

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 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 in order 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 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 which 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 setup a new measurement, which 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 located close to the transducer when feasible. Each USCA is characterized over 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 by the digital signal processor stage.

With USCA, when a transducer is calibrated, a memory chip (TAG RAM) is attached to it. This memory chip contains information pertinent to the transducer, such as excitation levels, output range, linearization coefficients and others. Before a 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

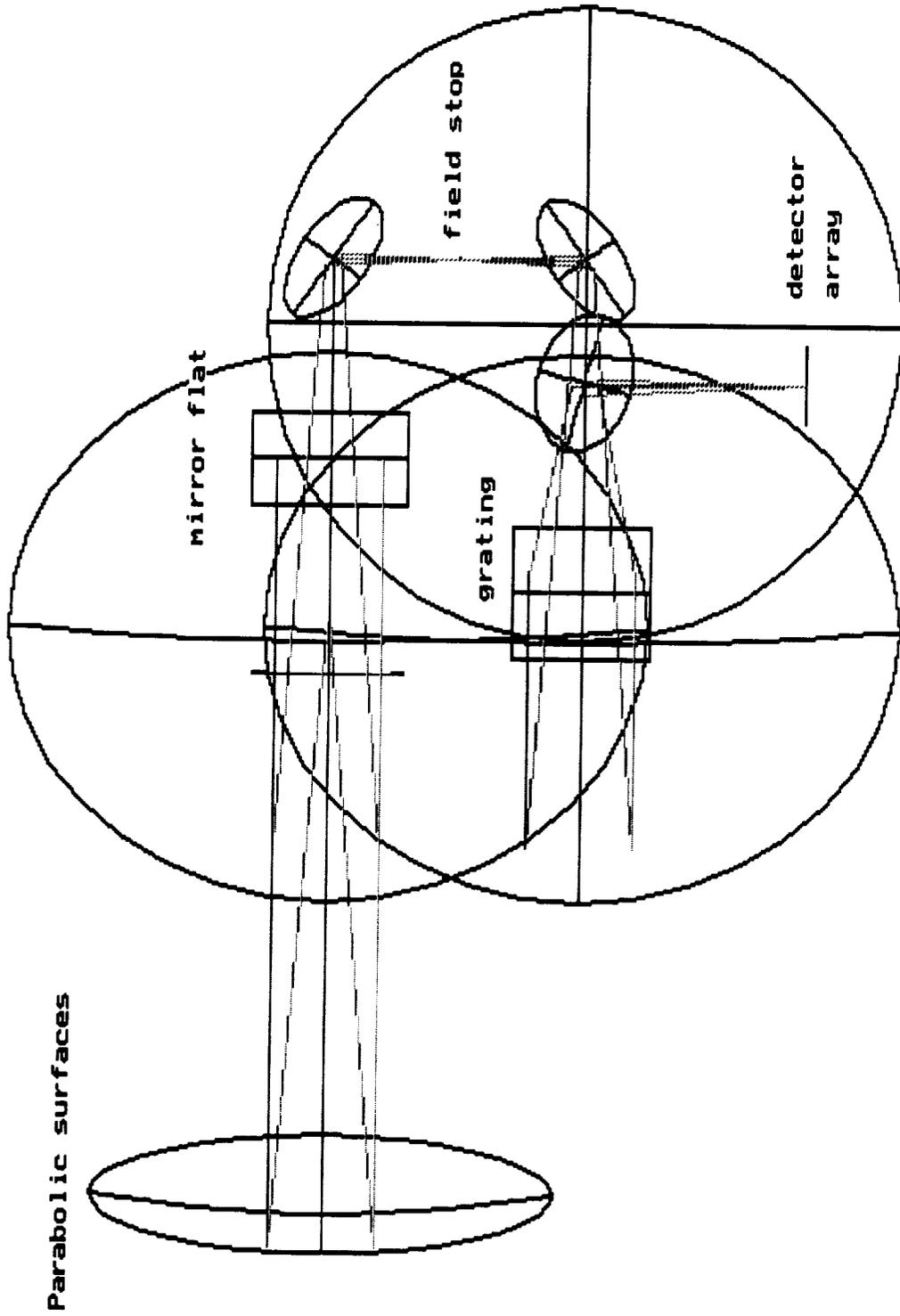


Figure 3. A schematic of the optical ray trace for our imaging/spectrometer camera design. The mirrors as depicted are the complete parabolic surfaces used by the ray tracing program BEAM4; only off-axis segments are used in the actual design.

