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Universal Signal Conditioning Amplifier

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ABSTRACT

Engineers at NASA's Kennedy Space Center have designed a signal conditioning amplifier which automatically matches itself to almost any kind of transducer. The product, called Universal Signal Conditioning Amplifier (USCA), uses state-of-the-art technologies to deliver high accuracy measurements. USCA's features which can be either programmable or automated include: voltage, current, or pulsed excitation, unlimited resolution gain, digital filtering and both analog and digital output. USCA will be used at Kennedy Space Center's launch pads for environmental measurements such as vibrations, strains, temperatures and overpressures. USCA is presently being commercialized through a co-funded agreement between NASA, the State of Florida, and Loral Test and Information Systems, Inc.

Keywords: signal conditioners, data acquisition, measurements, transducers, sensors

1. INTRODUCTION

Kennedy Space Center is the launch site for America's Manned Space Flight Program. The Space Shuttle can be launched from either of the two pads in the Launch Complex 39 (LC-39) area (Figure 1). The LC-39 launch pads were originally designed and built in the 1960's for the Saturn V moon rocket. Pad A was modified in the late 1970's for the Space Shuttle program and Pad B was finally modified in the mid 1980's to give the Shuttle program two launch pads.

The Permanent Measurements System (PMS) was designed and installed in the early 1980's to meet the needs of the Shuttle program and replace obsolete Apollo era equipment. The system was designed to support measurements at both launch pads and at the Vehicle Assembly Building. PMS supports multiple parts of the launch processing flow. During the stacking of the Solid Rocket Boosters (SRB) on the Mobile Launch Platform (MLP), the system monitors the strains on the booster hold down posts. These posts bear the load of the entire vehicle until it is released at launch. The strain measurements allow engineers to verify that the bearing assembly, where the booster meets the post, is not binding as each successive booster segment is stacked. After stacking and testing are completed, the vehicle and MLP are moved to the launch pad for final launch preparations. At the launch pad, the system is activated during the countdown and makes many different types of measurements. Some of these are monitored real-time, such as the liquid oxygen pump vibrations, and some are recorded at the time of launch for later analysis. Examples of these are, overpressure, temperature, vibration, displacement, strains and acoustic shock measurements.

The PMS consists of rack mounted signal conditioners which have programmable gains and four programmably selectable filters (Figure 2). The output of the signal conditioners, which are located in the MLP, are sampled by a unit which performs A/D conversions, as well as multiplexing the data into a PCM data stream. This data stream is sent to the Launch Control Center (LCC) where all of the data is recorded for later analysis. The system has limited real-time data display capabilities. Selected low rate data is placed on a 256Kbit PCM stream where it is decommutated and displayed. Only 32 channels of data can be displayed at one time.

