INTELLIGENT DATA ACQUISITION TECHNOLOGY

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ABSTRACT

Telemetry & Instrumentation, in conjunction with NASA's Kennedy Space Center, has developed a commercial, intelligent, data acquisition module that performs all functions associated with acquiring and digitizing a transducer measurement. These functions include transducer excitation, signal gain and anti-aliasing filtering, A/D conversion, linearization and digital filtering, and sample rate decimation. The functions are programmable and are set up from information stored in a local Transducer Electronic Data Sheet (TEDS). In addition, the module performs continuous self-calibration and self-test to maintain 0.01% accuracy over its entire operating temperature range for periods of one year without manual recalibration. The module operates in conjunction with a VME-based data acquisition system.

KEYWORDS

Signal Conditioning, Analog-to-Digital Conversion, Digital Signal Processor, Digital Filtering, Self-Test, Self-Calibration, Automated Data Acquisition, Multiple Transducer Support, Transducer Electronic Data Sheet

INTRODUCTION

For the last three years, Telemetry & Instrumentation and NASA have been developing the Universal Signal Conditioning Amplifier (USCA) for use on the Space Shuttle launch pad. Reduced operating budgets and NASA's desire to integrate zero or low maintenance electronic systems into its support equipment were the motivating forces for developing the USCA.

The first unit produced was a ruggedized module that could withstand direct exposure to the shuttle's solid rocket exhaust while remaining operational with better than 12-bit accuracy. That data acquisition module is currently being deployed on the launch pad, and a second version of the module, one that is rack-mountable, has now been developed. The goal of both of these modules is to reduce shuttle operational costs by automating the setup of the transducer measurements and eliminating the need to continually recalibrate the signal conditioner. To do this, the USCA was designed to be completely programmable, supporting all the transducers used by NASA on the launch pad. In addition, self-calibrating functions were built into the USCA, which significantly reduced the frequency of calibration requirements. Also, because of the distance between the transducer and the control room, up to four miles in some instances, transducer calibration information was designed to be stored with the transducer in an electronic data sheet, which is read by the USCA. After reading this information, the USCA configures itself to that transducer's requirements and loads in the transducer calibration coefficients.

USCA MODULE ELEMENTS

The USCA consists of all the elements required to build a complete intelligent data acquisition module, as shown in Figure 1.