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 scenario for the use of the USCA is shown in Figure 1. A Self-Aware Measurement System (SAMS) controller is shown in the block diagram. The main purpose of this 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 allows for configuration control of the system by monitoring the number and types of transducers in use and by tracking calibration-due dates of the transducers. It maintains a date/time log of USCA and transducer connects and disconnects.

The SAMS controller can perform the configuration control even without a USCA present for transducers that do not require a signal conditioning amplifier, provided they are 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. The communication between the USCA and the Tag Ram is done over a single pair of wires, and multiple Tag Rams can be connected to the single pair of wires. When long runs of cable are used to connect a USCA to a data acquisition system, each section of cable can be equipped with a Tag Ram. The SAMS controller then could perform the 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 which shows the main modules of USCA.

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 a 12 bit (1 part in 4096) accuracy. The programmable stage can select gains from 0.25 through 2000 V/V. The output of the amplifier stage is applied to a 16-bit analog-to-digital converter circuit which samples at 375 kS/s. A voltage reference with an stability better than 1 ppm/°C is used for the A/D converter. This is the most critical section of 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 which 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 the 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 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 USCA, or they can be downloaded through the SAMS controller. The filters designed for 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 which do not require such a fast sampling rate, larger order real-time linearizations can be performed.

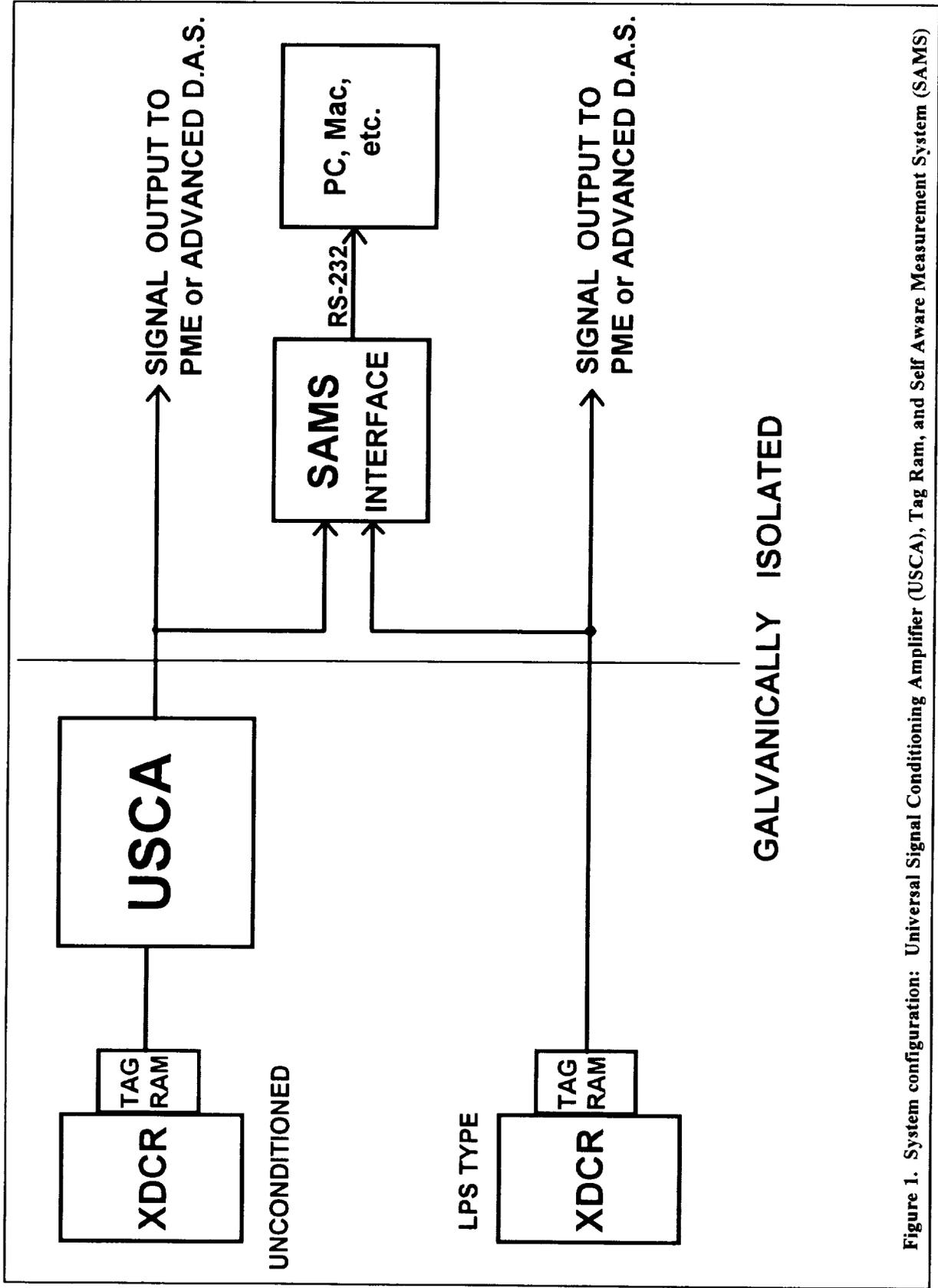


Figure 1. System configuration: Universal Signal Conditioning Amplifier (USCA), Tag Ram, and Self Aware Measurement System (SAMS)

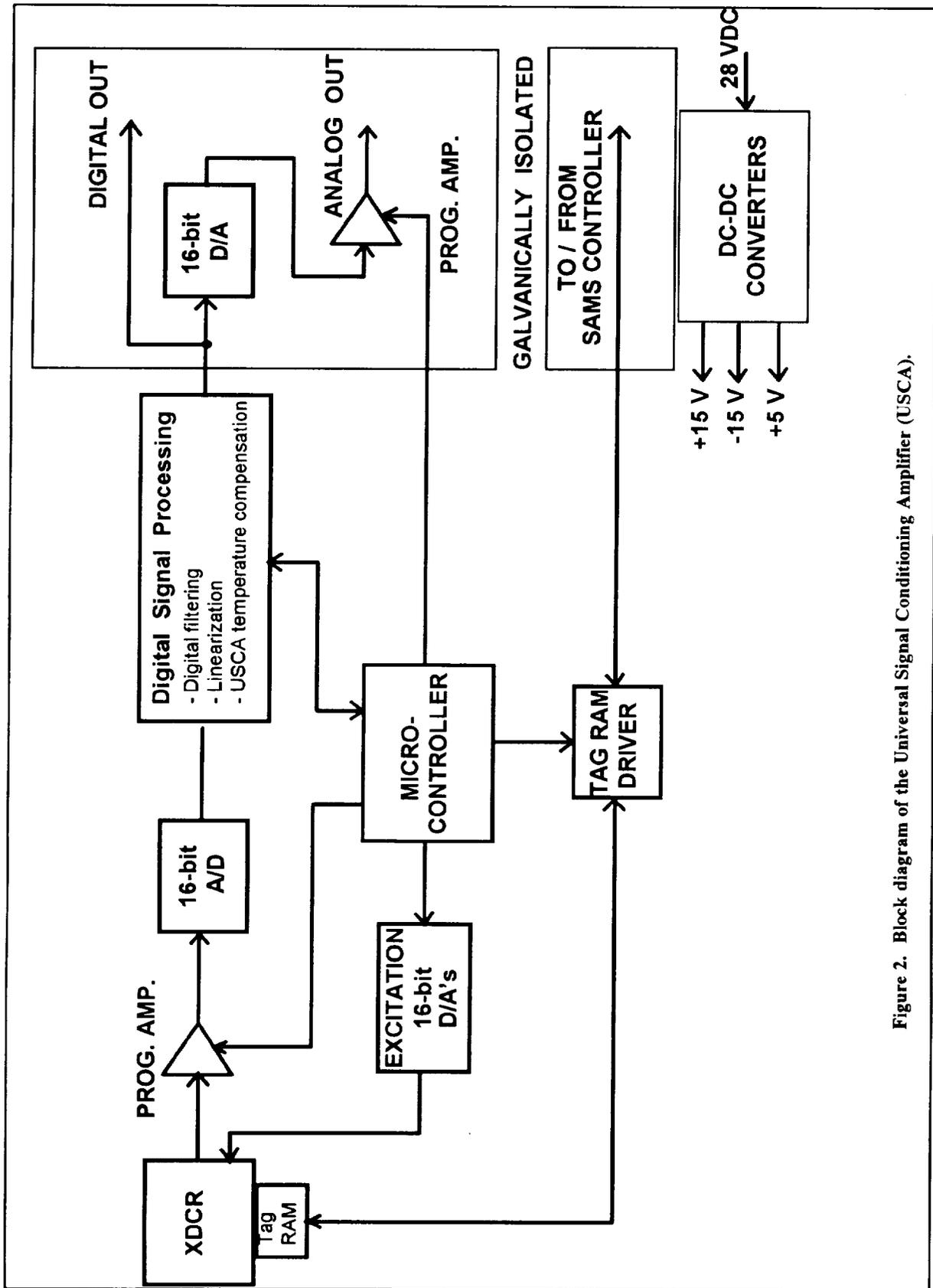


Figure 2. Block diagram of the Universal Signal Conditioning Amplifier (USCA).

