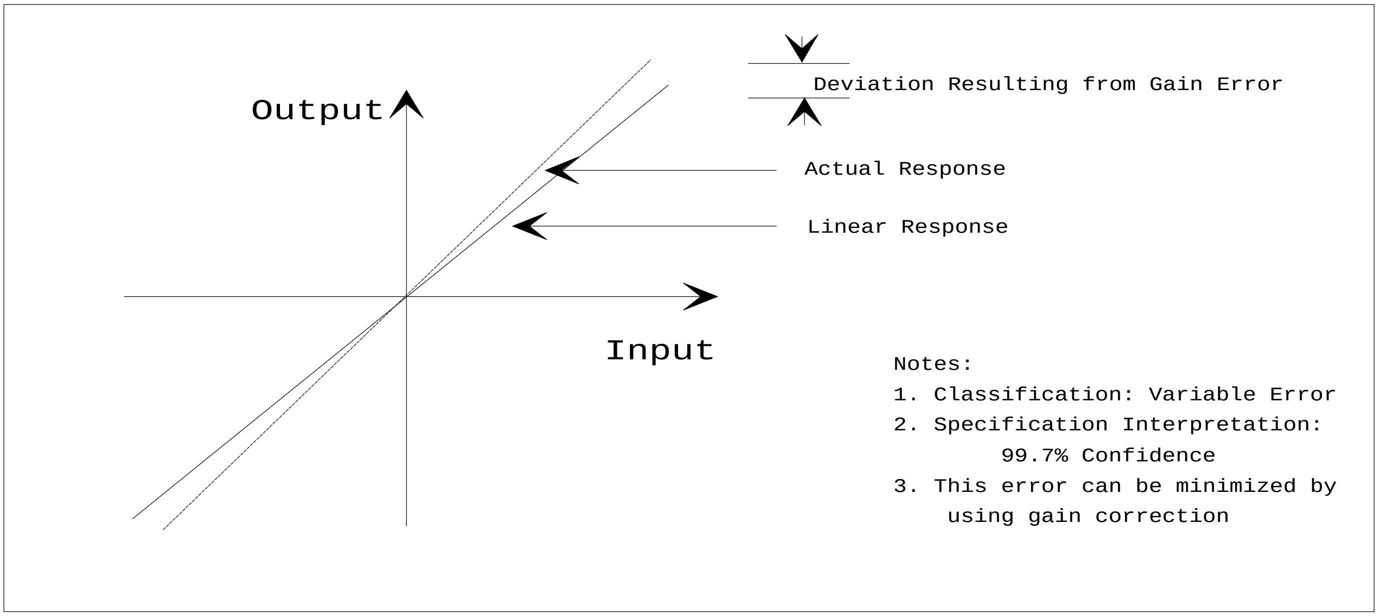
2.2.2 Gain Accuracy

Consider the input/output relationship illustrated in Figure 2.3. The error attributable to gain inaccuracy is fixed at a point but varies over the range. As with linearity, this error is classified as



Notes:
1. Classification: Variable Error
2. Specification Interpretation: 99.7% Confidence
3. This error can be minimized by using a non-linear relationship to describe input-to-output

Figure 2.2 Effects of Non-Linearity Over the Measurement Range



Notes:
1. Classification: Variable Error
2. Specification Interpretation:
99.7% Confidence
3. This error can be minimized by
using gain correction

Figure 2.3 Effects of Gain Error Over the Measurement Range

a variable error and the gain accuracy specification is interpreted as a 99.7% confidence level specification. This error can be reduced if a gain factor is computed and used or if the system's gain/zero adjustments are set according to a pre-defined procedure.

