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Development of a Portable Gamma Radiation Monitoring System

K. Arshak, D. Buckley, O. Korostynska

Abstract – This paper demonstrates the feasibility of a portable gamma radiation monitoring system, based on the Anderson Current Loop circuit, where Nickel Oxide (NiO) thick films are used as radiation-sensing elements. A cost effective prototype system was developed for remote ionising radiation monitoring that is required to minimise the necessity for human interaction and consequently prevent possible exposure.

I. Introduction

Ionising radiation is used extensively in areas such as environmental monitoring, food irradiation, diagnostic and therapeutic medical procedures, and aerospace and military applications, where accidents could pose serious health risks to those in the proximity of these radiation sources. Terrorist attacks are an ever-present and ever-increasing threat and as such we must be equipped to handle any type of possible attack, including exposure to ionising radiation. Successful and safe remediation of radioactive waste sites is dependant on accurate monitoring of radioactive plumes to ensure that they are not emitting radioactive material into the surrounding environment.

The ability to detect and measure radiation dose is of great importance, and necessitates the use of sensitive and accurate devices for these functions. It is therefore imperative to explore alternative detection strategies. This paper describes how the Anderson current loop [1] is used to measure the effect of Gamma radiation exposure on thick film Nickel Oxide radiation sensors [2]. This novel method is based on continuously measuring the resistance of the sensor as it is exposed to radiation and detecting a change in potential across the sensor as its resistance is increased due to absorbed dose.

II. System Description

The diagram in Fig. 1 shows a simplified overview of the prototype system's setup. The ADuC812 micro-converter, the Anderson Loop circuit, and the sensor are shown separately even though they are amalgamated on one printed circuit board (PCB) in the final prototype. The System consists of the thick film radiation sensor connected to the resistive conditioning analogue front-end of the circuit, the Anderson Loop, who's output is connected to the Analogue to Digital Converter (ADC) of the system's microcontroller, Analog Devices AduC812 micro-converter [3]. This microcontroller stores the output of the Anderson Loop in its internal memory and outputs the value to an on-board LCD display and to the serial port connection. This serial port connection can be (optionally) connected to a PC, using RS232 protocol, where a LabVIEW [4] graphical user interface (GUI) shown in Fig. 2 displays the voltage, dose and circuit temperature in real time as well as saving it to an Excel file (or to any other format the user wishes) for later use. It should also be noted that in Fig. 1 and in the final prototype the ADuC only receives readings from the Anderson Loop, however, two-way communication can be easily setup. This could allow the ADuC to access digital potentiometers in the Anderson loop circuit to allow control of the gains and other such configuration parameters through software (i.e. through the assembly code downloaded to the AduC812).

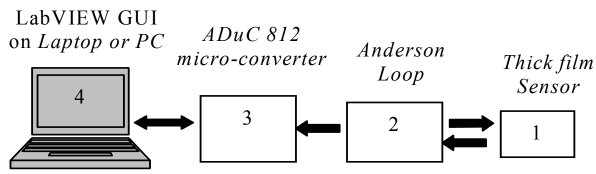

Fig.1. Prototype system overview.

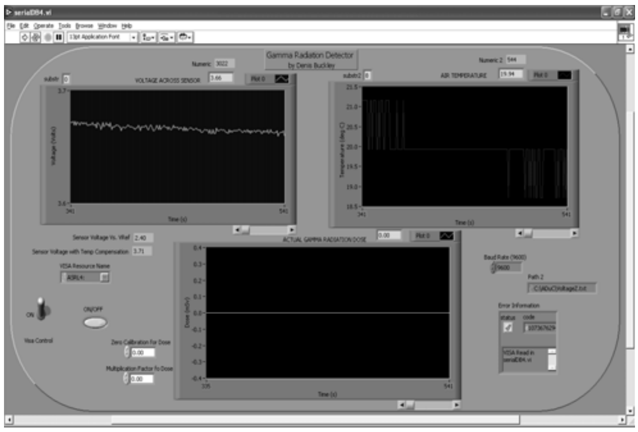

Fig. 2. LabVIEW graphical user-friendly interface, displaying voltage changes as a function of dose.

