SIGNAL CONDITIONING, THE NEXT GENERATION

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INTRODUCTION

This paper describes the changes in signal conditioning techniques used on flight test programs in recent years. Improved sensors require improved signal conditioning. Advanced distributed data acquisition systems, used on major flight test programs, move the signal conditioning closer to the sensor for improved performance and reduced wiring throughout the vehicle. These distributed systems use digital communication between the master controller and the remote conditioning units for improved accuracy and noise immunity. This requires sample- and-hold amplifiers, analog-to-digital converters, and serial encoder/decoders to be located at the signal conditioning location.

The changes in signal conditioning designs are driven by the sensors, the architecture of the data acquisition systems, and by vehicle designs (smaller aircraft, smaller missiles, composite structures, and hypervelocity vehicles).

A look at the signal conditioning technology employed in many of these systems as well as what is anticipated in the future is described in this paper.

The Need for Changing Technology

The technology used in airborne signal conditioners for flight test applications has changed considerably in recent years, Major areas which have changed are

a. Increased system accuracy.
b. Integral digitization in signal conditioning units.
c. Increased software control.

Increased system accuracy of the signal components has been driven from both sides. Improved techniques in sensor design has led to many bridge type devices which offer high accuracy. Many distributed data acquisition systems use A/D converters with a resolution of 12 bits. The signal conditioning must be consistent with the other components of the system to maintain the high accuracy required.

The signal conditioner as an analog-in/analog-out system component is now seldom used in large digital data acquisition systems. The conditioner has become a “signal conditioning remote unit”, with local digitization. The remote unit is controlled in a command response fashion from the master unit.

The cost of flight test operations is getting more expensive. “Cost per flight hour” and “cost per ground hour” are both escalating rapidly. Aircraft flight test time for military programs in the U.S. is typically quoted at approximately $100,000 dollars per flight hour. Cruise missile programs typically cost up to $1000,000 dollars per flight hour when the support vehicles are included. In the language of the attorneys “Time is of the essence”.

Of course, the number of channels in the system and the software programmability can have a significant impact of the cost of the data acquisition hardware. The cost of even the most sophisticated signal conditioning, however, can be insignificant when compared to the savings of reduced flight and ground time. The high cost of flight test operations has driven the following changes in signal conditioning design:

a. Increased number of channels in the system to reduce the number of flight hours. Typical systems have over 8,000 channels.

b. Increased software programmability to reduce ground time required for setup, calibration, and preflight operations.
c. Increased number of formats in the data acquisition system to reduce flight time and allow alternate missions to be flown.
d. Inflight format changing to ensure a high efficiency of flight time.
e. Built-in-test to ensure that the system is 100% operational during flight tests.

Available Monolithic Components

The changes in technology described in this paper could not be achieved without the improved analog and digital monolithic devices which have become available to the electronic designer in recent years. The introduction of semi-custom and full custom devices has also led to significant improvements in the size of components and increased system accuracy.

System Constraints

The design of signal conditioning used in digital data acquisition systems is driven by various factors. These are:

a. Sensor accuracy
b. System requirements
c. Vehicle type and design
d. Performance desired

System Accuracy

Many analog sensors are currently available with improved accuracy to 0.1% over the operating environments encountered in flight test operations. Digital sensors, of course are available to much higher accuracies.

System Driven

The design of the signal conditioning is driven by the data acquisition system requirements. These include architecture of the system, size of the components, and power availalbe.

Size

The size of the vehicle (and hence the size available for the system components) can have a considerable effect on the design of the signal conditioning. In some cases hybrid circuitry is required; in other cases semi-custom or full custom devices may be required. In extreme cases custom devices are incorporated inside the hybrids. System lead times increase with the degree of complexity in packaging.

Power

The power available for the system can have a significant impact on the system design. If very little power is available, multiplexed excitation may be required.

Vehicle Considerations

The design of the vehicle to be flight tested can have a significant effect on the design of the data acquisition system and the signal conditioning techniques which are used. Of course, smaller vehicles require smaller signal conditioning units. The material used for the vehicle skin (composite vs aluminum) and the flight envelope of the vehicle (hypervelocity) can also influence signal conditioning design. Many of the signal conditioning products being delivered by Aydin Vector have operating temperatures from -55 to +100 degrees Celcius to accomodate such vehicles.