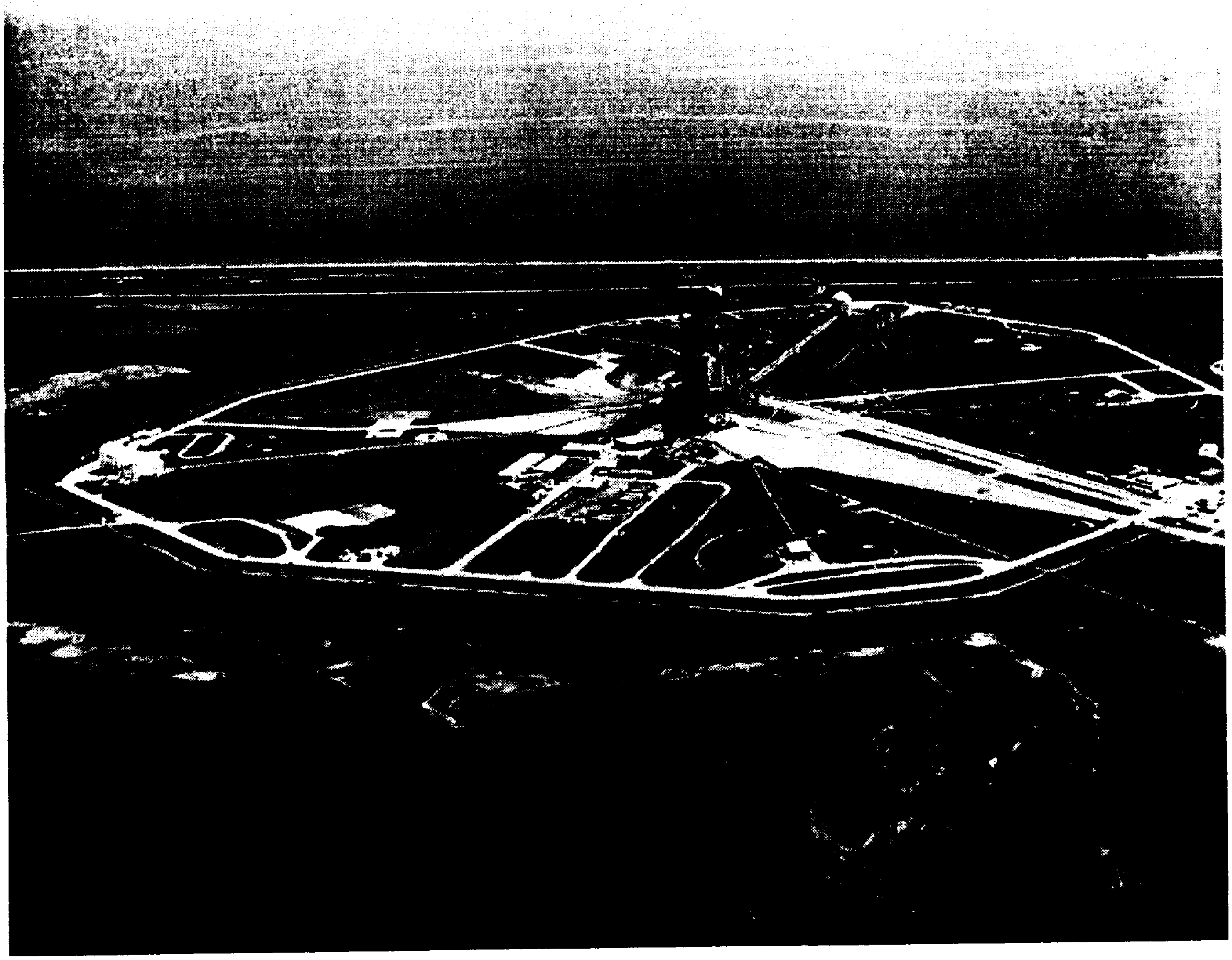

Figure 1: Launch Complex 39

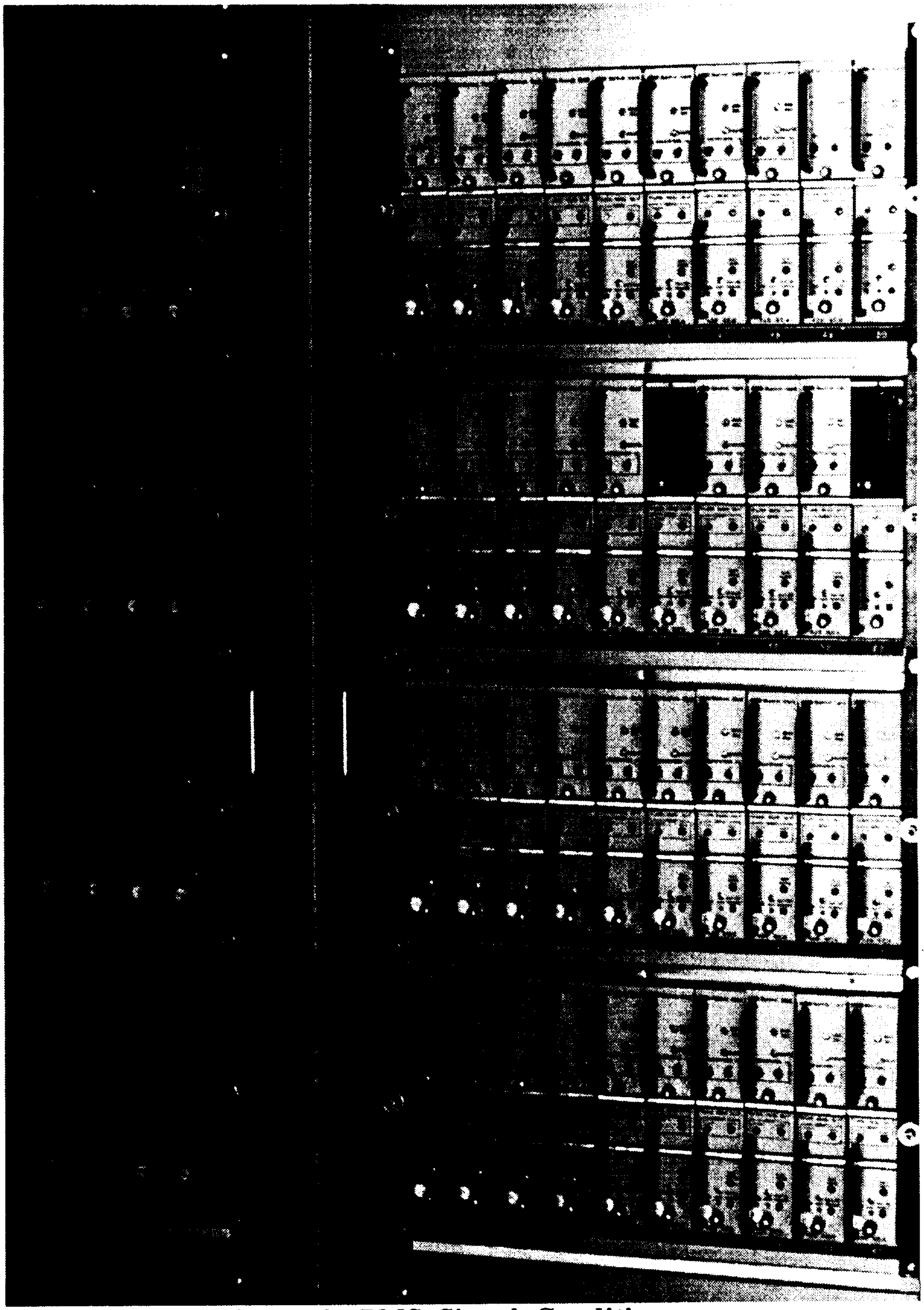

Figure 2: PMS Signal Conditioners

Several factors have led the Shuttle program to plan the replacement of the PMS. One of the primary reasons is the age of the system. The original equipment manufacturer stopped supporting the product line several years ago. KSC performs its own maintenance on the equipment, but the rate of failure has increased and parts are becoming increasingly difficult to obtain. In some cases, maintenance is being accomplished via cannibalization. The second, and equally important, reason that the system is being replaced is the large amount of manpower necessary to set up each measurement. Setting up a measurement in the current system is a four step process. First, the transducer is calibrated. Second, the signal conditioner is run through a series of certification tests. Third, the signal conditioner is custom matched to each transducer in a calibration laboratory and finally, the matched pair is installed in the field. The entire process takes between two to four man-hours. With the potential of over 200 measurements for each launch, this system consumes considerable manpower. If a measurement fails during use, the entire process must be repeated!