2.2.3 Hysteresis

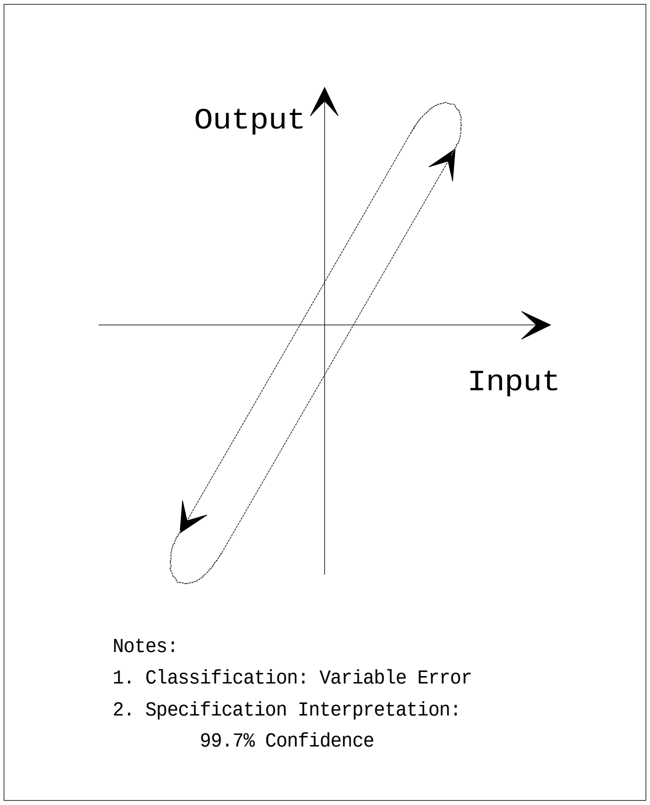
The effects of hysteresis are shown in Figure 2.4. This error is classified as a variable error and the specification is interpreted as a 99.7% confidence level specification. Generally speaking, it is impractical to reduce this error.

2.2.4 Noise

Of all the variable errors, noise is the only one that can be logically assumed to be random. Its magnitude over the measurement range is constant. Unless otherwise stated, the manufacturer's noise specification is assumed to be a 99.7% confidence level specification.

2.2.5 Thermal Induced Error

Thermal induced errors are classified as variable errors. To establish the magnitude, the manufacturer's specification which is generally stated in terms of % F.S. per degree is used in conjunction with an engineering estimate of the maximum temperature excursion. This error is interpreted as a 99.7% confidence level specification.



Notes:
1. Classification: Variable Error
2. Specification Interpretation:
99.7% Confidence

Figure 2.4 Effects of Hysterisis Over the Measurement Range

2.3 TRACEABILITY

Traceability is a key issue when absolute accuracies must be known, when correlation (either day-to-day or test facility-to-test facility) is important, or when measured data are used in a critical decision making process. Since it is generally impractical to perform a total-in-place calibration with sensor and data system, the current practice is to periodically calibrate the sensor in a metrology laboratory and to calibrate the data acquisition system in place. Regarding the data acquisition system calibration, the accepted technique involves inserting known analog inputs from a source whose calibration is traceable to a standard laboratory. By applying inputs over the measurement range, the data acquisition system's end-to-end performance can be quantified. The measurement system's fixed and variable errors determined in this manner must be combined with the voltage source's errors to establish total measurement uncertainty. This is further combined with the metrology lab's sensor calibration data to establish total measurement uncertainty.

Techniques commonly used with data acquisition systems depend on whether the system uses the amplifier-per-channel or the low level multiplexing technique. If the system uses the amplifier-per-channel technique, then calibration requires that an analog voltage be inserted at the amplifier's input and that the system be calibrated at one or more gain settings. This technique requires disconnecting each system input (normally electronically switched using a low ohmic device). If the system utilizes low-level multiplexing, then one input channel can be utilized to calibrate the system. With this type of data system it is not necessary to disconnect each input since all inputs share common equipment.

2.4 TRANSFERRING LAB CALIBRATIONS TO THE TEST FACILITY

2.4.1 Passive Sensors

Passive sensors are those requiring external excitation to produce an electrical output. Typical of these are strain gage transducers and RTDs. For such sensors the output is a direct function of excitation. To transfer a lab calibration to the test facility, it is critical that any changes in the excitation be compensated for. This applies to the excitation supply and all lead wire. Additionally, the lab's data system sensitivity will differ from the test facility and this must also be compensated for.

A widely used method for transferring lab cals with strain gage sensors is to use a resistive shunt technique. In essence, an imbalance is created within the laboratory by applying a precision resistor in shunt with one or more arms of the gage. If the same shunt resistor is applied in the test facility, then the test facility's data system can be adjusted (either excitation or gain) to produce the same results as the lab. This method of transferring cals is based on the following assumptions:

- Same shunt resistor is used (this includes effects of lead wire resistance as well as the shunt resistor).

- If only one arm is used, the assumption is that the bridge resistance when installed in the test facility is identical to the bridge resistance when calibrated in the laboratory.

For RTDs, an acceptable method of transferring cals is to substitute a known resistor in place of the RTD. With this technique, lab cals would take the form of resistance vs. temperature. If constant voltage rather than constant current excitation is used by the test facility data system, considerable care must be taken to minimize the effects of lead wire resistance.

2.4.2 Active Sensor

Active sensors are those not requiring external excitation to generate a signal. Typical of these are thermocouples and piezoelectric devices. For this class of sensor, transfer of lab cals is based on voltage measurement.

