THE UNIVERSAL SIGNAL CONDITIONING AMPLIFIER

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ABSTRACT

A state-of-the-art instrumentation amplifier capable of being used with most types of transducers has recently been developed at the Kennedy Space Center. This Universal Signal Conditioning Amplifier (USCA) can eliminate costly measurement setup time and troubleshooting, improve system reliability, and provide more accurate data than conventional amplifiers. The USCA can configure itself for maximum resolution and accuracy based on information read from a RAM chip attached to each transducer. Excitation voltages or currents are also automatically configured. The amplifier uses both analog and digital state-of-the-art technology with analog-to-digital conversion performed in the early stages to minimize errors introduced by offset and gain drifts in the analog components. A dynamic temperature compensation scheme has been designed to achieve and maintain 12-bit accuracy of the amplifier from 0 to 70° C. The digital signal processing section allows the implementation of digital filters up to 511th order. The amplifier can also perform real-time linearizations up to fourth order while processing data at a rate of 23,438 samples per second (23.438 kS/s). Both digital and analog outputs are available from the amplifier.

DESCRIPTION

The Universal Signal Conditioning Amplifier is a self- or remotely-programmable amplifier that internally provides transducer excitation. The USCA was designed to improve the performance of the Permanent Measurement System (PMS) currently in use at the Kennedy Space Center. The USCA significantly reduces the time required to set up a new measurement—a task that currently takes several hours since amplifiers have to be physically matched to the transducers. Many transducers used in the PMS have outputs in the order of a few millivolts, and their amplifiers are sometimes several hundred feet away. Noise coupled into the cables can significantly deteriorate the performance of the measurement system. The USCA was designed to improve the signal-to-noise ratio by allowing the amplifier to be closer to the transducer whenever feasible. Each USCA is characterized by a 0 to 70°C temperature range. By measuring the performance over the temperature range and by constantly monitoring the temperature, analog gain and offset drifts can be dynamically compensated for by the digital signal processor stage.

When a transducer is calibrated using the USCA, a memory chip (Tag RAM) must be attached to it. This memory chip contains information pertinent to the transducer, such as excitation levels, output range, linearization coefficients, and others. Before the transducer is connected to the USCA, all the output voltages or currents are set to zero and the input gain is set to unity. When the USCA is connected to a transducer, it sets itself up to adapt to the transducer by using the information stored in the Tag RAM. The default gains, excitation levels (voltage or current), filters, and output type (analog or digital) are set immediately upon connecting a transducer to the USCA. The default settings of the USCA can be changed remotely through the Self Aware Measurement System (SAMS) controller. The flexibility provided by the internal controller and the Digital Signal Processing module permits the use of non-standard transducers, such as pulse-type flow meters, sensors with frequency outputs, and A/C phase measurement transducers.

SELF AWARE MEASUREMENT SYSTEM

A block diagram of a typical USCA configuration is shown in Figure 1 . A Self-Aware Measurement System (SAMS) controller is shown in the block diagram. As shown, the main purpose of the SAMS controller is to provide an interface between a host computer and the USCA. Even though the USCA sets itself up upon connection to a transducer, the SAMS controller can allow the selection of input and output gains. It also permits the selection of standard filters in each USCA, and allows the downloading of custom-designed digital filters. The SAMS provides configuration control of the system by monitoring the number and types of transducers in use and by

Figure 1. System Configuration: Universal Signal Conditioning Amplifier (USCA), Tag RAM, and Self Aware Measurement System (SAMS)

tracking calibration due dates of the transducers. It maintains a date/time log of USCA and transducer connects and disconnects.

For transducers that do not require a signal conditioning amplifier, the SAMS controller can perform configuration control even without a USCA present. However, these transducers must be equipped with a Tag RAM.