In an effort to improve efficiency and reduce the cost of Shuttle operations at KSC, management has initiated a center wide search for improvement opportunities. With this in mind, NASA engineers and their contractor counterparts in the Data Acquisition Laboratory began looking for ways to improve the PMS measurement process. The primary goal was simple to identify; "Use state-of-the-art technologies to reduce the manpower necessary to make Shuttle measurements." A series of study projects funded by NASA's Office for Advanced Technology ultimately led to the development of the Universal Signal Conditioning Amplifier. However, in the process of meeting the stated goal, a signal conditioner with exceptional capabilities was created.

2. UNIVERSAL SIGNAL CONDITIONING AMPLIFIER

The Universal Signal Conditioning Amplifier has been designed to meet the needs of the Shuttle program for at least the next 15 years. USCA is a self or remotely programmable device which provides all the necessary capabilities to make an accurate measurement. It automatically configures itself to match the transducer to which it has been connected. This reduces the time that is required to set up a measurement to seconds. USCA contains multiple programmable components which allows this automated configuration to take place. The design consists of a programmable D/A converter for transducer excitation, a programmable gain amplifier, a 16-bit A/D converter, a Digital Signal Processor for filtering and data linearization, and an output stage which provides both analog and digital outputs. Figure 3 presents a block diagram which shows the major modules of a USCA. The following paragraphs describe each of the major modules.