2.5 OTHER ERROR SOURCES

2.5.1 Common Mode Voltage

Common Mode Voltage (CMV) is defined as that voltage referenced to a zero potential point and common to both input signal leads. CMV results from a difference in zero potential between the sensor and the data system. For example, strain gage sensors that use a grounded power supply have a voltage common to each signal lead of V/2 where V is the gage excitation. Other sensors that use internal signal conditioning also produce a relatively high CMV (typically several volts). Regarding CMV, there are three different areas of concern. These are:

1. *Damage to equipment.* Data system specifications describe the maximum safe input voltage. With many of today's systems, this can be as low as ±10V.
2. *Conversion of CMV to Normal Mode.* Signal lead line imbalance in conjunction with a CMV can result in conversion of the CMV to a normal mode voltage that is indistinguishable from a data signal.
3. *Inherent Ability of the Differential Device to Discriminate Against CMV.* The differential device's ability to discriminate against CMV is specified as Common Mode Rejection Ratio (CMRR). The output e_o from the differential device expressed in terms of CMV and gain G is:

$$e_o - \log^{-1}\left[\frac{-CMRR}{20}\right] CMV \times G$$

2.5.2 Lead Line Resistance

Since the data system's input impedance is relatively high, the effects of lead line resistance is generally negligible. However, there are several exceptions. These include:

1. *Effects of Signal Lead Line Resistance for RTDs.* If constant voltage excitation is used, the effects of lead resistance can be significant for RTDs configured in either the 2- or 3-Wire arrangement. While this fixed error can be calibrated out, the calibration is valid only at that value of lead resistance. Any further lead line resistance changes attributable to temperature cannot be distinguished from a change in the sensor. Constant current excitation enables the RTD to be configured in a 4-wire arrangement thus eliminating this error.
2. *Effects of Excitation Lead Line Resistance.* If excitation is locally sensed, then the excitation at the sensor will vary if the lead line resistance changes. Remote excitation sensing eliminates this error source.
3. *Effects of Lead Line Resistance for Shunts.* The premise by which resistive shunts can be used to transfer laboratory calibrations to the test facility is based on the test facility shunt resistance being exactly equal to the lab shunt resistance. If the test facility shunt resistor is located within the data system and is thus remote from the sensor, the effects of lead line resistance affect the calibration transfer. Using additional wiring for the shunt in effect eliminates this error.

2.6 SUMMARY

A reasonable estimate of static measurement accuracy for several components integrated together to form a measurement chain can be established based on manufacturer's specifications. However, interpretation and classification of manufacturer's published errors is critical and depends upon whether the measurement uncertainty is to be established at a single point or over a wide range. If the consideration is over a range, then errors such as gain accuracy and non-linearity are considered to be variable and the manufacturer's specifications are interpreted as 99.7% confidence level specifications.

As used here, measurement uncertainty consists of an estimate of the fixed or bias error and some multiple of the variable error. If absolute accuracy is of concern, then the data system should provide a mechanism for transferring sensor laboratory calibrations to the test facility. This typically would include a secondary voltage standard, resistive shunts for strain gage sensors and resistance substitution for RTDs.

SECTION 3
BANDWIDTH

3.1 INTRODUCTION

With sampled data systems, the question that always surfaces is “How fast must I sample?” The question is valid since information is lost as a consequence of representing a continuum with a finite set of discrete samples. Thus, an immediate concern is with the number of samples it takes to reconstruct a reasonably accurate facsimile of the continuous input using this finite set of samples. Accordingly, one of the specifications most often touted by manufacturers is analog-to-digital converter (ADC) conversion rates with the implication that faster is better. Unfortunately, there is another aspect of sampling which often is neglected but which must be addressed in establishing required sampling rate.

What if our concern is not with graphically reconstructing the input from the samples but instead is with some other type of analysis such as frequency analysis such as frequency analysis or even with establishing a steady-state value representative of the time averaged input? Must we be concerned here also with the number of samples and sampling rate? Since there is not a unique relationship between sampled data and the time varying continuous input, improper sampling can produce distortion referred to as aliasing. Thus, we must be concerned with sampling even if our intent is to simply establish a single value representative of the averaged in-put. In the following subsections we discuss some of the major attributes of a sampled system which affect bandwidth. These include ADC conversion rate, anti-alias filter characteristics and aperture time.

