ANALOG DATA ACQUISITION – FLEXIBILITY OR PERFORMANCE?

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ABSTRACT

When acquiring data from analog sources there has always been inherent trade-offs between accuracy, bandwidth, channel count and flexibility. Depending on the sensor type and application one or more of these attributes will be more important than the others. Having a catalog of acquisition cards each one optimized to a particular attribute has allowed the FTI engineer to select the optimal balance for his application. Today, there is increasing pressure on designers and manufacturers to provide a one size fits all approach, with very high accuracy, bandwidth, channel count and flexibility all in one card. This paper discusses the trade-offs between dedicated and generic hardware and concludes that although a generic card can have very high specifications, end users need to be aware that there are significant advantages to using dedicated hardware that may outweigh the flexibility benefits of a generic solution.

INTRODUCTION

Analog data acquisition has traditionally been designed in such a way that each channel offers the best performance and accuracy for a given sensor type or application while maximising the bandwidth and channel count. This approach requires the designer of the cards to have a stable and modular system architecture, a mature design flow, and a proactive approach to customer requirements in order to build up a catalogue of cards each of which is optimized for a particular sensor or measurement type. The benefits therefore of a single analog card, which could replace the need for this extensive catalogue of cards is of huge interest to vendors of data acquisition solutions.

This paper examines the design of such an analog data acquisition card with generic channels, each of which can be configured to accept any analog sensor and make any analog measurement. It investigates what the trade-offs are in terms of performance, functionality and channel count. The data acquisition card under consideration would have the existing connector and form factor for a particular Data Acquisition Unit (DAU). This would allow clear comparison with existing dedicated solutions and allow the card to be used in any existing chassis and configuration in tandem with the hundreds of other data acquisition cards currently supported.

EXISTING SOLUTIONS

Analog data acquisition covers a wide variety of sensors and interfaces. Before the cost and benefits of a one size fits all approach are discussed, the variety of different sensors and measurements that are needed by an FTI engineer should be examined. Acceleration, vibration, strain temperature, pressure, attitude and displacement are among the many measurements types taken during flight test. Depending on measurement range, cost and accuracy requirements, numerous different approaches and sensor types can be used for each of these measurement types.

Acceleration and vibration are often measured by a piezoelectric sensor**.** A piezoelectric sensor converts stress into charge. In order to convert charge into voltage such that the measurement can be captured the data acquisition card is required to have a charge-sensitive preamplifier. Some sensors, called IEPE (integrated electronic piezoelectric accelerometer)[1], contain electronic amplifiers and output voltage instead of charge removing the need to have a charge-sensitive preamplifier on the acquisition card. IEPE sensors tend to have a DC offset which requires some high pass filtering at the input to the card.

Strain and vibration are often measured using the humble strain gauge. The most popular configuration is the full Wheatstone bridge [2] with voltage excitation. Voltage excitation can be unipolar or bipolar. Bipolar is usually preferred as it gives better performance with temperature drifts. An alternative to using voltage excitation is to use current excitation. Current excitation offers better linearity and immunity to lead resistance. Of course the lead resistance can also be removed when using voltage excitation by using sense lines. These lines pull the top and bottom of the bridge to the desired voltage by compensating for the voltage that is lost in the lead wires. This however turns a 4 wire interface into a 6 wire interface. While the full bridge option gives the best accuracy and immunity to temperature variations for reasons to do with ease of installation and wiring sometimes the FTI engineer will use half or quarter bridge. On top of this an installed bridge may show a known deflection. The ability of the data acquisition card to balance or zero out this deflection can be a very useful feature. Also to mitigate the risk of flight data being corrupted due to faulty wiring or a faulty strain gauge, the data acquisition card may have the ability to shunt in a known resistance across the strain gauge before the flight begins. This shunted resistance will cause a deflection to be seen on the channel. The absence of such a deflection will alert the FTI engineer to the presence of any potential issue.

