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## Paper Session II-C - Low Cost Self-calibrating, Field Serviceable Signal Conditioning Amplifier

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# **Low Cost Self-Calibrating, Field Serviceable Signal Conditioning Amplifier**

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## **Abstract**

Multiple sensors are used to conduct measurements during every Space Shuttle flow. Often, these measurements have to be installed at locations where available space is minimal. Signal conditioners have a frequent need to be removed from service for calibration, typically, on an annual basis. The calibration must be performed in a shop with traceable test equipment, and can require several hours of manpower.

A low cost miniaturized Signal Conditioning Amplifier (SCA), based on the use of Application-Specific Integrated Circuits (ASIC) and IEEE 1451-compliant, will reduce the manpower required to set up new measurements and to replace or calibrate existing ones. The SCA is connected to a transducer attached to a Transducer Electronic Data Sheet (TEDS), which is read by the amplifier upon power up. The TEDS contains information required by the amplifier to configure itself to operate with a particular transducer. The signal conditioner is capable of performing continuous health checks and auto-calibration and significantly reduces operating and maintenance costs of a data acquisition system. The use of ASICs will also allow for the implementation of multi-channel devices for additional reduction in space and power requirements.

## **Description**

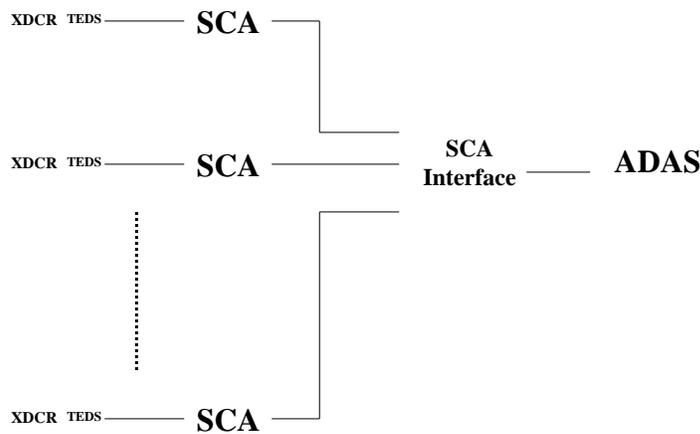
The Signal Conditioning Amplifier is a self-calibrating, programmable device which performs real-time signal processing. It is a self or remotely programmable amplifier, which sets itself up for operation with a transducer, based on information stored in an electronic data sheet. The signal conditioning amplifier was initially designed to improve the performance of the Ground Measurement System at the Kennedy Space Center (KSC). The SCA significantly reduces the time required to set up a new measurement, from several hours to a few minutes. Many transducers used at KSC have outputs in the order of a few millivolts. Noise coupled into cables deteriorates the performance of the measurement system. The small size of the SCA, as well as its rugged design, allow the amplifier to be located close to where the measurement is conducted thus minimizing cable lengths.

In the GMS system, when a transducer is calibrated, a small memory chip is attached to it. The memory device contains information required by the SCA to configure itself to operate with the transducer. This includes excitation level, linearization coefficients, digital filtering, sampling rate, and others. Upon power up, or

while no transducer is connected to the SCA, both the excitation voltage and analog output are set to zero, and the input gain is set to unity. When the SCA is connected to a transducer, it reads the information stored in the electronic data sheet, and configures itself for proper operation. The analog input gain, excitation level (voltage or current), digital filter, and output range are set within six seconds after connecting the transducer to the SCA. An operator can remotely change the settings specified in the electronic data sheet if required.

### Advanced Data Acquisition System (ADAS)

A block diagram showing the implementation of the measurement system is shown in Figure 1. The ADAS can control the operation of multiple signal conditioning amplifiers in the field. Digital data sent by the SCAs is received by the ADAS is stored and distributed as needed. The ADAS allows an operator to change gain settings, change digital filters, and download custom filters. The status of every SCA is continuously monitored, and alarms are issued if a faulty SCA is detected. The ADAS also maintains an activity log including any SCA or transducer connect/disconnect operation, or any changes from the default configuration.



**Figure 1. Measurement System Configuration**

### Transducer Electronic Data Sheet (TEDS)

The Transducer Electronic Data Sheet is implemented with a small 8-bit microcontroller containing a 256-byte non-volatile memory. The TEDS is loaded with data after the transducer is calibrated. The TEDS includes information regarding the transducer type, required excitation level, output voltage range, linearization coefficients,

measurement identification number, and others. The TEDS is placed inside a molded, sealed connector to protect it against harsh environments. Immediately after the SCA detects the connection of a transducer, the TEDS is read and within six seconds the SCA is configured for operation.

### Signal Conditioning Amplifier

Figure 2 presents a block diagram showing the main functional modules of the SCA. A combination of accurate analog amplifiers, multiplexers, and real-time digital signal processing is used to accomplish reliable signal conditioning even under extreme environmental conditions.