The output module provides both analog and digital outputs. The analog capabilities were implemented to assure the compatibility of the USCAs with the measurement system currently in use at the Kennedy Space Center. A 16-bit digital-to-analog converter is used 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, thus the resolution is one part in 65,536. The output module is connected to the digital signal processing module by means of optoisolators. This assures a complete galvanical isolation between the output stage and the remaining sections of USCA.

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 the operation of 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.

The operation of the USCA is controlled by a micro-controller. The information read from the Tag Ram is interpreted by the micro-controller, which uses it to define the settings for the operation of the USCA. This stage communicates with all the other modules. It sets the excitation voltages, the 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 micro-controller 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 the potential damage to another transducer when it is connected to the USCA and before the USCA reads its Tag Ram.

The micro-controller 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.

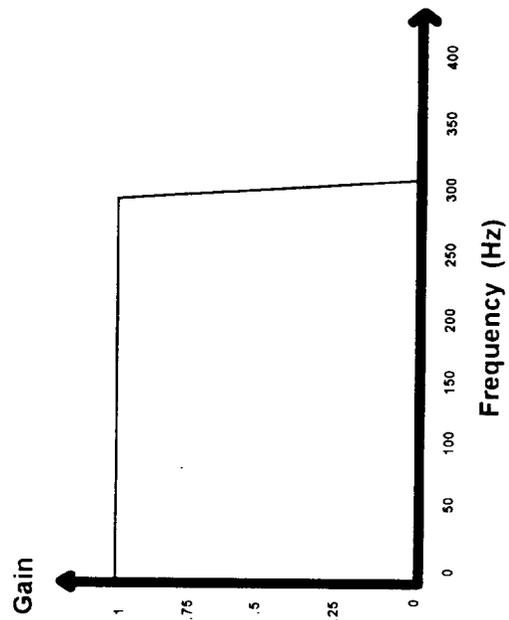
Digital Filters

A variety of digital filters were designed using Monarch DSP. The USCA micro-controller 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. The finite memory space limits the number of resident filters to eight. Figure 3 shows an example of two digital filters designed for 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, therefore better preserving the time domain waveforms.

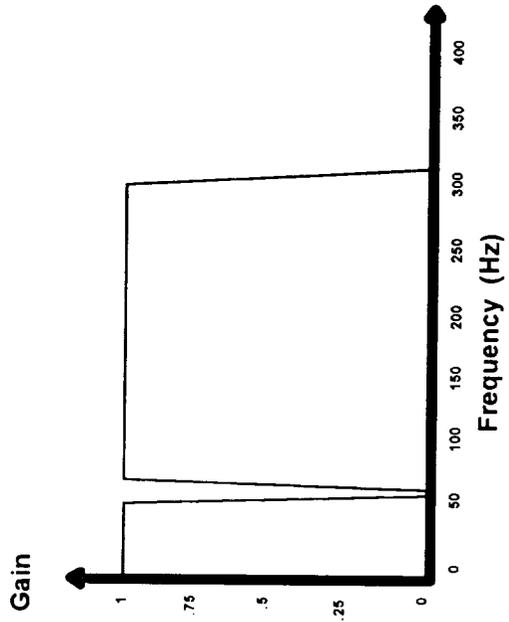
OPERATION

To utilize the USCA, a transducer must be provided with a Tag Ram containing the information pertinent to the transducer. To calibrate a transducer, its stimulus is varied and its output is recorded 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 at that time.

When a new measurement is installed, the transducer equipped with a 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.



(a)



(b)

Figure 3. Examples of digital filters generated for USCA.
 (a) 300 Hz lowpass filter.
 (b) 300 Hz lowpass filter with 60 Hz notch.

USCA DEVELOPMENT

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

The current work is concentrating on the miniaturization of 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 USCA will be placed in an explosion proof enclosure capable of withstanding the temperatures, pressure and vibration which are present at the launch pads when the Space Shuttle lifts off. To achieve better temperature stabilization, the USCA will be filled with a good thermal conductive fluid. The transient protection circuitry will be able to be replaced without opening 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 the need of opening the liquid-filled case. Final characterization of the performance of USCA will be conducted following the completion of the miniature unit.

COMMERCIAL APPLICATIONS

The technology used in the development of the USCA can be utilized also 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 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 cases 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 on using the USCAs in 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.

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