For temperature measurement the three main options are thermocouple, resistance temperature detector (RTD) and thermistor. RTDs have a smaller range of operation and slower response than thermocouples. However they tend to be more accurate and more stable. Thermistors have a smaller range than both RTDs and thermocouples but are the cheapest of the three options. All three measurements tend to be non-linear. This can be compensated using a linearization table in the data acquisition card. Another consideration is the fact that thermocouples measure the temperature difference between two junctions (measured and reference), not absolute temperature. To calculate the absolute temperature it is necessary to compare this measured temperature difference with the known value of the reference junction. The reference junction is typically measured using an RTD.

Angular displacement and velocity is typically measured using synchros and/or resolvers and linear displacement is measured using linear variable differential transformers (LVDTs). In its basic form, synchros are specially wound rotary transformers with the stator windings typically fixed. The primary winding of the transformer, fixed to the rotor, is excited by an alternating current, which by electromagnetic induction, causes currents to flow in three star-connected secondary windings fixed at 120 degrees to each other on the stator. From these three currents the data acquisition card can calculate the angle and angular velocity. A resolver is similar to a synchro, but has a stator with four leads.

There is of course a whole range of other sensors that capture other measurements such as pressure, linear displacement, liquid levels, battery life as well as some of these measurements mentioned previously. These sensors come with many outputs. For example, 3 wire potentiometer, 2 wire differential voltage, 1 wire single ended voltage, 3 wire current loop and 2 wire current loop. Each of these sensors will have different voltage range and different sample rate and filtering characteristics.

