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WIDE DYNAMIC RANGE BEAM PROFILE MONITOR*

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Summary

An economical harp multiplexer system has been developed to achieve a wide dynamic range. The harp system incorporates a pneumatically actuated harp detector with ceramic boards and carbon wires; a high-sensitivity multiplexer packaged in a double-wide NIM module; and flat, shielded ribbon cable consisting of individual twisted pairs. The system multiplexes 30 wires in each of the x and y planes simultaneously and operates with or without computer control. The system has operated in beams of 100 nA to 1 mA, 1- to 120-Hz repetition rate, with a signal-to-noise ratio of greater than 10/1.

Introduction

Quantitative profile measurements at LAMPF are made with wire scanners and multiwire grids.¹ The wire scanners have wide dynamic range and are usable with 1 mA primary proton beams, but are slow in accumulating a complete profile in a pulsed beam at low repetition rate. Consequently, the multiwire device is often preferred when low rep rate operation is planned, as in the beamlines serving the new Proton Storage Ring (PSR).

The secondary emission grid, or harp, can be made with small geometric cross-section to the beam (small wires to minimize H⁺ stripping), but the signal levels consequently are low, typically on the order of 100 pA average for tuneup-level beam currents.

For PSR instrumentation, we therefore undertook a harp multiplexer development project to fully exploit the low-noise characteristics of modern FET analog switches. Additional goals were low detector mass; simple cabling scheme, preferably using ribbon cable with mass termination; NIM modular construction; and stand-alone or computer-controlled readout.

The Harp System

The harp system can be conveniently divided into three general areas: 1) the sensor, 2) the electronics, and 3) the interconnecting pathway between the sensor and electronics. A well-designed system must consider all of these since, in practice, the lowest possible beam current observable is limited by either the electronics or the input noise pickup on the cabling.

In contemplating system improvements, the performance specifications were:

A. Multiplexer

1. Reasonably simple design (i.e., no amplifier per wire)
2. Less than 30 pA input offset per channel
3. Output gain switching $\times 1$ - $\times 100$
4. Local (oscilloscope readout) and computer readout
5. Standard NIM packaging with dual 32 channel x and y capability in a 2-wide NIM module
6. Controlled discharge or RC integration

B. Harp detector and actuator

1. Capable of operating in high beam currents
2. Sense wire resistant to radiation damage
3. Pneumatic actuator for simplicity

C. Cabling and shielding

1. High-quality, low-noise cable
2. Low noise pickup
3. Provide detector-electronics separation greater than 100 feet

We were generally able to achieve all of these specifications.

Harp Detector and Actuator

The harp detector and actuator are shown in Fig. 1. The detector assembly consists of two orthogonal planes of signal wires and three planes of clearing-field wires held at a potential of 100 V. The harp cards are plugged into printed circuit board edge connectors attached to the actuator shaft. Two flexible Kapton cables provide the connection between the edge connectors and vacuum feed-throughs on the beam box. The vacuum barrier on the actuator shaft is a metal bellows.

The harp detectors are printed circuit cards made of either ceramic or epoxy fiber glass. The sense wires can be any suitable material - metal wires or ribbons, carbon, or silicon carbide wires. Generally, carbon or silicon carbide wires are used for high-current applications.

Harp Cabling and Shielding

When high sensitivity, low current operation is required, care must be exercised in routing the harp signals from the detector to the multiplexer. We have taken the following steps to insure a minimum noise pickup on the cables:

Fig. 1. Harp detector mounted on pneumatic actuator.

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1. High-quality RG174 coaxial cable or shielded twisted pair ribbon cable is used
2. The cables are routed to the multiplexer in a separate conduit containing no other cables
3. The multiplexer amplifier ground is derived from the beam pipe and a differential amplifier is used in the multiplexer module

Tests have shown that these precautions have been successful. At the present time, the low current sensitivity is limited by the electronics.

