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Integrating Log-Ratio Position Processing for the Los Alamos Proton Storage Ring Extraction Line*

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Abstract

The Los Alamos Proton Storage Ring (PSR) is a compressor ring intended to accept 1-msec-long proton macropulses from the LAMPF linear accelerator and compress these pulses to 250 nsec in length. Beam position monitor sensors of the terminated strip-line design centered at 200 MHz are provided in the transport line from LAMPF, the PSR injection line, the PSR ring, and the extracted beam line. Strip-line sensors used in conjunction with phase processing are a good match for linac transport lines and PSR injection lines where there exists a strong 200-MHz frequency component but lead to difficulties in the ring and extracted beam line where this component tends to wash out. This paper describes the development of Integrating Log-Ratio processing techniques, which utilize the original strip line sensors to achieve a major improvement in position monitoring for the extracted beam line. The design concepts are discussed and the present hardware is described in detail. Operational difficulties encountered during the development process are discussed and actual beam-related results are provided.

I. INTRODUCTION

For the past several years, various alternatives to the existing 201-MHz amplitude-to-phase processing system have been investigated. In the PSR ring, the 201-MHz component is largely due to the most recently injected beam rather than stored beam, while the extracted beam lacks any appreciable 201-MHz component. In both cases, the present system performance is questionable. Many detectors, signal processing schemes, and position processing techniques have been evaluated as possible replacements [1], [2], [3], [4], [5].

We have placed the highest priority on extracted beam monitoring since the operation of our present system is least adequate in this application. PSR extracted beam intensity varies from a few hundred milliamperes in tune-up mode to 25 amperes during production times (a dynamic range of 100:1). For extracted beam monitoring, it makes sense to observe the total charge that passes the sensors. Our most encouraging test results have led to the selection of an integrating log-ratio processing scheme, which can fulfill both of these extracted beam monitoring requirements.

II. ELECTRODE SELECTION

For economy and simplicity, our recent efforts have emphasized using the existing 50-ohm strip-line detectors along with wide-band signal processing. Initially we worked with unmodified pickups. The 50-ohm terminated strip-lines have about 30 pF of capacitance giving rise to a 1.5-nsec decay time constant. The PSR extracted beam pulse is approximately triangular with a base width of 250 nsec. The short time constant these terminated strip-line detectors exhibit differentiates the relatively long beam signal. An integration function is required to recover the beam signal. To observe the total charge that passes the sensors, another analog integration function is needed. The inherent low frequency gain of these integrating stages enhances system noise and limits the available dynamic range to about 10:1. Since a dynamic range in excess of 100:1 is needed to adequately monitor the extracted beam position [6], a decision was made to modify the existing pickups by removing the terminating resistors and padding the electrodes with capacitance to increase the time constant.

A standard extraction line detector is modified by removing its terminating resistors and adding 500 pF chip capacitors between each of its strip lines and ground. The capacitors are actually installed in matching boxes connected to the electrode signal ports. This effectively creates a capacitive pickup that only requires a single integration stage in the processing electronics. Wide band (20 kHz to 36 MHz) RF transformers are used in a 5:1 voltage step down (25:1 impedance ratio) to drive the existing 50 ohm coaxial cables. A series connected 1200 ohm resistor is inserted to provide back termination in the primary circuit, resulting in a time constant of 1.25 µsec and giving 20% droop over the 250 nsec beam pulse. In addition to increasing the decay time

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constant, the transformers help reduce the system low frequency noise by breaking ground loops and limiting the low-frequency bandwidth [7]. A second transformer (wired in step-up configuration) is used at the receiving end of the cables to boost the signals back up to their original levels without degrading the signal-to-noise performance.

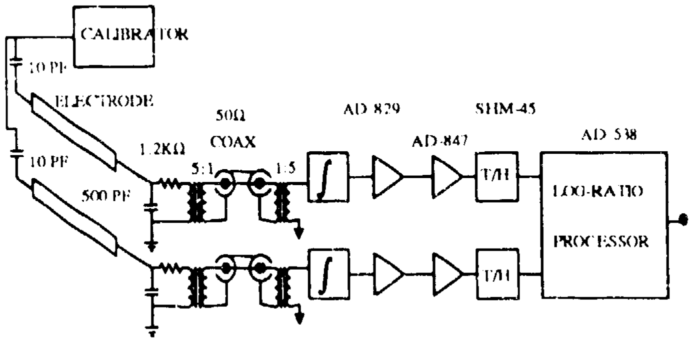

Figure 1: Integrating Log-Ratio Block Diagram.

III. CIRCUIT DESIGN

Figure 1 shows a block diagram of our Integrating Log-Ratio beam position monitoring system. A small matching box containing the shunting capacitor, series resistor, and cable matching transformer is placed at the electrode signal output ports. Calibrated test pulses may be injected at the electrodes to verify system integrity and perform active system calibration. One-hundred-foot-long 50-ohm coaxial cables transmit the beam signals to the remote processing electronics. Each processor signal path consists of the following elements: a 1:5 step-up transformer, a passive RC integrator, a low-noise gain stage (A=10), a switchable gain stage (A=1 or 10), a high-slew-rate track-and-hold amplifier, and the log-ratio processing circuit. The track-and-hold circuitry captures the signal peaks and holds these data for the relatively slow responding log-ratio position processors.