3.2 THE RELATIONSHIP BETWEEN ANTI-ALIAS FILTER & SAMPLING RATE

Figure 3.1 illustrates in the frequency domain the relationship between input and output signals for a sampled system where the sampling frequency (f_s) was chosen to be twice f_c^*. The cutoff frequency, f_c^*, is that input frequency beyond which there is no detectable or measurable energy. As shown, the sampler output consists of an infinite number of sidelobes with no overlap and thus no distortion. According to the Nyquist Sampling Theorem, a signal that is ideally band-limited can be constructed from impulse samples if the sampling rate is at least twice the highest (or cutoff) frequency. With regards to data system specifications, the key words here are *band-limited and impulse sampling.* From this we can see that to answer the question of how fast to sample requires that we know the frequency beyond which no measurable energy exists. That is, we must know f_c^*. Using this, we can compute

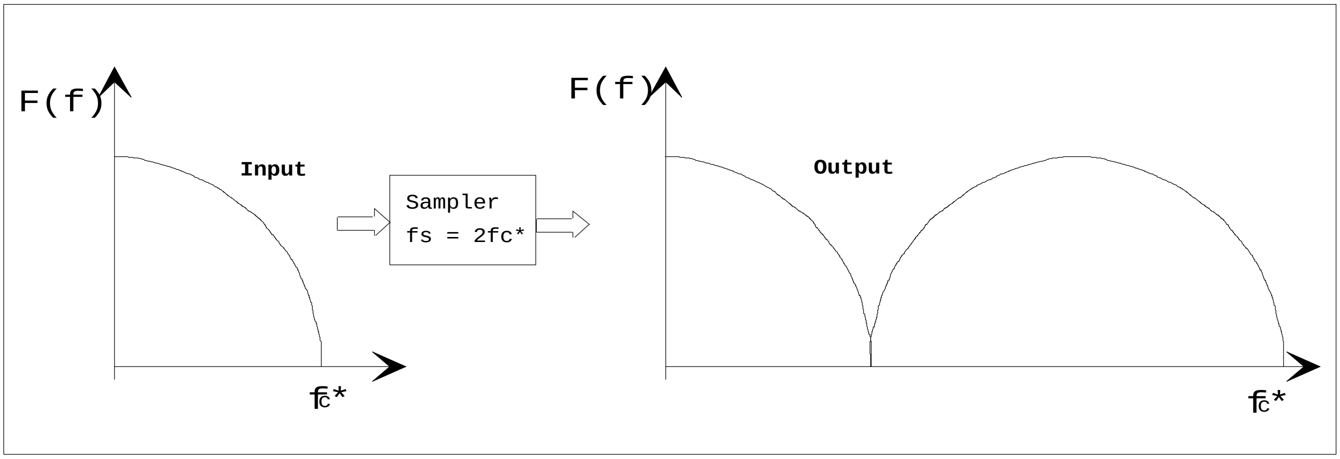


Figure 3.1. Relationship Between Input and Output Signals for a Sampled Data System