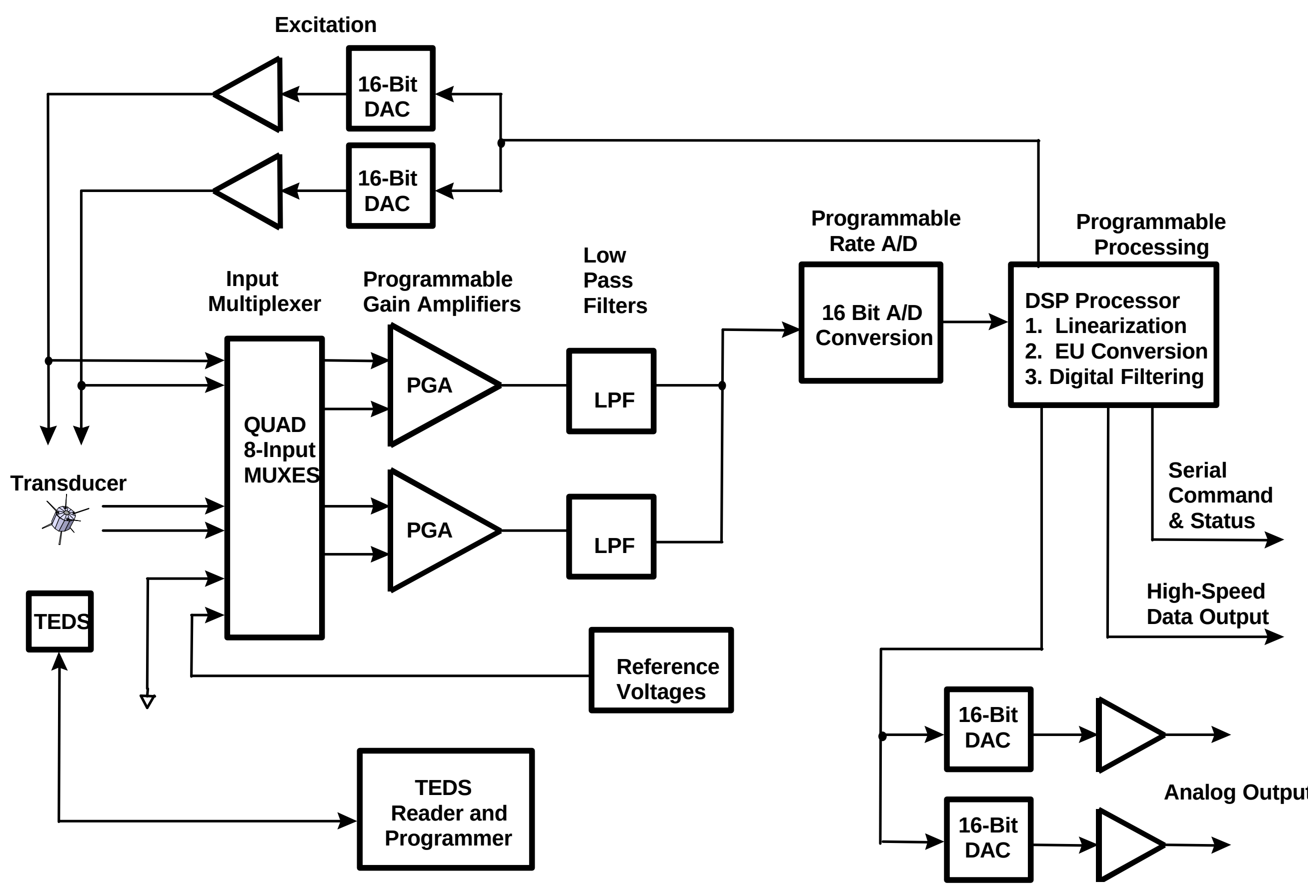

Figure 1. USCA Block Diagram

Transducer Electronic Data Sheet

The Transducer Electronic Data Sheet (TEDS) contains all the information about the measurement, the transducer, and the requirements for setting up the USCA. It contains the Measurement Name, Measurement Type, Transducer Type, Calibration Date, Excitation Type (Voltage or Current), Excitation Level, Input Type (Voltage or Current), Coupling (AC or DC), Gain, Sample Rate, Filter Cutoff Frequency, 8^{th}-Order Polynomial Coefficients for Transducer Calibration, and the Analog Output Level. The TEDS can be located at the transducer or inside the USCA itself. If located at the transducer, the TEDS also provides the ability to verify the correct transducer connection and match it to the input channel. In this case, a transducer can be plugged into any USCA, and the system will automatically configure itself and match the transducer and measurement name to the input channel corresponding to that particular USCA.

Reference Voltages

To perform USCA calibration, the USCA uses precision, temperature-compensated voltage references that have a temperature stability of better than 1 ppm per ^{o}C and less than 1 ppm drift per year. These references form the basis for maintaining high accuracy over all operating temperatures for one year through continuous self-calibration. The actual values of these voltages and other critical calibration values are measured during annual calibrations, and are stored internally in the USCA in non-volatile EEPROM.

Transducer Excitation

The USCA has two independent 16-bit digital-to-analog converter controlled excitation sources that individually can supply from 0 to ±11.5 Volts at 60 mA in 500 uV steps. When used in differential mode, they supply 0 to 23 Volts. They can also be configured to supply precision constant current excitation up to 10 mA in 1 uA steps. Pulsed excitation can be used in either current or voltage mode to reduce the effects of transducer heating or differential input noise.

Dual Gain and Filter Section

The USCA contains dual amplifier and filter input sections. While one input section is being used to input the measurement, the other is being calibrated. The amplifier of each section is a multi-stage programmable gain differential amplifier that provides gains from 1 to 2,000. The filter of each section is an 8-pole Butterworth-elliptical filter with programmable cut-off frequencies that are set to match the analog-to-digital (A/D) conversion rate and prevent aliasing in the passband of the digitized data — all while maintaining 14 bits of linearity.

Input Multiplexer

The input to each input section is a differential solid-state multiplexer that allows various inputs to be switched into each channel. Each of the two input sections is fed by a dual 8-input analog mux that allows one of eight inputs to be selected to each side of the differential input amplifier. This feature allows each channel to input any of the precision voltage references, the signal input, either of the two excitation voltages, the analog output, or the analog ground for reference to other voltages, or for zero reference.

Analog-to-Digital Conversion

The 16-bit A/D converter operates at either 10K samples per second or 40K samples per second. In both cases, every other sample is a measurement followed by calibration input so that only half the conversion rate is used for measurements. This capability provides measurement conversion rates of 5K and 20K samples per second. For lower measurement sample rates, digital filtering and decimation are performed by the digital signal processor.

Digital Signal Processor

A high-performance digital signal processor (DSP) is used to control the functions of the USCA. The DSP performs calibration, measurement linearization, scaling, digital filtering, decimation, output to a digital-to-analog converter (DAC) for analog output, and serial output to the digital multiplexer. It also controls the setup of the gain, excitation, and sample rates in the hardware, as well as continuous analog calibration and self-test. In addition to these functions, the DSP provides an intelligent interface to the control system for receiving setup commands and information, calibration commands, and diagnostics commands. The DSP reports the results of diagnostics, calibration, and self-test back to the control system. It sets up the acquisition from information received by the control system or by the Transducer Electronic Data Sheet (TEDS). It also updates the TEDS on command from the control system.