The serial port connection is also used to download readings stored in the ADuC812's internal memory that could have been previously taken at a remote location. This, along with the system's ability to run from the mains or battery power, allows the device to be portable or used directly with a PC. It can be worn on a person's body or clothing and used for personal radiation monitoring where

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the present dose can be easily read from the LCD display and will alarm if the dose level exceeds a preset safe level. It can also be left in a remote location taking measurements for up to 12 hours, a time easily increased, this was just for the prototype and only limited by memory capacity and battery life. It can then be retrieved, and information stored on it from radiation measurements, downloaded to a PC. The system also shuts off entirely when the battery potential falls below a certain level. This ensures that a false reading is not output to the user due to low battery power.

This system can easily be extended to a wireless format where data from many metres away, could be transmitted back to a receiver unit connected to a PC. Alternatively, up to eight sensor and Anderson Loop pairings (number only limited in the prototype by the number of ADC channels available on the microcontroller used) can be located with long wires at several locations and all eight sensors could relay information back to the ADuC812 and PC concurrently (every 300ns) as shown in Fig. 3. One of the applications for this could be the monitoring of radioactive plumes from radioactive waste storage sites. With the PC setup as a central monitoring station the system could detect and quantify radioactive plumes during remediation, verify the absence of radioactive materials and ensure that radioactive material is not contaminating the surrounding area.

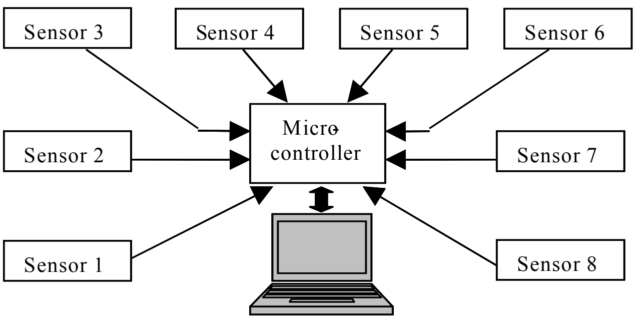

Fig. 3. Eight sensors relying radiation measurements back to PC.

A. Anderson loop

For resistive conditioning, this system uses an Anderson Loop arrangement. This was chosen for its low power consumption, and the accuracy that it achieves for its relatively simple design. The Anderson Loop concept was invented to deal with lead-wire resistance variation problems that occurred when connecting high temperature strain gages to conventional bridge signal conditioning in the Flight Loads Laboratory of the NASA Dryden Flight Research Centre. It was first described by Karl F. Anderson of NASA Dryden Centre in 1992 [1] and subsequently patented by NASA [5]. The Anderson Loop is a relatively simple, easy to design, reliable, cost effective, low power circuit with few components and can be easily calibrated for different sensors' resistance ranges.

The underlying concept of the Anderson Loop is a simple blending of continuous analog subtraction with Kelvin sensing as shown in Fig. 4. A current source provides the excitation for a reference resistor and a resistive sensor. The voltage differences induced across each resistor are subtracted from each other, and the output voltage is proportional to the difference in resistance between the two (when using a high-impedance device, like an instrumentation amplifier, to measure the reference and sensor resistances, such that very little current is drawn).

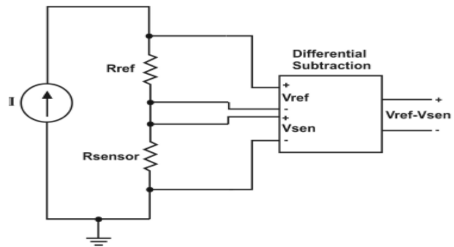

Fig. 4. The Anderson Current Loop concept showing active differential subtraction.