The entire measurement system revolves around the contents of a device called the Tag Ram. The Tag Ram is typically installed in the molded end of the "pig-tail" cable, which adapts the transducer to KSC's standard eight conductor instrumentation cable. Most of the information is loaded into the Tag Ram at the time of calibration. Other information can be loaded by measurement engineers at any time prior to measurement installation. This small circuit board (Figure 4) contains all of the information necessary to allow USCA to configure itself for the transducer to which it is connected. When a USCA is connected to a transducer "pig-tail" it reads the contents of the Tag Ram using a serial data communications protocol. Information such as, transducer type, excitation requirements, input gain, digital filter type, analog output levels, and sample rate are some of the basic information contained in the Tag Ram. The Tag Ram also contains information about the transducer's full scale range, the range over which it was calibrated and its linearization coefficients, and the measurement range over which the transducer will be used. This information allows the USCA to optimize the input gain, delivering a measurement of maximum accuracy. It also allows USCA to perform up to a seventh order linearization of the transducer's output in real-time. This distributes some of the data processing effort away from the host computer, freeing it to perform other tasks such as high speed data display. Other areas of the Tag Ram are set aside for user definition. For example, KSC will add fields for measurement name and a unique identifier, which allows the host computer to perform automated system setup and configuration control.

Once USCA has read the setup information in the Tag Ram, it is ready to configure itself for operation. The excitation module is commanded to the output levels which were read from the Tag Ram. This dual channel, 16 bit, D/A converter is capable of providing a highly regulated voltage or current output. The module allows the selection of an excitation voltage between 0 and 27VDC with a resolution of about 500 μV. In current mode, the module can provide currents between 0 and