TAG RAM

The Tag RAM consists of a memory chip, backed by a battery with a 10-year lifetime. This Tag RAM is loaded with data and sealed to the transducer after the transducer is calibrated. The Tag RAM includes information regarding the transducer type, required excitation level, output voltage range, calibration due date, linearization coefficients, ID number, and others. The Tag RAM is password-protected to prevent the calibration data of the transducer from being changed inadvertently. Communication between the USCA and the Tag RAM is done over a single pair of wires. Multiple Tag RAMs can be connected to that single pair of wires. When long cables are used to connect the USCA to a data acquisition system, each section of cable can be equipped with a Tag

RAM. The SAMS controller can then perform configuration control of the complete measurement, including the cabling.

USCA

The USCA combines state-of-the art analog and digital hardware to accomplish reliable and accurate signal conditioning. Figure 2 presents a block diagram that shows the USCA's main modules.

The Input module consists mainly of a highly stable programmable-gain amplifier. This module also includes transient and overvoltage protection circuits. The circuits have been designed to provide a DC to 10 kHz 0.02 dB passband with 12-bit (1 part in 4096) accuracy. The programmable stage can select gains from 0.25 through 2,000 V/V. The output of the amplifier stage is applied to a 16-bit analog-to-digital converter circuit that samples at 375 kS/s. A voltage reference with stability better than 1 ppm/°C is used for the A/D converter. This is the most critical section of the USCA, since the accuracy of the amplifier is mainly limited by the behavior of the analog section.

The Excitation module provides a highly regulated voltage or current for the transducer. The excitation level is determined by the information read from the Tag RAM, and is controlled by a 16-bit digital-to-analog converter. This module allows the selection of an excitation voltage with a resolution of better than 500 μ V. The excitation stage has a current-limiting circuit that restricts the maximum current to about 100 mA. The excitation can also be programmed to provide pulses with variable duty cycles and amplitudes.

The Digital Signal Processing module performs digital filtering and real-time linearization functions. This module consists of a Decimating Digital Filter (DDF) and a Digital Signal Processing (DSP) microprocessor. The DDF receives a data stream at a rate of 375 kS/s from the A/D converter. The decimator lowpass filter filters the input data and reduces the sampling rate to 23.438 kS/s or lower. The DDF also performs digital filtering up to 511th order using 20-bit coefficients. The available digital filters include lowpass, highpass, bandpass, and notch filters. The coefficients for the filters can reside inside the USCA, or they can be downloaded through the SAMS controller. The filters designed for the USCA allow for passbands with ripple lower than 0.02 dB. While running at 23.438 kS/s, the DSP processor can perform linearizations up to fourth order using the coefficients read from the Tag RAM. When running measurements that do not require such a fast sampling rate, higher order real-time linearizations can be performed.

Figure 2. Block Diagram of the Universal Signal Conditioning Amplifier (USCA)

The Output module provides both analog and digital outputs. The analog capabilities were implemented to ensure the compatibility of the USCA with the measurement system currently in use at the Kennedy Space Center. The USCA uses a 16-bit digital-to-analog converter for the analog output. The output range can be selected to be 0 to 5 V, -5 to 5 V, -10 to 10 V, 0 to 10 V, or 4 to 20 mA. The digital output consists of a serial stream containing 16-bit data. The resolution is thus one part in 65,536. The Output module is connected to the Digital Signal Processing module by optoisolators. This ensures a complete galvanical isolation between the output stage and the other sections of the USCA.

The USCA is powered by a 24-32 V source. The power supply module, consisting of several DC-DC voltage converters, provides the different voltages required for operating the USCA. It also isolates the main circuitry from the Output module, the Data I/O module, and the power source.

A Data Input/Output module is used to communicate with the SAMS controller and to read the information stored in the Tag RAM. Custom filters and new gain settings are downloaded through this module from the SAMS controller. This module is also galvanically isolated from the rest of the circuitry.

USCA operation is controlled by a microcontroller. The information read from the Tag RAM is interpreted by the microcontroller, which uses it to define the settings for operating the USCA. This stage communicates with all the other modules. It sets the excitation voltages and output range, selects the filters and gains, and continuously monitors the temperature inside the USCA. The temperature information is passed along to the digital signal processor, which uses it for the dynamic temperature compensation scheme. When the microcontroller detects that a transducer has been disconnected from the USCA, it will set both the excitation voltage or current, and the output voltage to zero. This prevents potential damage to another transducer when it is connected to the USCA and before the USCA reads its Tag RAM.