The output of the Anderson loop is simply a voltage that represents the differences in resistance of the sensor and reference resistor, as described by Eq. 6. These are initially setup to be of similar resistance and the output voltage can be set to null (or a predefined agreed "zero" point) and will remain like this until the resistance of the sensor is altered due to exposure to radiation dose. The Anderson Current loop automatically maintains a constant current across both the reference resistor and sensor and the output is then a change in potential. This potential or voltage change is relative to the change of the absorbed dose of the sensor as is shown in the Results section below.

By altering various variable resistors within the circuit the gain can be adjusted and essentially the output can be modified to suit any sensor or measurement range the user desires so essentially sensors manufactured to be more sensitive to particular radiation dose ranges can be multiplexed to give wide ranging sensitivity.

The basic Anderson Loop circuit configuration used is shown in Fig. 5. There were several additions made to this circuit, for example, filtering and necessary interfacing with the ADuC812 micro-converter some of which can be seen in the system block diagram in Fig. 6.

B. Thick film sensors

Gamma rays produce a change in the density of charge carriers in semiconductor material, which alters the material properties in measurable way. This change provides information on the dose absorbed by the material. It is believed that ionising radiation causes structural defects (called colour centres or oxygen vacancies in oxides) leading to a change in their density on exposure to γ-rays. In this work, thick film NiO sensors were used, whose electrical properties are altered by the presence of ionising radiation [2].

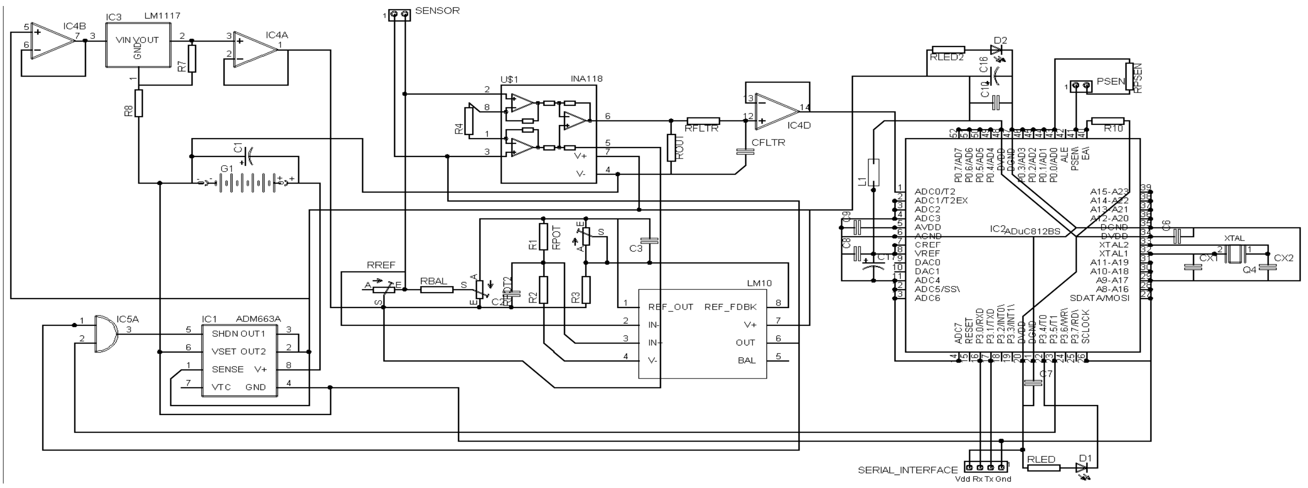

Fig. 6. The basic system block diagram used for the prototype.