Analog Output

The analog output section is formed by dual 16-bit DAC and amplifier sections that provide output ranges of 0-5V, 0-10V, ±5V, and ±10V. The DSP writes 16-bit, calibrated and linearized values to the DAC that are scaled so that the input range of the measurement is mapped to the range of the analog output. As in the dual input section, one output section is used for output while the second is being calibrated.

Digital Output

Following digital filtering and decimation, the resulting 16-bit value is output to a serial RS-485 output to a digital multiplexer, which can be up to 1,500 feet from the USCA. At the multiplexer, the measurement is time stamped and merged with other data on the Measurement Data Bus.

OPERATION

Setup

On Power-up, Reset, or on Command, the USCA performs initial self-test and self-calibration. It then reads the Transducer Electronic Data Sheet (TEDS) and sets up the excitation, gain, filtering, DSP processing, and analog output per the data in the TEDS. The input multiplexer is set to input the measurement input into the first input section, and reference voltages into the second. After one section is calibrated, and the excitation and analog output sections are calibrated, the USCA begins to input measurements.

Calibration

To calibrate an input section, the DSP selects one of six reference voltages, or the analog ground, and feeds it to the input. The known value for that reference voltage, which is stored in the EEPROM, is compared to the reading taken by the A/D converter. An offset and gain correction is calculated for the positive polarity of that section. The reference voltage is then reversed on the inputs, and offset and gain corrections are calculated for the negative polarity of that section. For gains of greater than 10, this process is performed in multiple steps, with each gain stage calibrated separately. After all stages are calculated, a cumulative offset and gain are saved for both the positive and negative polarities of that input section. These values are used to correct the A/D values that are received by the DSP when this section is used for measurement input. They are also used when this section calibrates the excitation and analog output.

After the input section is calibrated, it is used to calibrate the excitation voltage. The DSP selects the excitation as input to the input section. The values received by the DSP are first corrected with the offset and gain correction for that section. The DSP then compares the corrected value with the programmed value for the excitation level. If the excitation value is incorrect, the excitation is adjusted until it is within 500 uV or 1 uA of the desired value.

Finally, the input stage is used to calibrate the dual analog output section. The DSP sends an output value to the output section and measures the result with the calibrated input section. After several values are output, an offset and gain are calculated for both the positive and negative polarities of that analog output section. These values are used when this half of the analog output is used for the actual analog output.

While one input section is in calibration, the other is used to input measurement data. After one section completes calibration, it is used for input while the other is used for calibration. The calibration process takes about five seconds.

Measurement Input

To input a measurement, a calibrated input section is set to the proper gain and low-pass filter frequency. The input multiplexer selects the differential transducer measurement for input to the input section. A programmable gain amplifier boosts the input signal so that the maximum dynamic range of the ±10V input of the A/D converter is utilized. After amplification, but before A/D conversion, the measurement is filtered by a low-pass filter to prevent frequencies of greater than ½ the conversion frequency from aliasing the digitized measurement. The A/D converter then performs a 16-bit analog-to-digital conversion on the measurement.

Measurement Processing and Output

When the DSP receives the measurement from the A/D converter, it first corrects the value with the offset and gain values calculated during calibration. It then performs the 8^{th}-order operation for linearization and calibration for the specific transducer connected to the USCA. The polynomial coefficients are stored in the Transducer Electronic Data Sheet (TEDS), and are defined by the user for calibrating the specific transducer connected to the USCA.

The DSP then performs another offset and gain correction for the active analog output section, and writes that value to the analog output DAC. The DSP then performs digital filtering on the measurement using a one- or two-stage 127 tap finite impulse response (FIR) filter, with decimation if necessary. Such flexibility allows the user to specify a frequency passband of interest and a level of oversampling. The filters are designed to provide a minimum of passband ripple, less than 0.1dB, and a stop band attenuation of better than –80 dB. With the two-stage filtering and decimation, sample rates, F_s, of 10 Hz to 10 kHz can be selected with passbands that are 40% of F_s. This capability allows efficient data rates relative to the frequency of interest, where the sample rate is only 2.5 times the highest frequency of interest, and with no aliasing above -80 dB in the passband. Each output sample rate offers several selections of passband frequencies that typically range from 2% of F_s to 40% of F_s (see Figure 2).