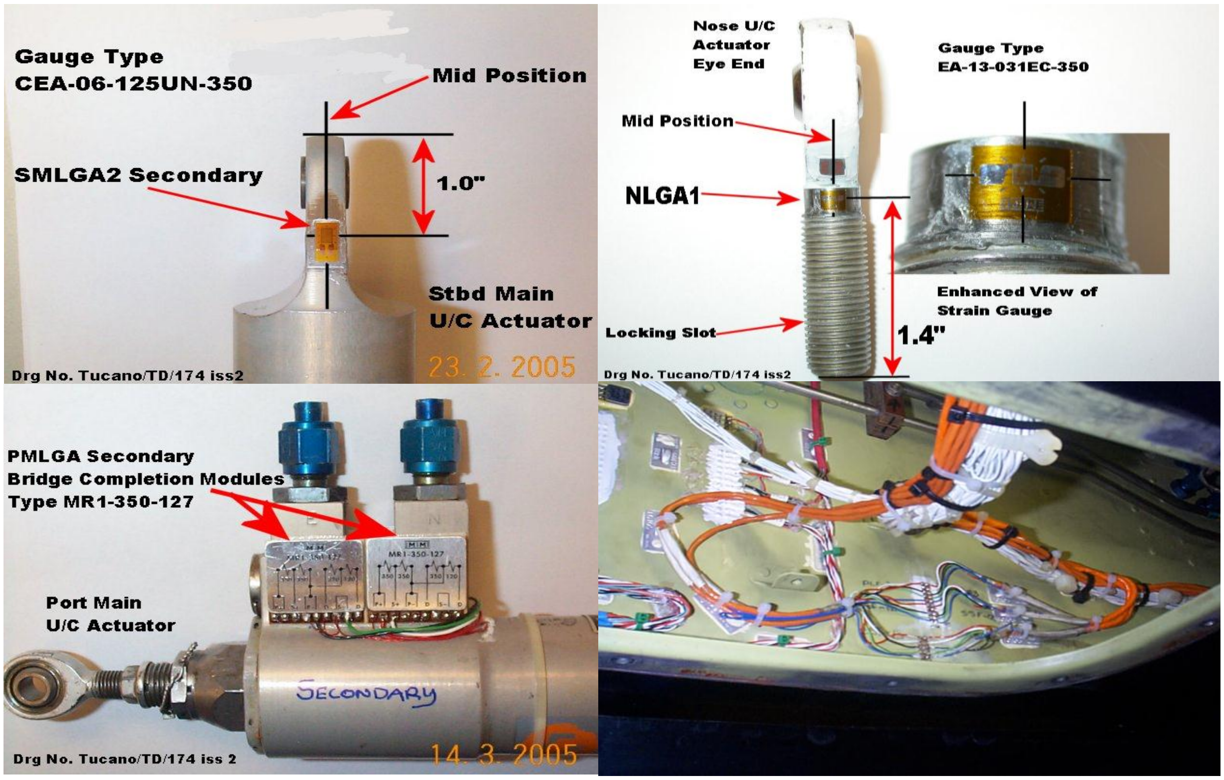

Figure 1: Sensors and wiring considerations inform module selection

Certainly there is some flexibility in existing solutions. Some channels can already handle multiple measurement types, for example strain gauge and differential voltage can be measured by the same channel. Other flexibility exists in terms of input range. Many measurement channels offer several decades of analog gain. In terms of one acquisition card handling many different sensor or measurement types there are hybrid modules which can measure say temperature on one channel and strain on another. However, the individual channels themselves would not be configurable to measure strain or temperature.

CONSIDERATIONS

Today's leading edge FTI data acquisition card has to meet a lot of demanding performance specifications. First and foremost it must be rugged and must survive in harsh environmental conditions and temperatures. After that comes a host of considerations including resolution, DC accuracy, SINAD, aliasing, crosstalk, sharp filtering, sample rate, synchronous sampling, common mode rejection ratio, input impedance and over voltage protection.

Aliasing refers to an effect that causes different signals to become indistinguishable (or *aliases* of one another) when sampled. Once any noise is aliased into your signal it will be impossible to distinguish it from your signal. For baseband signals the sampling theorem [3] states that aliasing does not occur if the highest frequency component is less than half the sampling rate. When the measurement moves from the analog domain to the digital domain and when the sample rate of the measurement is programmable you can encounter an aliasing issue. If you oversample the data with a high bandwidth A/D and use cascaded half band decimate by 2 filters in the digital domain many decades of filtering can be offered while maintaining anti-aliasing in excess of -72 dBs. The shape of the digital filter is also of importance. Previously filtering had been done in the analog domain. Moving to the digital domain allowed increases in flexibility in terms of frequency response of the filter, decreases in temperature drift and increases in channel count. However some FTI engineers want the digital filters to have the same shape as the older analog filters. 8^{TH} order Butterworth filters offer similar frequency and phase responses to older analog filters. However the linear phase response of FIR filters makes these filters a preferred choice for some.

Common mode rejection ratio is another important feature. Using twisted pairs and matched signal wires will help ensure that the majority of the environmental noise gets conducted equally on both leads and that common mode noise is a large percentage of the conducted noise. A data acquisition card with a high common mode rejection ration will then reject the majority of this common mode noise. High specification data acquisition cards will have CMRR specifications in the region of 90 dB.

Crosstalk is any phenomenon by which a signal captured on one channel of a data acquisition card creates an undesired effect in another channel. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one channel to another. It can be minimized by careful placement of components and routing of tracks on a PCB. High channel counts or high component count per channel can make maintaining crosstalk figures in the region of -90 dB very challenging. Flexible channels by nature of their configurability and multiple functions tend to have significantly more components than dedicated channels that only handle one type of measurement.

Intra chassis time correlation of sampled data has always been straightforward when parameters sampled at the same rate are sampled at exactly the same point in time. Designing every analog channel so that it has its own antialiasing filter, instrumentation amp, analog to digital converter and programmable digital filter allows simultaneous sampling of every channel in a system. Even when several channels are sampled at different sampling rates, because they are done so at the start of the acquisition cycle, all channels will be aligned as seen in Figure 2. Intra chassis accuracies have for some time been sub 100 ns. The IEEE 1588 protocol [4] enables inter chassis time correlation to now be sub 100 ns. This means every channel in the system is sampled to an accuracy of sub 100 ns.