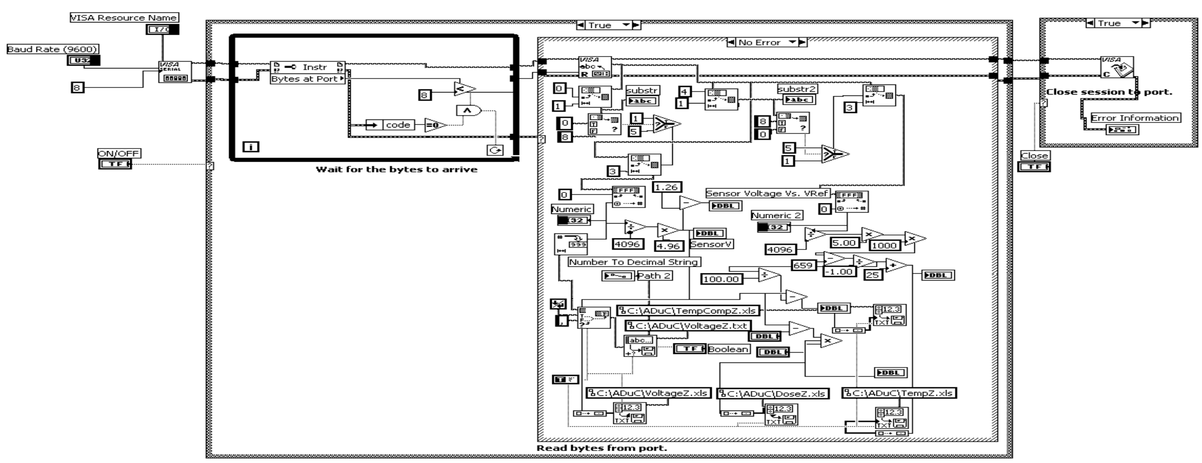

Fig. 7. The source diagram of the LabVIEW GUI shown in Fig. 2.

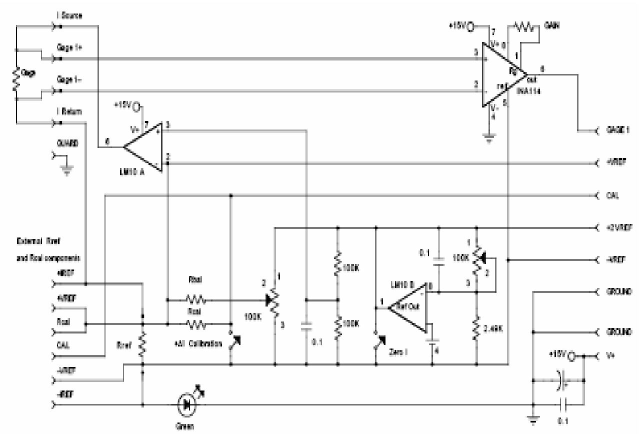

Fig. 5. Basic single-sensor Anderson Loop signal conditioner configuration used for the prototype circuit. [6] © IEEE 1998.

C. Software

The ADuC812 micro-converter required assembly code to be written and downloaded to its internal non-volatile memory. The code controlled the serial port settings, the ADC channels and conversion timing, as well as features such as the power supply monitor. Several code examples can be found on the Analog Devices web site [5]. This code and hence the settings can be altered for different system requirements depending on its application

National Instruments LabVIEW software was chosen due to its myriad of prewritten functions that allow simple manipulation of data and serial port communication. Its graphical programming environment makes program design intuitive and its use-friendly GUI minimises the user necessity for involved interaction. The source diagram for the GUI shown in Fig. 2 is shown below in Fig. 7. It shows how data received serially from the ADuC812 is dealt with. It is here that the byte streams from the ADuC812's ADC are separated, to be graphically displayed and saved into different locations. In this example, there are just two different blocks of information to separate: the temperature of the circuit and the sensor reading, each 4 bytes long, the first byte of each block being the channel ID and the next 3 bytes the actual measurement value. This can easily be extended to deal with all 8 ADC channels and hence 8 sensors.

III. EXPERIMENTAL PROCEDURE

A DEK RS 1202 automatic screen printer was used for thick film fabrication. A polymer paste was made of 92% NiO and 8% $C_8H_{18}O_3$ by weight with Diethylenglycolmonobutylether as a solvent. NiO polymer paste and commercial DuPont 4929 silver paste were used to fabricate the radiation sensitive material and contacts respectively. Pastes were printed on glass to form a sandwich Metal-Semiconductor-Metal structure with an active area of 1cm^2 and a film thickness of 70μm.

