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MICROPROCESSOR BASED BEAM LOSS MONITOR SYSTEM FOR THE AGS*

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Abstract

An array of 120 long radiation monitors (LRM) have been installed around the AGS. Each monitor is an extended coaxial ion chamber, 5 meters long, made from hollow core coaxial transmission cable pressured with argon. The LRM's are each connected to a low current preamplifier and voltage-to-frequency converter (VFC). The digital output of each channel is fed to a 16 bit counter chip which bridges the bus of an 8085 microprocessor. This circuit is connected to the AGS PDP-10 for data taking or may function as a stand-alone unit. Various operating modes can be selected for data readout. System design and operating performance are described.

Introduction

Improvements in the AGS have lead to increased intensity, making beam loss a more serious problem. A radiation detection system had been in use for many years,[1] but since the detectors are no longer available and the computer interface involved redesign of the electronics, it was decided to install a new system.

System Requirements and Design

The detector array must provide complete and uniform coverage around the ring. Conventional detectors are small compared to the distance between their locations, and must be considered point detectors having inverse square sensitivity with distance from the source. The use of extended detectors, such as the long coaxial cable ion chambers used in the 200 MeV linac injector for the AGS,[2] results in uniform response along the length of the detector. Physical placement strongly influences the uniformity of response since losses viewed thru a large mass would be lower than those viewed thru only the beam pipe. Thus care must be taken in choosing the mounting location to assure all detectors have an equal view of the potential radiation sources. To satisfy these requirements and allow localization of the source of the radiation, an array of 120 extended ion chambers was deployed around the AGS just below the top plate of each magnet support girder.

Losses at injection occur over microseconds, while slow beam extraction losses can extend over a period of seconds. Tests on the LRM's used in the linac indicated that these had the necessary fast response time, but the electronics used did not have the dc response required for the AGS slow extraction. A unique approach has been employed to provide the necessary high voltage bias while allowing dc signal response.

The operational use of the data placed other restrictions on the design. The system had to provide data of the accumulated radiation in a time window which could be placed anywhere within the AGS cycle. The window could vary in duration from several msecs to seconds. This provides the capacity to isolate injection, capture or transition losses and is a powerful tool for studies. Whatever means of integrating the signals are used must be capable of spanning a range of more than 3 orders of magnitude.

Studies of the activation pattern around the ring indicated 1000:1 variation of losses. Tests with prototype detectors confirmed this estimate. This implies a similar signal-to-noise ratio for the detector and electronics, requiring a low noise, low drift front-end circuit and careful cable grounding and routing. To meet the window data accumulation requirements with a conventional electronic integrator would require the gain to be adjustable over 3 decades on each of 120 channels. This is possible but care must be taken to calibrate the gain of each channel to .1% to be consistent. Further, those channels in which the losses are of high amplitude but short duration might be lost at the highest gain setting. It was for these reasons that digital integration was investigated.

The availability of several new integrated circuits made the digital approach practical at low cost. Conversion of analog data to a pulse train by means of a voltage-to-frequency converter (VFC) is a well known technique. A VFC will produce a digital pulse each time a specific amount of charge is applied to the input. This flow of pulses related to the incident radiation is applied to a digital counter to provide the integration. Reading out the counts at specific times produces the required window data. Since this is to be done for 120 channels, it is well suited to a computer. Fortunately, a new chip containing 3 independent 16 bit counters became available. Since it was part of the 8085 microprocessor family, it was logical to design the system using these chips readout through an 8085.

This resulted in the system shown in Fig. 1. The LRM's are each biased by individual floating dc-dc converters. The low signal currents are amplified to suitable levels for the VFC and a video buffer amplifier. Each VFC output goes to a 16 bit counter on the 8085 microprocessor bus. A DAC programmed by the 8085 provides a video histogram of the radiation data. Not shown is an analog multiplexer array which allows any 4 individual video signals to be selected via the AGS computer for display in the control room.

The Detector

The radiation detector is an extended ion chamber formed by putting a bias voltage on the inner conductor of hollow coaxial cable containing argon gas at 10 psig. The cable is available from Andrews Corporation as type HJ5-50 Heliax cable. It is 7/8 in. diameter with the center conductor supported by a polyethylene spiral. The cable was cut into 5 meter lengths and terminated with a type 75AV (UHF) connector, and a pressurization fitting containing a standard bicycle valve. Further information about the detectors and their characteristics may be found in Ref. 2.

Each LRM is mounted on one of the 120 magnet support girders in the AGS. This allows a uniform view of the beam pipe and keeps them from being damaged during routine machine maintenance. They are attached to the girder by means of commercial spring clip conduit hangers, which need only be pushed onto the girder flange.

Argon flows to and from the detectors from 6 stations outside the ring. All detectors in a sextant are daisy-chained using polyethylene tubing to prevent ground loops. Pressure sensing relays set at 9 psig warn of problems in the gas system.