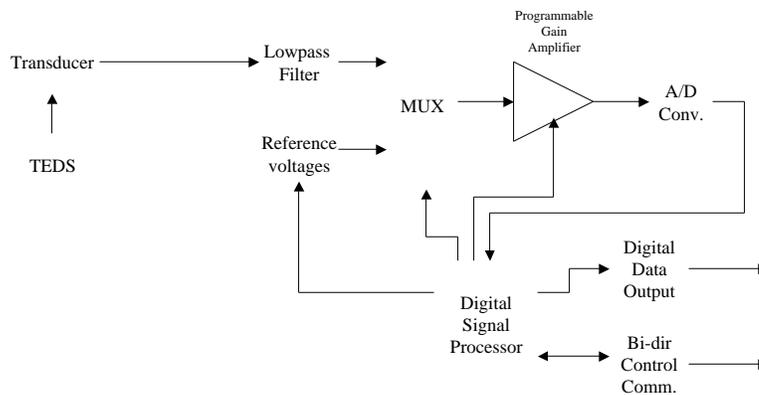


Figure 2. Signal Conditioning Amplifier

The SCA is powered by a 20-36V source. Four DC-DC converters provide the power required by the SCA for operation, and provide the electrical isolation between the power, analog input, and digital output sections.

The input section consists mainly of three amplifier sections, multiplexers, and analog switches. The lowpass filter has been designed for a 500 Hz cutoff. The programmable stage allows for gains ranging from 1 to 1000 V/V. The output of the amplifier stage is digitized at 1000 samples per second, using an analog-to-digital converter with a 16-bit resolution.

The excitation driver provides a highly stable voltage or current for the transducer. The excitation is set to the level specified in the TEDS, and is controlled by a 16-bit digital to analog converter. The excitation driver can set an excitation voltage with a resolution better than 500 microvolts, and an excitation current with a 0.1 microamp resolution. The current output from the excitation driver is limited to 60 milliamps in order to prevent damage in case of a short circuit condition.

The digital signal processing section performs real-time digital filtering and linearization. Up to eighth-order linearization can be achieved while operating at 1000

samples per second. Digital filtering is done using 128<sup>th</sup> order finite-impulse-response (FIR) filters. Standard coefficients for the digital filters reside in the SCA, and custom coefficients can be downloaded through the ADAS.

Signal conditioning amplifiers have to be calibrated periodically to ensure their accuracy. Deviations from nominal performance are usually caused by component degradation or aging, and by temperature changes. The SCA has an internal reference that is used to perform continuous self-calibration, while using only one amplifier path. Amplifier gains can range from unity up to 1000. The continuous calibration is used to verify and adjust the gain and offset of the amplifier using the internal reference voltages. This allows the amplifier to compensate for rapid variations introduced by temperature changes and slower variations caused by component aging.

The continuous calibration using a single amplifier path is achieved as follows: The output of the transducer is first lowpass filtered in order to eliminate high frequencies that could result in aliasing when the signal is digitized. The reference voltage, a zero reference, and the signal from the transducer are sequentially applied to the amplifier, under control of the microprocessor, with only one amplifier stage calibrated at a time. The amplifier has a large enough bandwidth to allow for the signals to settle before a sample is taken. The DSP processor combines the gains of each stage and calculates the overall gain of the complete amplifier path. These values are then used to dynamically compensate for shifts in gain and offset.

### External Calibration

Since even a stable internal reference can degrade over time, the signal-conditioning amplifier needs to be periodically calibrated by an external traceable source. A miniature microprocessor-based portable calibrator can be connected to the SCA in the field, without the need to remove it from its location. The calibrator device automatically commands the SCA to cycle through its different operating modes (gains, filtering, etc) and applies the appropriate voltage or current to its input. The software inside the SCA then calculates and updates the internal reference voltage, updates reference resistors, and other parameters as needed. The results of the calibration are then reported directly to a central logging station, where calibration records are automatically updated. This calibration eliminates the need for an external calibration station. The calibrator itself is calibrated periodically in the lab to ensure its accuracy.

The output of the SCA is digital, and is suitable for use in systems using the emerging IEEE P1451 standard. A small device can be plugged at the output of the SCA to produce analog data from the digital stream. This is a useful tool when testing or troubleshooting a measurement in the field. A custom “configuration card” could be added for specific applications where special requirements are needed. This card could be used to increase amplification, allow frequency measurements, and others.

## Conclusions

The Signal Conditioning Amplifier described here can satisfy most requirements at KSC as well as most commercial applications. The SCA is an ideal solution for test cells, where sensors are frequently reconfigured for individual tests. The rapid configuration of the SCA once a transducer is connected to it can save several hours of measurement setup time. A ruggedized version of the SCA could be used in situations where a harsh environment can be expected.

The main novel features of the SCA and its support devices are:

- 1) Continuous self-calibration and health checks are non-disruptively performed, while using a single amplifying channel.
- 2) The digital design is suitable for use in systems using the emerging IEEE P1451 standard.
- 3) A field calibrator, capable of fully calibrating and certifying an SCA in the field, without the need to remove it from its location. Human intervention is limited to connecting the calibrator to the SCA.
- 4) A miniature digital-to-analog converter that can be attached to the output of the SCA in the field for testing and debugging purposes.

The SCA can be manufactured at a significantly lower cost than existing devices, while providing several important benefits. The capability for the SCA to be calibrated in the field, along with its continuous health check monitoring can result in large savings in manpower by reducing operating and maintenance costs of a data acquisition system