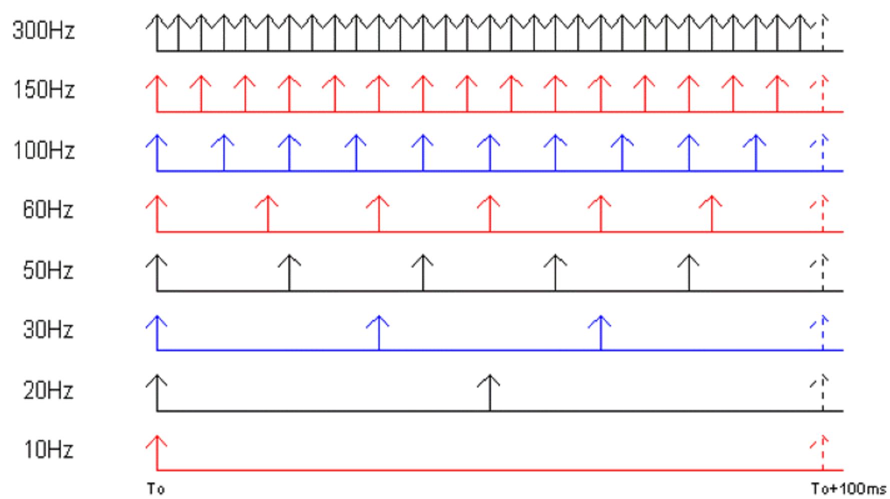

Figure 2: Sampling different data rates in an acquisition cycle

During installation and testing a data acquisition channel may occasionally be exposed to voltages outside its normal operating range. If the channel is damaged as result of this then considerable time and expense will be spent replacing the card. Overvoltage protection of +/-40V allows all channels to survive exposure to any voltage commonly found on aircraft.

A low input impedance on the data acquisition card may cause the card itself to affect the measurement value. On top of this depending on how an aircraft is wired up, a low input impedance may affect the measurement on a different card. This is avoided by having input impedance of several mega ohms whether the chassis is powered on or off.

Resolution and accuracy are probably the most important features of the analog data acquisition card. Todays data acquisition cards typically have a resolution of 16 bits. There are several different ways of representing accuracy. DC accuracy is typically represented as the % error over the full scale measurement range. High specification cards will have DC accuracy better than 0.1 % FSR across the full temperature range. AC accuracy includes both noise and total harmonic distortion and is represented by signal to noise and distortion ratio (SINAD) or the effective number of bits (ENOB) [5]. ENOB specifies the number of bits in the digitized signal above the noise floor. High specification cards will have ENOB in excess of 13 bits across the full temperature range.

ANALYSIS & PROTOTYPE

The first phase of this investigation involved an analysis of all existing data acquisition card types, features and specifications and the identification of any of these that would not be possible in a generic channel. Some sensor types including piezoelectric sensor (without built in electronic charge amp), synchros, resolvers and LVDTs were judged unsuitable. For piezoelectric sensors the presence of the charge amp on the data acquisition card means that special cables and connectors need to be used to ensure that no excess charge is generated which would spoil the accuracy. Synchros and resolvers typically require a separate converter chip to convert the amplitude signals to a digital angle and velocity. On top of this when the signal, reference and excitation lines are considered synchros can have up to 7 pins per channel and resolvers can have up to 8 pins per channel. This would be too many extra pins to accommodate on a generic channel. LVDTs have 4 input voltages and often require AC excitation making them unsuitable for a generic card.

Some features including sense lines to compensate for lead resistance for voltage excitation were excluded. The presence of these extra 2 wires per channel would have limited the channel count. The analysis also estimated the amount of channels that it was possible to fit into the standard DAU used in these test – an Acra KAM-500 from Curtiss-Wright Controls Avionics & Electronics (CWC-AE). Due to the extra components required to make the channels generic 8 channels was the most that it was possible to fit on the PCB.