The microcontroller also stores the program for the digital signal processor chip. This program is transferred to the DSP upon powering the unit up. The DSP program can be upgraded remotely through the SAMS controller when required.

DIGITAL FILTERS

A variety of digital filters was designed using Monarch DSP software. The USCA microcontroller has a total of 32 kB of non-volatile memory, a section of which is used to store the 20-bit-wide coefficients for the digital filters. This memory space limits the number of resident filters to eight. Figure 3 shows an example of two digital filters designed for the USCA. Figure 3(a) depicts a 300 Hz lowpass filter and Figure 3(b) presents the same filter with a 60 Hz notch filter added to it. The passband ripple of these filters is 0.02 dB and the out-of-band attenuation is greater than 50 dB. Additional filters can be downloaded at any time using the SAMS controller. Filters can be customized to any given application. All the digital filters were designed using a Finite Impulse Response (FIR) implementation. FIR-type filters provide linear phase delays and therefore better preserve the time domain waveforms.

OPERATION

To utilize the USCA, a transducer must be outfitted with a Tag RAM containing the information pertinent to the transducer. The transducer is calibrated by varying its stimulus and recording its output on a calibration data sheet. The linearization coefficients are then calculated and stored in the Tag RAM, along with information regarding the excitation required by the transducer. Information regarding the output range and the required gain/filter settings is also stored in the Tag RAM.

Figure 3. Examples of Digital Filters Generated for the USCA
(a) 300 Hz Lowpass Filter
(b) 300 Hz Lowpass Filter with 60 Hz Notch

When a new measurement is installed, the transducer equipped with the Tag RAM is connected to the USCA, without the need for any further calculations. The gain, filter, excitation and offset are automatically configured in a few seconds. The complete system configuration can then be reported by the SAMS controller to the PC.

USCA DEVELOPMENT

A working prototype of the USCA has been implemented at the Kennedy Space Center. The Tag RAM concept was developed and tested in 1991. A working USCA prototype and a 32-channel SAMS controller were implemented in 1992 and demonstrated in 1993.

Current efforts are concentrated on the miniaturization of the USCA. New designs will be implemented using surface mount technology. Where available, surface mount components with a 50 or 25 mil pitch will be used. The miniature version of the USCA will be placed in an explosion-proof enclosure capable of withstanding the temperatures, pressure, and vibration present at Space Shuttle launch pads. To achieve better temperature stabilization, the USCA will be filled with a sound thermal conductive fluid. The transient protection circuitry will be replaceable without having to open the liquid-filled portion of the environmental container. The calibration parameters for the USCA itself are stored internally on non-volatile RAM. A USCA can therefore be recalibrated by loading new calibration parameters, without opening the liquid-filled case. Final characterization of USCA performance will be conducted following completion of the miniature unit.

COMMERCIAL APPLICATIONS

The technology used in the development of the USCA can also be utilized in commercial and industrial applications. The USCA is an ideal solution for test cells, where sensors are frequently reconfigured for individual tests. The instantaneous matching of the USCA to a transducer can save several hours of measurement setup time. The ruggedized version of the USCA can be used in situations where the environment is hostile, such as oil exploration and mining, where the USCAs would be subject to severe environmental conditions. A hermetically-sealed USCA could be used when measurements need to be conducted under water. A simpler and less expensive USCA could be implemented for applications where large temperature variations are not expected and where the USCA would not be exposed to extreme shock or vibration. An interest has already been expressed in using the USCA for wind tunnel measurements. We anticipate the use of the USCA in the automobile and aircraft industries, where multiple sensors are used during development and testing of components.

We expect that within two years NASA will be able to procure USCAs from a commercial vendor. We anticipate that the private sector will be interested in the commercialization of both ruggedized and laboratory-grade USCAs in the near future.