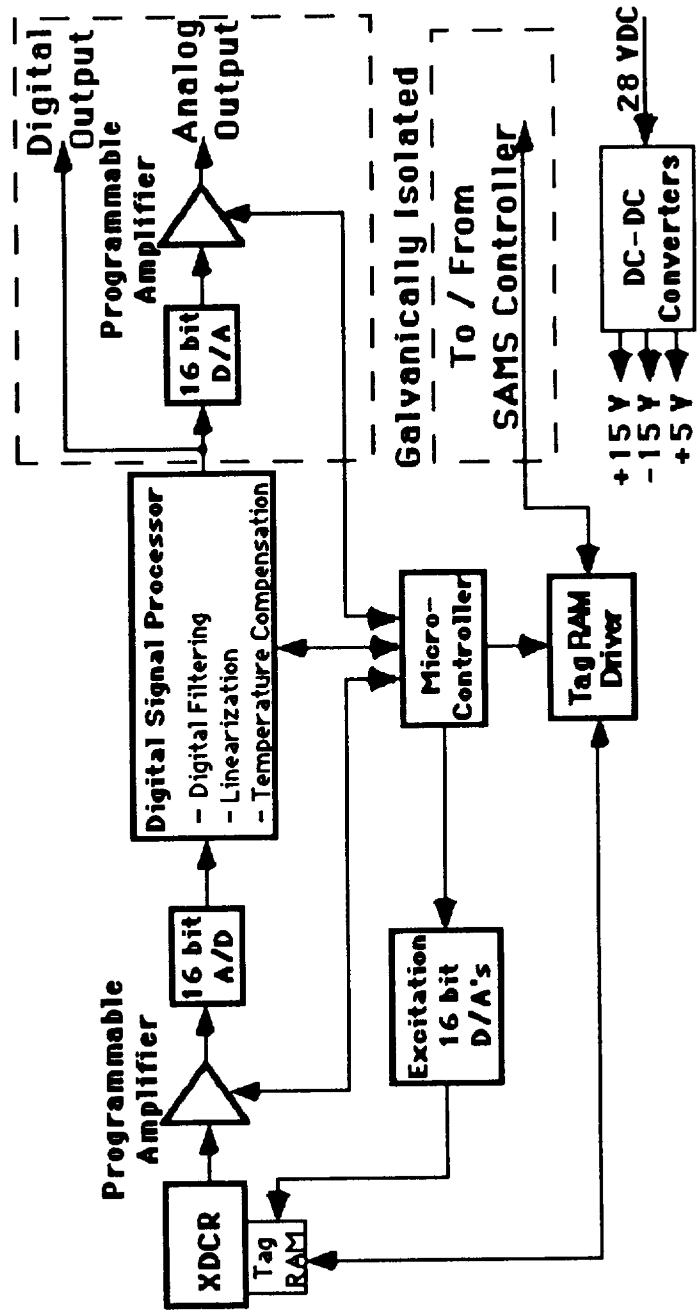

Figure 3: USCA Block Diagram

60 mA with a resolution of better than 1μA. Current limiting circuitry limits the output current of the excitation module to 100mA. A bypass mode is available for both the voltage and current modes which allows the USCA to pass through the output of the remote power supply. The accuracy of this mode is limited to the resolution of the remote supply.

Once excitation is applied to the transducer, USCA then configures it's input module. USCA contains a highly stable programmable gain amplifier which includes transient and over voltage protection. The circuits have been designed to provide a DC to 9.6kHz passband which is flat to within 0.2 dB. The programmable gain stage can select gains between 0.25 and 2000, allowing USCA to accept full scale inputs from 40V down to 5mV. An anti-aliasing filter is then applied to the signal before it is sampled at 38.4k Samples/sec by the dual channel 16 bit A/D converter.

Both the excitation and input modules are controlled by a Digital Signal Processor (DSP). The DSP performs multiple tasks insure the accuracy of the measurement. Taking advantage of the dual channel A/D converter, the DSP performs a continuous calibration check. A highly stable voltage reference, better than 1ppm/°C, is sampled by the inactive A/D channel and digital gain adjustments are made by the DSP to correct for errors. Once that A/D channel is calibrated, it is swapped with the other A/D channel so that it can be calibrated. This entire process takes place continuously and is transparent to the user. However, it does allow USCA to constantly check on it's health and report any serious deviations back to the host CPU immediately.

The DSP also provides the USCA with many other features. Using the linearization coefficients downloaded from the Tag Ram, up to a seventh order equation can be performed in real-time. Another use of the coefficients will allow frequency based measurements to be made by a USCA. To eliminate noise in the measurement, a 64^{th} order digital filter can be applied to the data. Memory space has been set aside in the USCA to accommodate seven standard high pass and low pass filters. An eighth memory area has been set aside to allow the user to download custom filter coefficients from the host computer. Using commercially available filter design packages, passband and notch filters can be designed and downloaded. Another feature that the DSP allows is the dynamic control of the excitation module. This gives USCA the ability to do more than simple DC excitation. It can provide pulsed excitation with various duty cycles and amplitudes. This can be useful when making strain measurements where high excitation voltages may cause a self heating problem. Pulsing the excitation can significantly reduce the self heating while still allowing an accurate measurement to be made.

Once the DSP has completed the signal processing functions, it also handles the data output functions. USCA has two data output paths, one is analog and the other is digital. The analog output can select from several output ranges. Ranges of 0-5VDC, 0-10VDC, ±5VDC and ±10VDC are selected based on the contents of the Tag Ram. A dual channel 16 bit D/A converter performs the output function. The DSP checks and calibrates the analog output of the USCA in the same manner as the input module described above. A serial port on the DSP is used to send digital data back to a serial data multiplexer (also a development of KSC). The serial port supports data transfers at 19.2k samples/sec.

USCA is mechanically designed to be installed as near as possible to the transducer. Therefore it is engineered to survive the harsh environment of the launch pad. A cylindrical stainless steel enclosure ≈3.25" x 6.0" houses the USCA circuit boards. The major circuit boards are rectangular with the analog circuits on one, with the digital functions on the others. Interconnects between the boards are handled by circular boards located at both ends of the enclosure. The edge connectors on these boards capture the ends of the rectangular board as well as handling the wiring to the external connectors. USCA is designed to operate in an environment of -10° to 60° C and during the shock and vibration of a Shuttle launch.