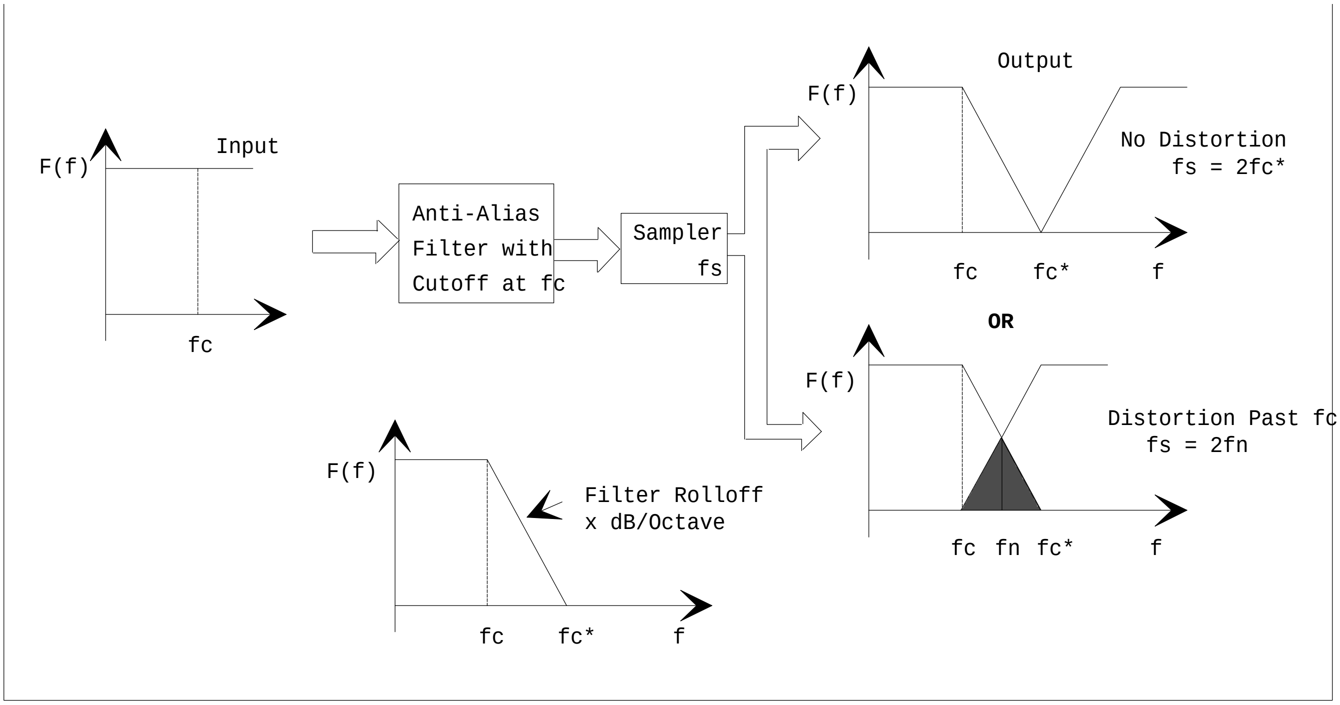


Figure 3.2 Relationship Between Desired Bandwidth, Anti-Alias Filter, and Sampling Rate

the minimum sampling rate f_s as:

$$f_s>2f_c^*$$

There are three options available in choosing sampling rate. First, the user can simply ignore this relationship and sample at whatever frequency he desires. The consequences are that the sampled data may contain significant distortion error that cannot be eliminated. The distortion error can even occur at zero frequency. Second, the user can determine the cutoff frequency f_s^* by analyzing each input with a spectrum analyzer and choosing f_s accordingly. The implied assumption with this method is that the observed spectrum will not change over the course of the test period. Third, the user can establish f_c^* by inserting an anti-alias filter prior to the sampler. With this technique the filter's cutoff frequency is selected based on the desired band of frequencies to be passed. Knowing the filter's well-defined attenuation characteristics, the frequency beyond which all energy is diminished to an acceptable level can be calculated and used to establish the required sampling frequency. Of these, the third option is the most conservative since it allows the user to quantify the maximum distortion in the bandwidth of interest.

The relationship that exists between the desired bandwidth, anti-alias filter attenuation characteristics and sampling rate is illustrated in Figure 3.2. As shown, the input signal to the filter is assumed to consist of equal amplitude energy at frequencies that extend beyond the highest frequency of interest denoted as f_c. With the filter's cutoff frequency set at f_c all frequencies beyond f_c are diminished in amplitude. The frequency beyond which there is no measurable (detectable) energy is denoted as f_c^*. If the ADC is a 12-bit, excluding sign, converter with full-scale input of ±10V, then the minimum voltage that can be detected is:

$$\text{Resolution} = 10\text{V}/2^{12} = 0.0024\text{V}$$

The converter's dynamic range is thus:

$$\text{Dynamic Range} = 20 \log 10\text{V}$$

For this application, -72.2dB is the required attenuation. For the chosen filter with attenuation specified in terms of dB/octave, we can compute f_c^* as:

$$f_c^* = 2^N f_c$$

Filter Attenuation	N	f_c*	$f_s^{(2)}$	f_n	$f_s^{(3)}$
1-Pole, 6dB/Octave	12	4,096	8,192	2,048	4,097
2-Pole, 12dB/Octave	6	64	128	32.5	65
6-Pole, 36 dB/Octave	2	4	8	2.5	5

NOTES:

1. f_c = 1Hz, 0dB = 10V, Required Attenuation = -72dB
2. Minimum f_s for no sidelobe overlap
3. Minimum f_s for no distortion in passband only

where N is the number of octaves and is given by

$$N = \frac{\text{Required Attenuation/Filter}}{\text{Rolloff Attenuation}}$$

There are two choices in selecting the sampling frequency f_s. If we want no distortion (sidelobe overlapping), then we can select f_s as $2f_c^*$. However, since we are not concerned about distortion above our desired bandwidth denoted f_c, we can select a sampling rate that will permit overlapping of sidelobes beyond f_c. To compute this sampling frequency, we establish the folding frequency f_n as:

$$f_n = ½(f_c + f_c^*)$$

Sampling frequency, f_s, is then computed as:

$$f_s = 2f_n$$

Table 3.1 summarizes these different results for three different filters: 1-pole, 2-pole and 6-pole. Here the desired bandwidth (f_c) is 1Hz. Each of the three filters has the cutoff frequency set at 1Hz. For simplicity, we have assumed that the filter introduces no distortion in the passband. It should be noted that this is a worst case since the input is assumed to have equal amplitude at all frequencies.