^{137}Cs (0.662 MeV) disk-type source (provided by AEA Technology QSA GmbH as a standard reference γ-source) was used for exposing the samples to γ-radiation. The source was held at a distance of 1 cm from the NiO film at an angle of incidence of 0°.

IV. RESULTS

To validate the stability, reliability and repeatability of the system, extended tests with many different experimental setups were carried out. This included testing with: variable resistors in the place of the sensors; sensors that were not being exposed to radiation; sensors during exposure, exposing the circuit and sensors at the same time to radiation and also just the sensor on its own. All the results from these tests were similar and correlated with what was expected from the circuit.

To ensure the repeatability of the sensors results, multiple tests were performed on various sensors. Fig. 7, shows the output of one such test. A graph of change in voltage measured across the sensor, against accumulated gamma radiation dose. This real-time graph describes the potential change from the moment the sensor was exposed to the ^{137}Cs source until 10 hours later when the source was removed. This represented a total dose of 3420 μGy.

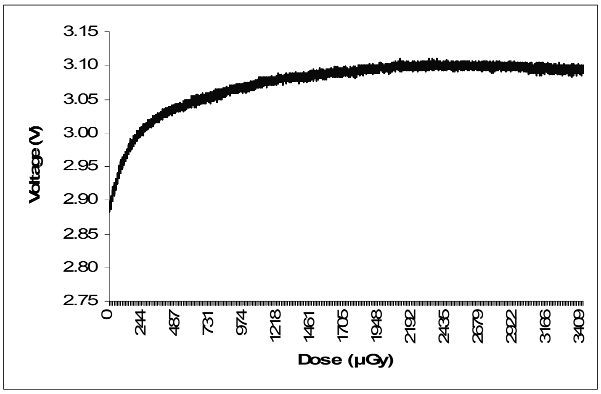

Fig. 7. Sensor voltage increase with dose.

It is important to monitor the response of both the sensor and the system as a whole during this period but it is the initial sharp rise slope that we are mostly interested in from a dosimeter perspective. This is shown in greater detail in Fig. 8, which shows the response of the system for the initial dose range from 0 to 223μGy.

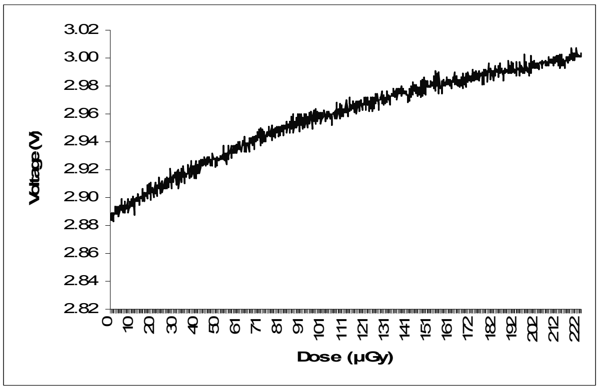

Fig. 8. Initial voltage response to radiation.

IV. CONCLUSION

A prototype real time portable gamma radiation monitoring system employing thick film NiO sensors was developed. The system employed the Anderson Loop for analogue resistive conditioning, which is a novel application of this concept. It is a cost effective circuit with very few components required. The system is portable, as it is battery operated and data can be saved locally in non-volatile memory for subsequent downloading and analysis. It is real-time in that it outputs its readings immediately to an LCD display or to a PC. The system described, provides a simple method of collecting, storing and displaying data from one or more radiation sensors. This monitoring system can be applied to a wide range of areas, such as homeland security tasks, environmental and personal radiation monitoring and nuclear waste control, where personnel's exposure to radiation can be minimised.

The system was exposed to a disc-type ^{137}Cs gamma source and the output voltage of the circuit was shown to monotonically increase with a corresponding increase in dose as expected. Repeatability, reliability and stability were demonstrated. All of which shows that this is a viable low cost alternative to existing Gamma radiation dosimeters and monitoring systems.

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