Composite Vehicles

Composite vehicles do not conduct heat as well as aluminum. This can create problems with strain gages since self-heating can be a source of error. Three techniques have been successfully used to eliminate the problem:

a. Multiplexed constant current excitation
b. Increased gage resistance
c. Reduced bridge excitation voltage

Multiplexed constant current excitation has been used in many aircraft and missile applications by Aydin Vector. This technique can only be used in time division multiplexing applications (PAM, PCM) and is described in the “system integrated features” selection of this paper.

The trend in strain gages is to increase the gage resistance (350 Ohm gages are being replaced with 1000 Ohm gages in many applications). This reduces the current required when a bridge is excited with a constant voltage source which reduces the errors associated with self-heating. The high differential input impedance of the instrumentation amplifier allows the higher source impedance to be used without a significant increase in error.

A reduced level of excitation voltage can also be used with strain gages on composite materials to eliminate self-heating effects. In many applicatons a constant voltage excitation of 0.5 Volts has been used. Since most vehicles have a mixture of strain gages on composite materials and on aluminum, a programmable excitation source is desirable. Aydin Vector has several systems which offer programmable excitation. Of course, the output of the bridge is reduced when the excitation is reduced, but improvements in monolithic amplifier components allow the programmable amplifier to be operated at higher gains to compensate for the reduced excitation voltage.

Thermal design of the signal conditioning units is even more critical when the signal conditioning is used on a composite vehicle since the structure is not an effective heat sink. The reduction in excitation current (with 1000 Ohm gages), multiplexed excitation, or reduced excitation voltage to the bridge can offer significant advantages in the power dissipated by the signal conditioning components.

Hypervelocity Vehicles

Hypervelocity vehicles have extremely high skin temperatures. This imposes unusual demands on transducers and the signal conditioning equipment. Skin temperatures to 5000 degrees Celcius can be encountered. With distributed acquisition systems, the remote units are close to the point of measurement. Special precautions must be taken to ensure the survivability of the remote unit.

Performance Driven

Changes in signal conditioning design can be driven by the performance of the data acquisition system to satisfy the analysis engineers monitoring the data.

Critical Time Correlation

In many applications precise time correlation between parameters is critical. Some of these applications include pressure and strain surveys for helicopter rotor blades and turbine engine inlet distortion tests. Two techniques are typically used to achieve precise time correlation:

a. Multiple sample-and-hold amplifiers
b. Multiple analog-to-digital converters.

Aydin Vector builds products which use both of these techniques.

The MMSC-800 Microminiature Signal Conditioner offers bridge signal conditioning modules which contain a sample-and-hold amplifier per channel. The multiple sample-and-hold technique is adequate for most applications but care must be exercised in the sampling sequence to ensure that sample-and-hold droop is not a significant source of error. Systems which contain an analog-to-digital converter per channel (such as the SSC-900 Super Signal Conditioner) do not have this limitation since all data in the system can be sampled, digitized, and latched at the same time. The data from the latches can be formatted, as required, by the master controller without concern since droop is not a problem.

Improved Accuracy

Sensor accuracies have increased in recent years; signal conditioning for these sensors has undergone a similar change. Significant improvements in system accuracy have been achieved through the availability of advanced monolithic components which are used in the signal conditioning designs. Incorporation of the sample-and-hold amplifiers and the analog-to-digital converters within the signal conditioning unit has also significantly improved performance.

The resolution of data acquisition systems has also increased. Typical resolution of signal conditioning for data acquisition systems is shown below:

a. Analog - 12 bits
b. Synchro or resolver - 16 bits
c. Frequency - 24 bits

In high accuracy measurements an analog-to-digital converter per channel (or a direct to digital conversion) is often required.

Programmability

The technology has increased from little or no programmability of the hardware used decades ago to full programmability which allows the user to set-up calibrate, and preflight the vehicle without access to the hardware. Aydin Vector builds products with simple (more conventional) programmability of gain, offset, and sampling; to more complex hardware which has programmability of excitation, bridge balance, gain, offset, filter cutoff, and sampling sequence.

High Technology Hybridized Signal Conditioners

Aydin Vector has been building hybridized signal conditioners since the early 1970's. These products range from a simple amplifier-filters to exotic signal conditioners with full software control.