3.3 APERTURE TIME

A finite time is required by the ADC to convert from analog to a discrete value. If the ADC utilizes the integration technique, then conversion time is chosen to be a multiple of power line period. If the ADC utilizes the successive approximation technique, a finite time is required to make the various comparisons required. Regardless of which technique is used, a finite time is required. If the input is changing during the conversion time interval, then an error will be introduced. To reduce this error, ADCs often incorporate a sample and hold circuit that functions to capture and hold an instantaneous measure of the analog signal for the ADC. For low bandwidth applications,

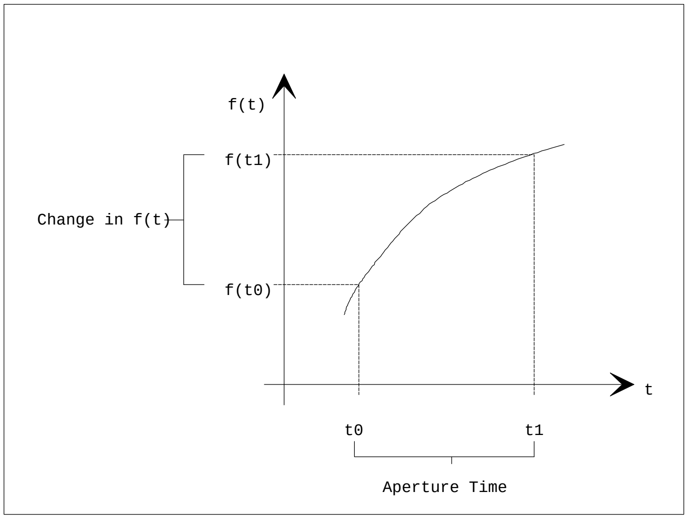


Figure 3.3 Error in Input Function Resulting from Aperture Time

the error introduced by aperture time is generally considered insignificant.

The classical technique for approximating amplitude error resulting from aperture time is based on the point-slope technique (Figure 3.3). If t_0 denotes the beginning of the digitization which continues until time t_1, the input function will change by an amount equal to $f(t_0) - f(t_1)$. This can be approximated as:

$$\delta f = (df(t)/dt)\Delta T$$

where ΔT is aperture time. If we assume that the input is of the form

$$f(t) = f^0 + A \operatorname{Sin}(\omega t)$$

Where f_0 is a constant and ω is angular frequency defined as

$$\omega = 2\pi f$$

then the time derivative is

$$df(t)/dt = A\,\omega \cos(\omega t)$$

Since $|\cos(\omega t)| \leq 1$, maximum value of the derivative is $A\omega$

Thus

$$|\,\delta f\,| \leq A\omega\Delta T$$

This equation can be used to estimate the error (δf) resulting from a fixed aperture time ΔT for an input signal of frequency ω and amplitude A. Conversely, the equation can be used to establish a specification for aperture time based on maximum error δf.

3.4 CHANNEL-TO-CHANNEL CORRELATION

If channel-to-channel correlation is critical, then it may be necessary to incorporate a sample and hold circuit for each channel depending upon sampling frequency and bandwidth. However, for low bandwidth applications, this is generally not a requirement.

3.5 SUMMARY

There are no simple answers to the question of “How fast must I sample?" As stated above, improper sampling can produce distortion even at zero frequency. Furthermore, once sampled, there are no techniques to eliminate these errors. Accordingly, the answer to how fast to sample depends upon the desired bandwidth, the anti-alias filter’s characteristics and the amount of acceptable distortion in the passband.

SECTION 4
SENSOR COMPATIBILITY

4.1 INTRODUCTION

Data acquisition systems generally remain in active use for 10-15 years. Unfortunately, the measurement requirements for most testing applications are not fixed. New improvements in sensors coupled with changing test needs suggest that an important criterion to consider when selecting a data system is sensor compatibility. Will the system accommodate changes in inputs or different sensors? Can the bandwidth be changed? Can the gain on each channel be changed? Can the scan list be changed? Can the sampling rate be changed? In the following subsections we address several areas where flexibility is considered critical.