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A single coaxial cable runs from each detector to the centrally lcoating RF Building. Typical cable runs are 1000 ft of single-piece cable. Considerable care was used in selecting the routes out of the tunnel and the cable trays used to minimize noise pick-up. Most important was strict enforcement that the only ground connection be made at the electronics racks in the RF Building. Accidental grounding of any cable becomes immediately apparent from the large 60 Hz and SCR noise pick-up.

Bias Voltage Supply

Approximately 200 V bias is required for the ion chamber to work in the saturated region. Since the signal must be dc coupled, this presents a problem in the design. If the power supply is put in the opposite lead from the signal, which is taken from the inner of the coax, then the outer conductor will be at 200 V. Then one must either tie all outer conductors together in order to bias them from a single supply, or use individual supplies for each of the 120 units. This would be expensive. If all signal returns are tied together at the processing electronics rack and connected to the single biasing supply, then noise appears which is the sum of that on all the detectors and long signal cables. Since this is a high voltage supply at low current, its output impedance is high and the noise voltage can be appreciable.

An alternative is to float the power supply in the signal lead in series with the detector and amplifier. As long as the coupling impedance to ground is high at all frequencies of interest, ground noise will not appear in the signal. One possible approach is to drive a transformer at high frequency and rectify the stepped-up secondary output to produce the bias voltage.

This was tried and proved very noise free. In order to keep the cost per channel low, the step-up transformer was built with 4 secondaries. The final circuit is shown in Fig. 2 and is described fully in Ref. 3. The production circuit is housed in a single width NIM module and provides high voltage bias for 8 detectors. The unit operates with an input from -14 V to -35 V, (330 mA). It exhibits 10^{12} Ω leakage resistance and has a $-0.1\%/^{\circ}C$ temperature dependence. Regulation is 1.8% at full rated current of 15 μA.

Amplifier and VFC

Prototype LRM's indicated peak signals of several microamps during normal running. While the VFC was sensitive to currents as low as 100 pa, it was decided to precede the chip with an amplifier to provide for video waveform display. Figure 3 shows the completed circuit. Eight such channels are packaged in a single width NIM module. The first stage acts as a current amplifier because the detector is a true current source. For noise, however, there is a voltage gain of 10.

The VFC is a single chip monolithic integrated circuit.[4] As such it has proved superior in linearity and drift to other units tested including some at 25 times its price. The parameters are selected to provide a maximum reading of 10^5 counts/sec for a 14 V input.

Observed signals are shown in Fig. 4. Due to careful grounding it has been possible to keep the noise on most channels below 5 mV. A few channels show sensitivity (20-50 mV) to the ring rf power amplifiers housed in the same equipment bay, but RFI filters will eliminate this. Since the VFC is an integrator, externally coupled noise signals which appear with equal area above and below the baseline do not contribute to the total counts.

Microprocessor

Signals from each of the 120 VFC's are applied to a separate 16 bit counter. These are packaged 3 on a chip as an INTEL 8253, for use with 8080 or 8085 microprocessors. Using this approach, the cost per counter channel is very low. The 8085 microprocessor, associated 8253 counters, 8155 RAM's (2 K), 8755 PROMS (2 K) and decoding and interface circuits (85 chips) are contained on two 9½" x 9½" wire wrap boards. The unit is located adjacent to the signal processing electronics in the RF Building.

There are a number of benefits which result from using the microprocessor. First must of the processing burden is removed from the AGS PDP-10 and placed locally. Second, the unit can function without input from the AGS control system to provide a repeated histogram display of the data in all channels. Third, the flexibility of the microprocessor allows programming of more sophisticated modes of data presentation.

In its initial operation the PROM's have been programmed to allow on-line selection from 3 modes of data presentation:

Mode 1: The counters are preset to an initial value at the beginning of the AGS cycle. At a prescribed time (T_1) all counters are read and stored in RAM1. At a second time (T_2), they are again read and data stored in RAM2. At the end of the AGS cycle a final reading is made and the data stored in RAM3. The microprocessor takes the data from RAM3, which represents the integrated radiation over the whole cycle, and sequentially applies it to the DAC to present the histogram. If the AGS control computer has requested data in this mode, it receives two 16 bit words for each radiation channel; one represents the difference between RAM1 and RAM2 data, and is therefore the total counts during the window, and the second word is the total counts for the cycle.

Figure 5 shows a computer generated display from DAC at the end of the cycle in Mode 1.

Mode 2: At preprogrammed intervals the counters are read and compared to their values from the previous interval. If greater, the new value is stored. The time of the greatest count interval is also stored. At the end of the cycle the readbacks are the maximum count in each channel and the time at which this occurred.

Mode 3: It is often desired to observe the growth of radiation in real time on all channels. This cannot be done easily via the AGS control computer so the microprocessor is programmed to cycle in 35 msec intervals and apply the total to the DAC for direct viewing on an oscilloscope in the control room. It is intended in the future to expand this mode to send back the total counts on each channel upon request from the AGS computer.

Beam Alarm Option: One additional feature provided for but not implemented at this time, is the ability to deliver an alarm signal when high radiation exists. This option makes use of the ability of each of the counters to be preset individually. Since the 8253's are count-down devices with an accessible zero-crossing bit, "OR-ing" of the 120 counters provides a real time beam alarm signal. At present these zero-crossing bits have been brought to connectors from which they can be interfaced to a suitable OR circuit.