3. USCA SYSTEM CONTROLLER

USCA is a key component in the an overall measurement system which has been named the Self Aware Measurements System (SAMS). The SAMS controller provides an interface between USCA and the host computer. It has circuitry which manages up to 256 USCAs at a time. It dynamically detects USCA connects/disconnects and maintains a date/time log, which allows the host computer to automatically manage an instrumentation configuration database. Other configuration

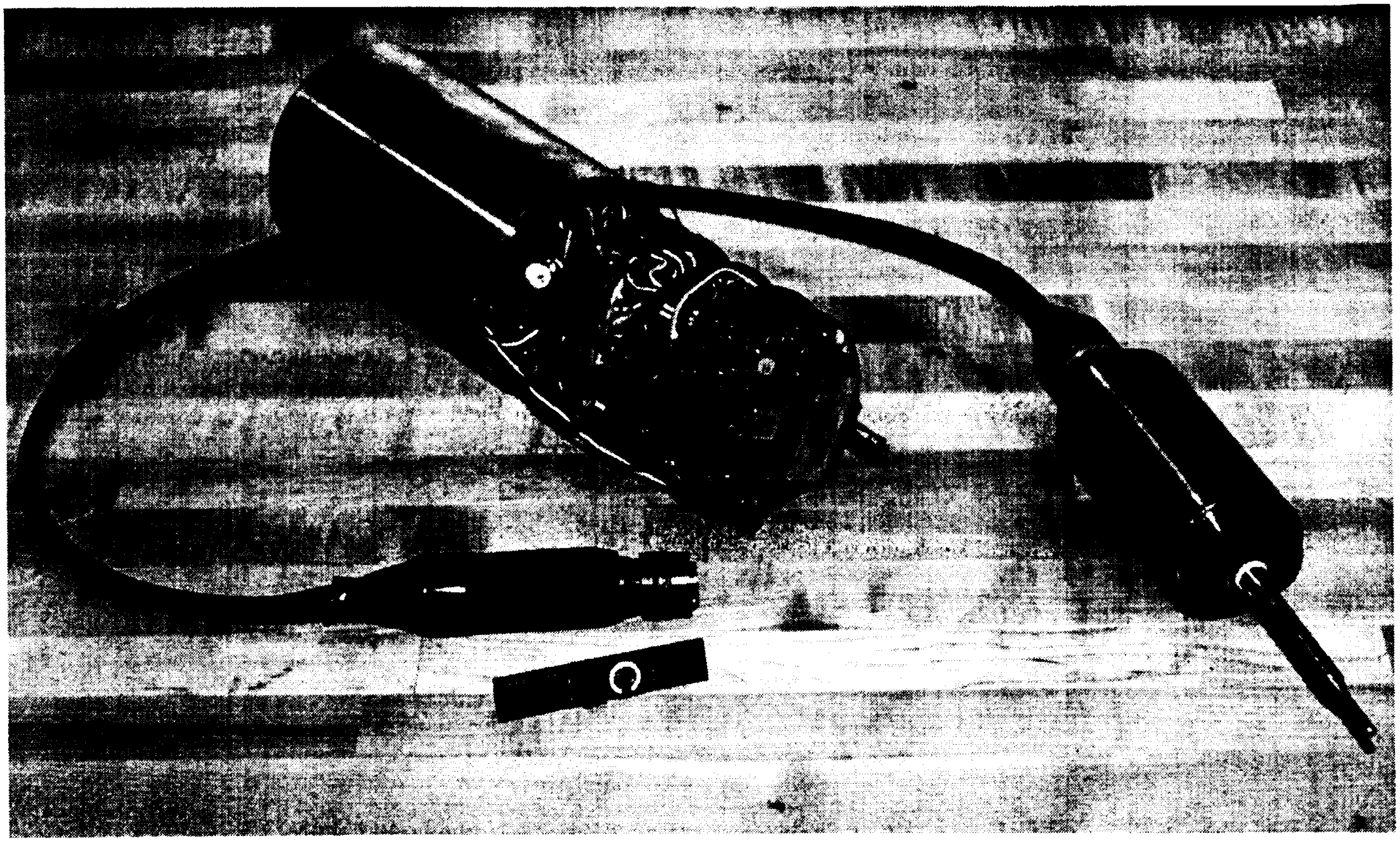

Figure 4: USCA Prototype/ Tag Ram in foreground

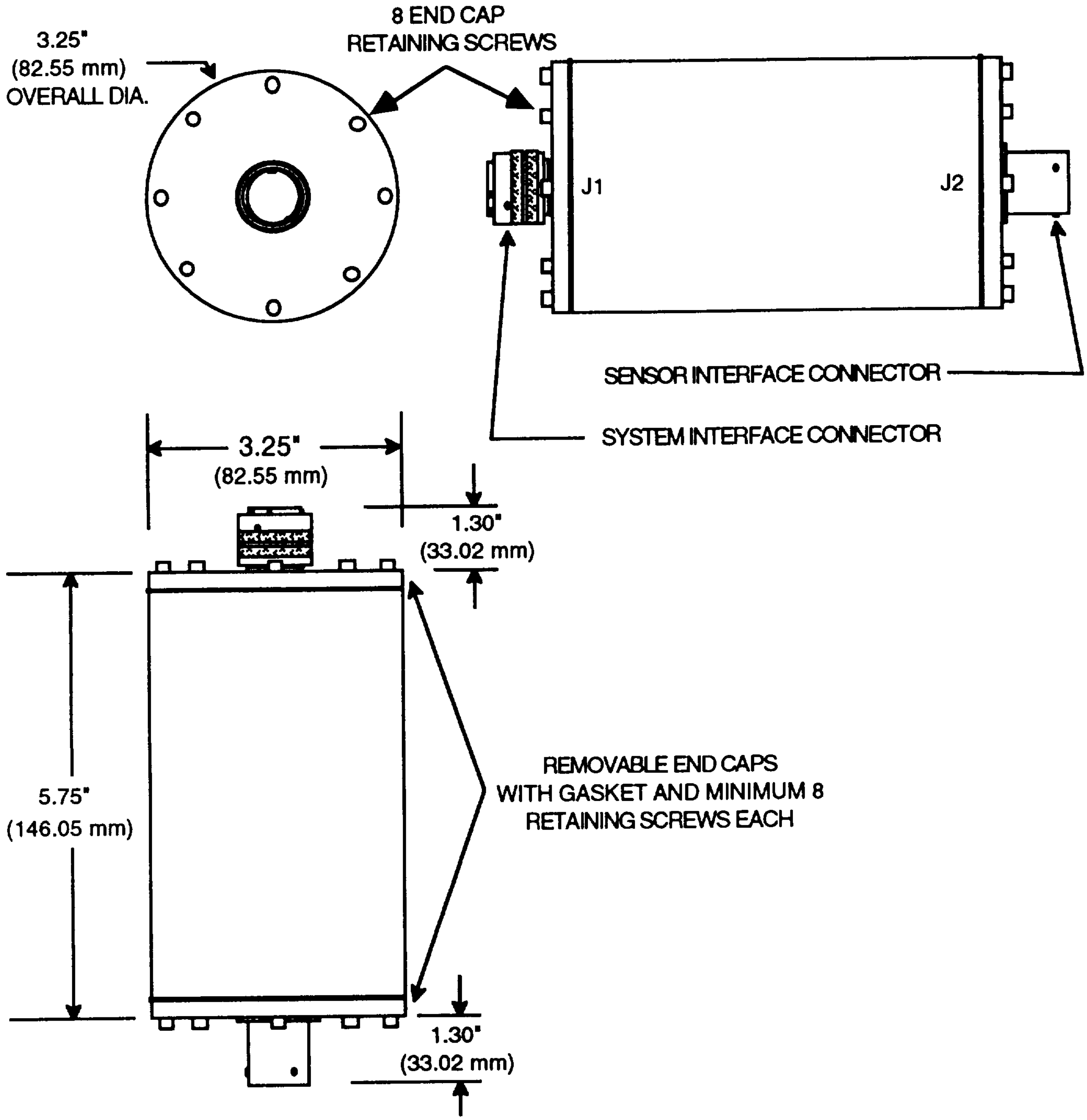

Figure 5: USCA Sketch

information can also be managed by SAMS. For example, if calibration due dates are placed in the Tag Ram when the transducer is calibrated, SAMS can track the need for recalibration and provide a report of transducers needing to be replaced. SAMS responds to USCA status interrupts in case a USCA requires service. SAMS can provide a synchronization clock pulse to the USCAs so that the sampling clocks of all USCAs remain synchronized to within 1 μsec. Even though USCA configures itself upon connection to a transducer, SAMS allows the user to modify the USCA configuration when needed. It is also the conduit through which standard filters are selected and custom filters are downloaded.