4.2 ANALOG INPUTS

A general-purpose measurement system today should have the capability to accommodate strain gage sensors, different types of thermocouples, RTDs, etc. Regarding analog inputs, the capability to accommodate a variety of different inputs requires that the system have certain attributes.

Table 4.1 presents an overview of required system characteristics that should be considered from a sensor compatibility or flexibility point of view. The table is not intended to be all-inclusive but rather to point out several of the more critical attributes. System characteristics affecting measurement uncertainty have been excluded with the exception of the power supply. Specific comments regarding each major system attribute affecting analog sensor flexibility are presented below.

4.2.1 Power Supply

The power supply is a critical element for passive sensors such as strain gages and RTDs since the sensor output is a direct function of applied excitation. Some systems share a common power supply whereas others have a dedicated power supply for each channel. If a common power supply is used, then the consequences of multiple sensor failures must be considered.

Mode and Sense. While constant voltage with remote sense is typical, constant current is important if the effects of lead resistance are to be compensated for. It should be noted that constant current is required if an RTD is to be input in the more accurate 4-wire configuration. Remote sensing of excitation at the sensor aids in compensating for changes in lead resistance.

Grounded. If a grounded power supply is used, then consideration must be given to CMV (a strain gage using a grounded power supply has a CMV equal to one-half the applied excitation).

Regulation and Noise. Both directly affect the measurement accuracy for sensors such as strain gages and RTDs. The effects can be calculated and used as a basis for establishing these specifications.

4.2.2 Signal Conditioning

Wiring Configuration. Various wiring configurations are offered ranging from 4-wire to 10-wire. The 4-wire configuration restricts the user to local excitation sense and limits the usefulness of remote shunting. On the other extreme, the 10-wire provides the greatest flexibility by providing separate wiring for the sense leads and four separate leads for remote shunt.

Remote Shunt. There are numerous variations ranging from a simple one-position to double shunts in increments. The key element is to provide easy removal of the shunt resistor for calibration by a metrology lab and to provide adequate input wiring (i.e., 8- or 10-wire systems). Remove activation of the shunt is essential for automatic calibration.

System Attribute		**ANALOG INPUT**				
		Strain Gage	**RTD**	**Thermocouple**	**High Level Sensors**	**Voltage or Current**
Pwr Sup	Constant V	●			●	
	Constant I	●	●			
	Remote Sense	●				
	Range	●				
	Per-Channel	●			●	
	Grounded	●			●	
	Regulation	●				
	Noise	●				
Sig Cond	Wiring Configuration	4,6,8,10W	2-W,3-W,4-W			
	Bridge Completion	●				
	Remote Shunt	●			●	
	Resistor Substitution		●			
	Balance	●				
Preamp	Differential	●	●	●	●	●
	Max CMV	●		●	●	●
	CMRR	●		●	●	●
	Gain Adjustment	●	●	●	●	●
	Range	●	●	●		●
Filter	Type	●			●	●
	Change Cutoff	●			●	●
	No. Poles	●	●	●	●	●
ADC	Sample & Hold	●			●	●
	Rate	●	●	●	●	●
	PGA	●			●	●
	Interface	●	●	●	●	●
Other	Voltage Calibration	●	●	●	●	●
	Input Cabling	●	●	●	●	●

Table 4.1 System Requirement Checklist for Analog Input Flexibility

Resistance Substitution. For RTDs, substituting a fixed value of resistance for the sensor provides a fixed upscale test point.

Bridge Completion. For systems that offer only constant voltage excitation, RTDs are generally configured as one arm of a Wheatstone bridge. The signal conditioning should have the capability of providing the other three inactive arms to complete the bridge.

Balance. Resistive balance is the most common technique used. The ability to hardware compensate for non-zero outputs enables maximum use of the system's dynamic range. The technique can, however, introduce a non-linearity error if the value of R is improperly chosen.

4.2.3 Preamplifier

As stated elsewhere, one feature that is used to distinguish data systems is the input preamplifier. Not all systems have a dedicated amplifier-per-channel and thus are limited to providing only passive anti-alias filters.

Max CMV and CMRR. The maximum CMV is a critical concern for several input sensors. As noted above, strain gage sensors that use a grounded power supply have a CMV equal to one-half the excitation. This CMV is converted to a bias error (offset) in accordance with the amplifier's CMRR. Considering the proliferation of solid state sensors, both of these specifications become increasingly important. There are solid state sensors whose rated output is ±5V but which exhibit CMV of 5-7V. If the maximum input voltage is rated as ±10V, then possible damage can result.