Summary

The system described has been undergoing shakedown at the AGS. It appears to have a suitable dynamic range. The detector signals viewed thru the first stage amplifier exhibit better than 1000:1 signal to noise ratio.

The microprocessor appears to perform its basic functions, but some problems with the original software have been observed. These are being corrected and should result in shorter scan intervals, easier resetting capability and greater confidence in the processed data.

Acknowledgments

As with any large project, this work was a team effort. Especially contributing to its success were J. Klein, R. Murgatroyd and M. Zguris. J. Curtiss was responsible for much of the design of the bias supply as well as supervising the systems installation along with M. Zguris. M. Brown designed the microprocessor hardware and software. He was ably assisted by R. Zapasek. G. Cornish prepared the Fortran display programs on the PDP-10.

References

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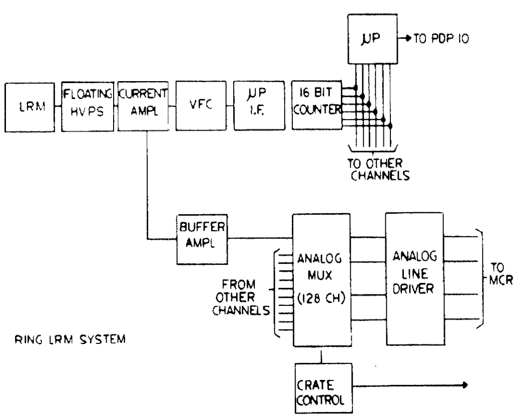

Fig. 1. AGS ring LRM system.

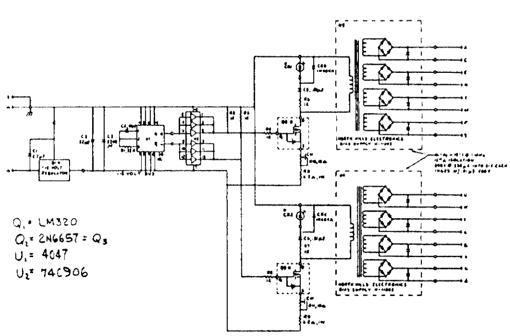

Fig. 2. Floating HV bias supply.

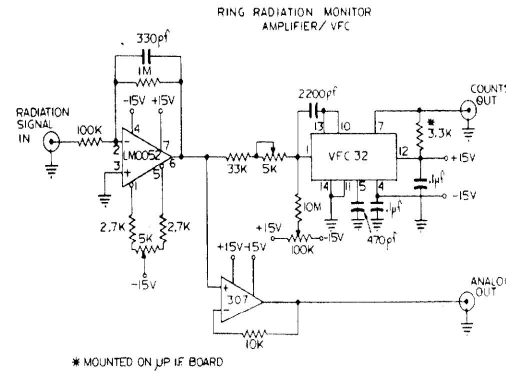

Fig. 3. Amplifier, voltage-to-frequency converter.

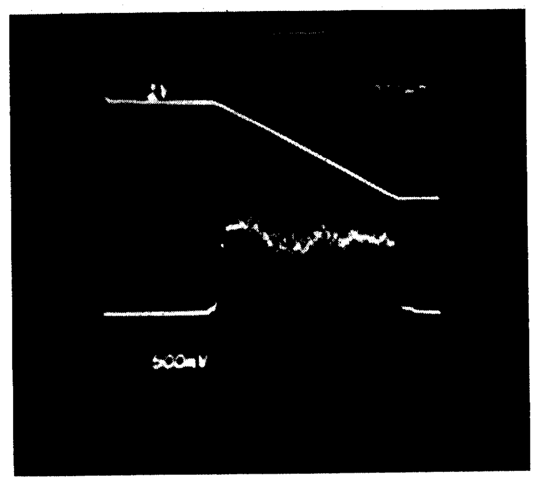

Fig. 4. Top: AGS intensity (3.3×10^{12}/div).
Bottom: LRM output at F16 magnet.

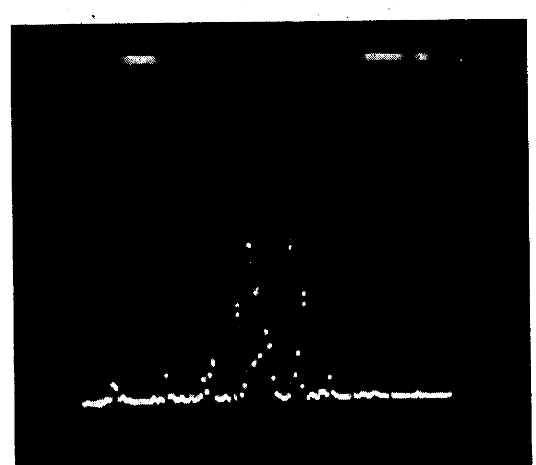

Fig. 5. Computer radiation plot.