Amplifier-Filter

The first Aydin Vector hybridized amplifier-filter product was the PDF-106 which was designed in the 1970's and is still available today. Tens of thousands of these products have been delivered to customer throughout the world. Improvements in monolithic components over the years has led to the introduction of the PDF-107, PDF-108, PDF-202, and PDF-203 amplifier-filters. Most of these products have accuracies consistent with 12-bit digital data acquisition systems.

Self-balancing Amplifier

The self-balancing amplifier (BCA) was developed for the Trident II missile program. It uses a digital autobalance technique which will balance the bridges on the application of power. In addition to the self-balancing circuitry, the BCA hybrid contains a fixed voltage excitation, a fixed gain instrumentation amplifier, and a fixed frequency pre-sameple filter.

Automatic Gain Ranging Amplifier

The Automatic Gain Ranging Amplifier was developed for the Flight Dynamics Laboratory of Wright Patterson Air Force Base. The AGRA-100 is a hermetic hybrid module which can automatically adjust the gain to accmodate variations in input signal level. It can be used to achieve 120 dB of dynamic signal range. The AGRA-100 has the following features:

a. AC or DC coupling modes
b. 7 gains
c. 4 programmable cutoff frequencies
d. Three modes of operation:
   External - digitally programmable from address line.
   Down only - amplifier steps down and locks.
   Internal - gain is controlled by internal peak detector.

Super Signal Conditioner

The Super Signal Conditioner is fully software controlled and is designed to be the ultimate signal conditioner. The hermetic hybrid device (SSC-2008) contains the following features:

a. Dual-tracking constant current source
b. Programmable constant voltage source (4096 steps)
c. Programmable bridge balance (4096 steps)
d. Programmable offset (4096 steps)
e. Programmable gain (16 values)
f. Programmable filter (4 frequencies)
g. Sample-and-hold amplifier
h. Analog-to-digital converter

Since the SSC-2008 contains a sample-and-hold amplifier and an analog-to-digital converter, it can be used in simultaneous sampling applications as described above.

Microminiature Conditioning Encoders

Aydin Vector has a microminiature conditioning encoder which offers stackable signal conditioning modules. Some of these conditioning modules are :

a. Dual Bridge conditioner
b. Bridge conditioner with Sample-and-hold

c. Analog Multiplexer
d. Digital Multiplexer
e. Synchro or Resolver converter
f. Frequency-to-digital Converter

The MMSC-800 can be operated as a stand alone conditioning encoder which outputs PCM data, or as a remote unit to a large data acquisition system.

System Integrated Features

System integrated features are often incorporated into distributed data acquisition systems to enhance overall system operation. Some of these include multiplexed excitation and digital filtering.

Multiplexed Excitation

Aydin Vector developed multiplexed excitation for use in data acquisition systems in 1980. The Aydin Vector design approach uses a dual-tracking constant current source which is multiplexed (at the PCM word rate) to excite the bridges. The bridge output is also multiplexed at the word rate, amplified, and digitized as required. The excitation is applied only during the period of interest (just prior to sampling) and removed after the channel is digitized. Since the duty cycle is low, self-heating is eliminated. An added advantage of this type of conditioning is that the bulky power supply required with conventional excitation is eliminated. The technique has been used successfully with bridges, accelerometers, and resistive temperature devices.

Digital Filtering

Aydin Vector developed a system with digital filtering for use in aircraft flight testing. This system, designated as the 914 Series is currently in use onboard various aircraft. The system is a distributed data acquisition system which accepts up to 32 remote units. Digital signal processors (DSP) are distributed (in each remote) to allow the system to operate at high bit rates. The user has software control of gain, offset, and pre-sample filter cutoff frequency of all analog channels in the system.

The Future

The performance required for signal conditioners will continue to increase in the future. The operating bit rate of distributed data acquisition systems will continue to increase to greater than 10 MBPS in the near future. This will allow more high frequency response channels in the system. Resolution of most analog channels will be 12 bits; resolution of some analog channels will be 16 bits.

Size and power consumption will continue to be major factors in signal conditioning design. Vehicles will continue to have smaller surfaces and use more “radar invisible” components. The signal conditioning designs will use more custom devices to achieve high performance in a small size. The custom components will be incorporated in hybrids for an even greater size reduction.

Software programmability of signal conditioners will become a standard feature on all types of vehicles to reduce the cost of flight test operations.