Gain Adjust. One of the most significant static error sources results from gain inaccuracy. For flexibility, the system should have the ability to either manually trim each channel's gain or to provide gain compensation through software.

Range. For maximum flexibility, a wide input voltage range is important. Typically, full scale input range from ±5mV to ±10V. Provision for changing the preamplifier gain with hardware or software is necessary.

4.2.4 Filter

To accommodate a wide range of bandwidths, the filter should incorporate a method for changing filter cutoff frequency. Critical considerations are the filter type (e.g., Bessel, Butterworth, etc.) and its rolloff characteristics. It should be noted that systems that do not use an amplifier-per-channel are restricted to using simple passive filters. Additionally, since there is no buffering between the sensor and the passive filter, the sensor's output impedance and cabling capacitance affects the filter's cutoff frequency.

4.2.5 ADC

S/H. Depending upon the incoming signal bandwidth, a S/H may be required to reduce the error that results from non-impulse sampling. The maximum aperture time can be computed as a function of frequency and allowable error and used to establish this specification. Maximum flexibility results when the system includes a S/H.

Rate. The required conversion rate is a function of desired bandwidth, anti-alias filter attenuation, and allowable dynamic distortion. Other factors which influence this specification are total number of channels (used to establish aggregate bandwidth) and processor interface. For example, improved filtering reduces the sampling rate requirement that in turn relaxes both the processor interface and application software burden.

4.2.6 Other

Voltage Calibration. Inserting known inputs using a secondary or traceable voltage standard to establish the uncertainty associated with measuring analog voltages is considered essential regardless of the type of analog input.

Input Cabling. Using barrier strips or individual channel connectors to terminate input sensor wiring provides flexibility in changing inputs and in isolating measurement problems.

4.3 DISCRETE INPUTS

General-purpose measurement systems today must have the capability to accommodate a wide range of discrete inputs. Data system inputs can come from control panel logic switches, process limit switches (such as pressure, temperature, or position) and instruments which provide a digital input. The specific areas of concern regarding discrete inputs are listed below.

Level. The source voltage level and impedance must first be established before specifying data system input. For reliable operation, sensors that use TTL output stages require data system inputs designed for TTL compatibility. Voltage levels commonly used, excluding TTL devices, are 5V, 12V, 24V and 48V. Provisions for selecting the logic level (i.e., positive-true or zero-true) is desirable from a flexibility viewpoint.

Latching. Instruments incorporating digital outputs (e.g., counters, DVMs, etc.) Which are to be input to the data system must be equipped with an output storage register and logic signals which indicate when the output data are valid. This is necessary to avoid reading the instrument output during a transitional stage. For flexibility, the data system input should provide a hardware logic interface to accommodate this type of data input.

Debounce. Discrete inputs derived from mechanical switches or relays are subject to bouncing. For reliable reading of these type inputs, some method of hardware debouncing is required.

Isolation. To avoid ground loops and problems caused by CMV, isolation is a desirable system characteristic.

4.4 OUTPUTS

System outputs may be used for annunciation, alarming, on-off control or continuous control. For flexibility the system should have the capability of providing TTL outputs, Form-C relay outputs and analog outputs. To avoid ground loops, isolated outputs are desirable.

4.5 SUMMARY

For the majority of test applications, changes over the life of the data system are inevitable. If the data system does not provide the capability to accommodate a wide range of inputs, then external equipment must be purchased and integrated to accommodate the new requirement.

SECTION 5
SUMMARY

There are two major classifications of multi-channel data acquisition systems -- low level multiplexing and amplifier-per-channel. It is of interest to note that systems in both classifications exhibit comparable static measurement accuracy yet have vastly different bandwidth capability. Since amplifier-per-channel systems multiplex high level rather than low-level signals, they typically utilize active anti-aliasing filters. The active filters provide both a wide range of cutoff frequencies and increased attenuation. The net result is increased bandwidth at a reduced sampling rate.

In evaluating data systems, the engineer must sort through different manufacturer's marketing literature and specifications to determine whether parameters and system attributes critical for it is low level multiplexing or an amplifier-per-channel system as well as to isolate those parameters and system attributes critical for his application. Regarding this, Table 5.1 is presented as an aid in isolating each system's major attributes and critical performance parameters. The intent here is that the engineer would complete a worksheet for each system to be considered. Depending upon the application, some characteristics may be more critical than others. For comparison purposes, an arbitrary weight can be assigned each item in the checklist. The weighted value represents the criticality of that system characteristic for the specific application. The weights are then used to establish a score for each system being considered. An objective selection of the most cost-effective solution for the given application can then be made using the cost and total score.

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