The feature discussed here are just a few of the existing capabilities of the SAMS system. As the system matures, additional features will be added. Software will be implemented in the next year to automatically configure the serial data multiplexer. This will allow the system to assign a unique identifier to each USCA, at the time it is plugged in, and then transmit each USCA's data in a tagged format back to the data recording computer. The data recording computer will be integrated with the SAMS host, which will result in a totally automated data acquisition system.

4. COMMERCIALIZATION OF USCA

Within the last year, NASA has adopted a more aggressive approach in moving agency developed technologies into the private sector. USCA is the subject of one of the ground breaking commercialization efforts. USCA's completion is presently being co-funded by two other parties, the State of Florida and Loral Test and Information Systems Inc., of Florida. The State's involvement is through the Technological Research and Development Agency (TRDA). The agency was created by the Legislature to help spur high-tech economic development within the State. Loral was selected by the TRDA through a competitive process which was based on technical as well as economic factors. All three parties contribute an equal share of capital to the development of USCA.

USCA has been through several prototype stages and is now in its final stage of development. Initially a breadboard prototype was constructed to perform a proof of concept demonstration. Next, the design was reduced to a set of circuit boards with enhancements added. Recently, the final miniaturization of the circuit design was completed. This unit is intended to meet all of the electrical and mechanical requirements for a USCA. Testing will be performed throughout the remainder of the summer. Any adjustments to the design will be made by the end of August and Loral will manufacture production prototype units by the end of October. These units will undergo full qualification testing in KSC laboratories before being installed at the launch pad for field trials in December.

Loral is planning to manufacture two versions of USCA. The first, will be the rugged NASA version of the product. The second, will be an industrial version which can be used in a more normal environment. Loral plans to layout the USCA circuitry on VME style cards. The hope is to provide multiple channels per card while improving the ease of manufacturing the units. Loral plans to have this version available in the first quarter of 1995.

5. SUMMARY

KSC has developed a unique signal conditioner which automatically configures itself to match the transducer to which it has been connected. The unit reduces the time required to set up a measurement to a few seconds. The design revolves around a memory device attached to a transducer which is called a Tag Ram. The Tag Ram stores all of the information necessary to use a transducer. USCA uses the information in the Tag Ram to set itself up. USCA contains a DSP chip which performs measurement filtering and linearization. The DSP also performs continuous health checks and calibration of USCA's analog input and output paths.

USCA has become part of a special commercialization effort between NASA, the State of Florida and a private firm, Loral Test and Information Systems. NASA/KSC will provide the majority of the engineering while Loral will address the issues of manufacturability. Loral will manufacture the ruggedized version of USCA for KSC's use. Loral will also design an industrial version of the product which will have a VME form factor.

6. ACKNOWLEDGMENTS

USCA is the result of the efforts of many innovative and dedicated individuals. Without their efforts, the authors would been unable to complete this project. As such, we gratefully acknowledge: Dr. Stuart Gleman for the SAMS design concepts and numerous helpful discussions throughout the USCA design process, Steve Thayer for initial software design and implementation, James Simpson for further software design as well as digital design enhancements, Dave Thompson for his work on the USCA, Tag Ram and SAMS concepts, Curtis Ihlefeld for his work on digital data transmission, Yosef Yariv for schematic entry, board layout and logistics support, Jim Henderson, Rick VanGilder, and Johnny Kerce for USCA prototype fabrication, W. A. Crawford for SAMS prototyping, Dean Becker for critiquing our designs and finally Mark Nurge, Jim Cecil and Jeff Ake for help in all aspects of this project.