Harp Multiplexer

The harp multiplexer is the heart of the harp system. A block diagram of the multiplexer is shown in Fig. 2. For each coordinate, the individual signals from the harp detector are multiplexed to a low noise precision instrumentation amplifier followed by a sample and hold and a current buffer. The multiplexer timing is shown in Fig. 3. An important feature of the 16-channel multiplexer chip (Harris HI-506A-5) is that the switches are designed to have one channel open before the successive channel closes, i.e., a break-before-make condition. This reduces adjacent channel crosstalk. Further, an additional circuit discharges the output side of the multiplexer before each successive wire is enabled. This also preserves the channel-to-channel isolation.

Each input line has a 100 M Ω terminating resistor which sets a signal decay time as determined by the cable capacity (typically a few nF) and optional integrating capacitor. If no clamp signal is used, the input signal is continuously averaged with this time constant, $\sim 0.1\mu$ s. The averaging time can be shortened by using a clamp signal to discharge each wire. This feature is useful to extend the dynamic

range at high beam rep rates (above 10 Hz). The clamp sequentially discharges each wire before the beam arrives by grounding the output of the multiplexing chip and multiplexing through all of the inputs. The clamp signal is provided either by the computer or a rear panel connection and its duration is internally adjustable. The total clamping cycle is $\sim 200\mu$ s.

The multiplexer has three control modes - local, remote, and computer. In local mode, the only control signal required is the ADDRESS RESET. All other timing and control signals are derived internally from the ADDRESS RESET. The dwell time per channel is internally variable between 100 - 500 μ s. Remote mode provides remote control of gain and selects the source of clamp.

In computer mode, the multiplexer must receive ADDRESS RESET and START READOUT commands. In the absence of ADDRESS ADVANCE command, the multiplexer will step through the channels with dwell time as set internally, 100 - 500 μ s, the same as in local mode. Each ADVANCE will be followed in $\sim 50\mu$ s by DATA READY pulse from multiplexer to signal computer ADC to digitize the analog level. The computer may speed up the scanning by sending an ADDRESS ADVANCE pulse.

Performance and Results

The new harp system was tested in the LAMPF high-intensity beamline under typical conditions, i.e., all potential noise sources were present, magnets, power supplies, pumps, etc. The results are shown in Fig. 4. The harp system consisted of:

1. Harp detector
  - a) ceramic harp
  - b) 30- μ m diam wires of carbon
  - c) 1.2-mm wire spacing
  - d) beam spot $\sigma_x = 3\text{ mm}$, $\sigma_y = 2\text{ mm}$
2. Cabling and noise shield
  - a) cable length - 30.5 meters
  - b) shielded twisted pair ribbon cable or RG174 - 23 meters
  - c) mineral-insulated cable - 7.5 meters
3. Computer readout - CAMAC and PDP 11/10

Fig. 2. Harp multiplexer block diagram.

Fig. 3. Harp multiplexer timing diagram.

A variety of beam intensities and cable combinations were tried to investigate the sources of noise and to test the overall sensitivity to beam. In Fig. 4, OLDMUX refers to the existing multiplexer and ASUM indicates the number of beam pulses integrated at a repetition rate of 120 Hz. Backgrounds have been subtracted. At an average beam current of 100 nA (4c), reasonable profiles were easily obtained. The signal-to-noise with backgrounds subtracted was $\approx 20/1$. However, the signal-to-noise with no backgrounds subtracted was $\approx 2/1$. The difference is due to the fixed offsets on each channel due to the multiplexer switches. The peak channel in the profile of Fig. 4c has a signal current of about 10 pA average.

A clear reason for care in cable routing can be seen in Figs. 4d, e. An order of magnitude in sensitivity was lost when the cable was not in the conduit. Most of the noise was due to pick up from SCR magnet power supplies.

Conclusions

An inexpensive harp multiplexer system has been developed that provides a wide dynamic range of operating conditions. A dynamic range greater than 10^4 is possible and the current sensitivity at the input is 1 pA or better.

Acknowledgment

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References

1. "High-Intensity Beam Profile Monitors for the LAMPF Primary Beamlines," E. Hoffman et al., IEEE NS-26 (3420) June 1979.

Fig. 4. Harp multiplexer test results. In all cases backgrounds have been subtracted.