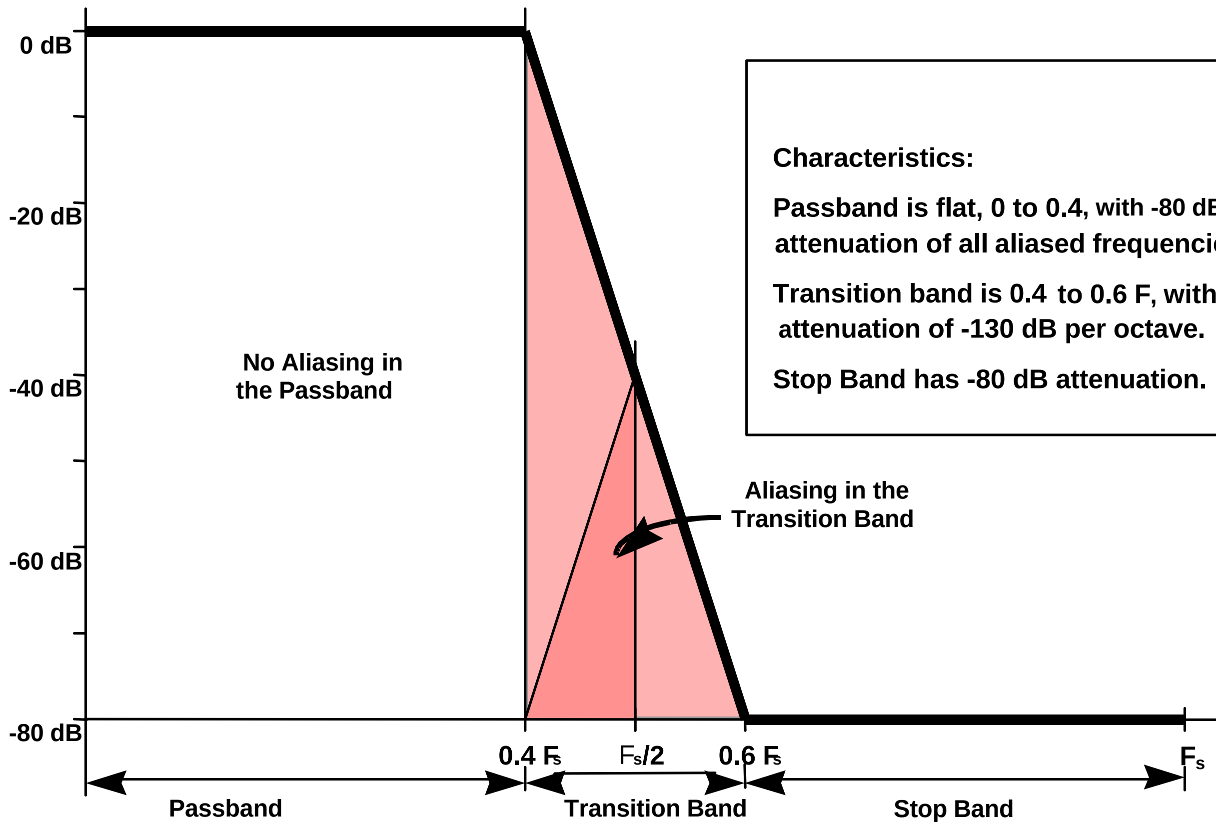

Figure 2. Low-Pass Filter Without Aliasing in the Passband

Digital Output

After the FIR filter and decimation operations are complete, the DSP performs a final scaling of the measurement output that corresponds to the predefined output range of the measurement. The measurement is scaled so that the linearized minimum and maximum values are at the minimum and maximum values of the 16-bit digital output. This output can be 2's complement, binary, or offset binary. This value is then output through the serial port of the DSP at 460 Kbps to the digital multiplexer via an RS-485 differential driver.

Status and Control

All functions of the USCA are controlled by the control system via the digital multiplexer through a second serial interface to the USCA. The USCA receives commands and responds with data and status. Commands include "send status," "run diagnostics," "receive new setup info," "return current setup," "write data to TEDS," "read data from TEDS," etc. If any error is detected by the USCA in its calibration of self-test, this status is returned to the digital multiplexer and reported to the control system.

CONCLUSION

The USCA minimizes operational costs by reducing calibration and system checkout times. Because the USCA can support most measurement and transducer types, it reduces system complexity and eliminates the need for supporting multiple types of signal conditioning modules. It also provides a highly accurate measurement system that can automatically calibrate and configure itself to the connected transducer.

With its sophisticated filtering capabilities, the USCA reduces data rate requirements by maximizing the passband frequency for any given sample rate without allowing aliasing in the passband. The built-in test also provides a highly reliable system with minimal failure detection and repair times.

Summary of Advantages

- Reduced operations costs
- High end-to-end accuracy
- Automated setup
- Pre-test system validation
- Continuous self-calibration and self-test
- Real-time transducer calibration correction
- Real-time digital filtering and processing
- Reduced data rate requirements
- Complete integrated solution