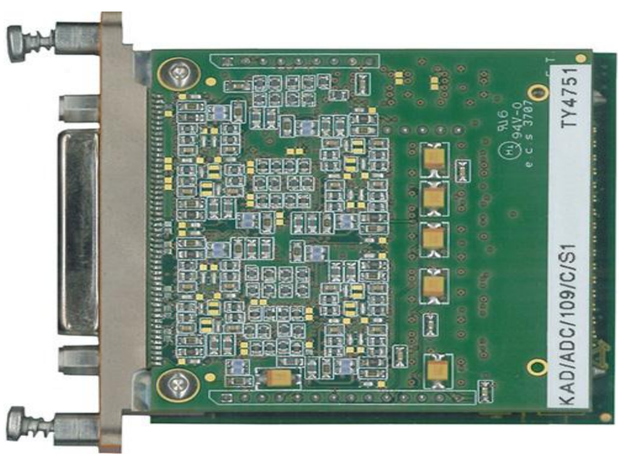

Figure 3: Prototype uses an Acra KAM-500 form factor

The second phase of the investigation involved the building of a prototype. The following measurement types were supported in the prototype, single ended voltage, differential ended voltage, full bridge, half bridge, quarter bridge strain gauge, IEPE, RTD, thermocouple and potentiometer, while providing constant current or constant voltage excitation programmable per channel. Features included input impedance of mega ohms, +/- 40V overvoltage protection, strain gauge shunt and strain gauge balance and choice of filtering type. In terms of performance it was the design goal was such that no degradation of CMRR, crosstalk, SINAD, DC accuracy or anti-aliasing would be noted.

It was shown that a generic channel could be designed to be single ended voltage, differential ended voltage, full bridge, half bridge, quarter bridge strain gauge, IEPE, RTD, thermocouple and potentiometer without compromising on performance. The measured performance was consistent with the design goals such that it was possible to get ENOB better than 13 bits, DC accuracy better than 0.1% FSR and CMRR better than -80 dB. On top of this it was shown that it is possible to offer a choice of 8^{TH} order Butterworth IIR or FIR digital filter while maintaining aliasing in excess of -72dB by using mature off the shelf IP which has been used in tens of modules and involved in hundreds of successful flights.

One thing to note is that for thermocouples to calculate the absolute temperature an RTD sensor would need to be added either on the PCB or in the connector. Measuring the value of this RTD would also use up one of the channels and therefore reduce the number of thermocouple channels available to 7.

CONCLUSION

The investigation found that it is possible to design a flexible analog acquisition card without degrading performance and accuracy and without many compromises in terms of feature list. This card could be useful for a number of applications. For a configuration with a small number of measurements or some spare measurements this card could be used where before several cards would have been needed. This card could be used for one measurement type on one program and reused for a different measurement type on another program. This card could be installed on an aircraft and the sensor type could be changed at any stage without having to reinstall or rewire the aircraft.

However it is believed that this card will not replace the dedicated analog acquisition cards. Some existing measurement types such as piezoelectric (non IEPE), synchro and resolver are simply not suitable for a flexible module. Some features such as sense lines for strain gauges cannot be included. But most importantly the channel count for a dedicated card can still be much higher. The generic module will do 8 channels in an Acra KAM 500 form factor where a dedicated temperature card or a dedicated strain gauge card could do 16 and a dedicated differential voltage card could do 24. This of course has an impact on size weight and cost.

A flexible analog module is a useful addition to a catalogue of scores of dedicated analog modules. However, true flexibility comes when the FTI engineer can optimize their configuration to match their priorities, whether that be the configurability of the input channels, the weight and cost of the instrumentation, the particular sensor type favoured or the extra features required on the data acquisition channel.

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