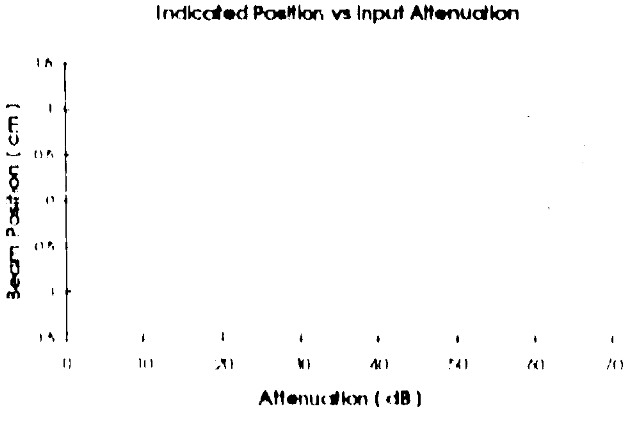

Figure 2: Processor Response vs Input Signal

Figure 2 gives the response of our processor to varying input signal levels. The vertical axis is in cm and the input signal with no attenuation is a 3-volt peak triangular pulse 250 nsec at the base repeated at a 20-Hz rate. Adequate dynamic range is not available from the high-sensitivity range alone. We have included a low-sensitivity range to allow for future increases in PSR beam intensity and to extend system performance to cover the desired 40-dB range.

IV. HARDWARE DIFFICULTIES

We chose to incorporate a passive integrator in our final design. In an earlier design, we configured the first low-noise amplifier stage as an AC active integrator. Active integrators offer improved accuracy over passive circuitry but are difficult to implement in the high-frequency high-slew-rate range (in excess of 100 V/µsec) we operate in.

At low signal-levels, the Log-Ratio circuits are quite sensitive to noise and small offset voltages at their inputs. The topology of the signal processing section was chosen to minimize noise and DC offset effects. The AD829 High Speed, Low Noise Video Operational Amplifier is used as the first gain stage because of its excellent noise characteristics (1.7 nV and 1.5 pA / root Hertz at 1 kHz). AC coupling at the track-and-hold inputs removes DC offsets from the early gain stages with no loss of accuracy. The pedestal offset error common to fast track-and-hold circuits remains a problem. Figure 3 shows the resulting output of an ideal Log-Ratio processor with a 1-mV offset difference added to various common mode offset levels in the presence of an equivalent 1-cm beam displacement signal. Overall transfer gain has been adjusted to match our processor transfer gain.

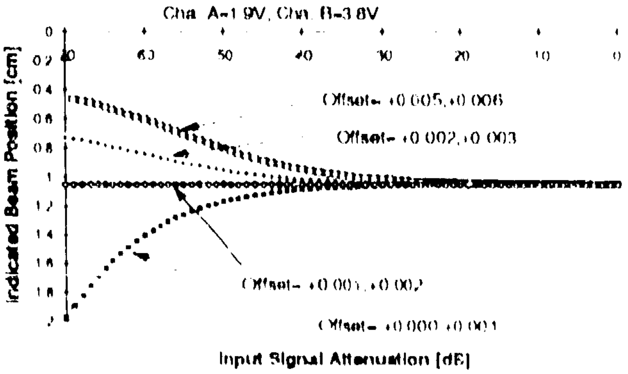

Figure 3: Effect of Small Offset Voltages at Log Ratio Circuit Inputs.

Our search for a fast track and hold circuit with low pedestal offset initially led us to the SHM 30C/HA5330. This is a high slew rate track and hold circuit employing monolithic integrated circuit technology with an extremely low pedestal offset specification (0.5 mV). Bench testing revealed a strong slew rate dependence on input signal amplitude, making this device a questionable candidate. We replaced it with an industry standard 4860 track and hold circuit module, measured pedestal offset voltages, and corrected the resulting data to produce the live beam results of Figure 4. These data show apparent position shifts at the lowest input signal region. The pattern repeats with changes in beam position provided by upstream steering magnets. We believe this to be a real effect resulting from off-center injection of just a few beam bunches into the PSR.

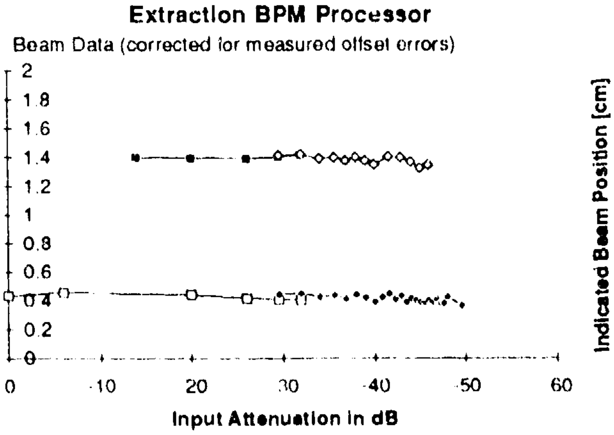

Figure 4: Beam Position Data with Offset Correction.

A second attempt to resolve the pedestal offset difficulty led us to the SHM-49 track-and-hold circuit. This is another monolithic integrated device offered as a high-slew-rate low-cost unit. No attempt has been made by the manufacturer to balance the pedestal offset, but an inverting input is available and a compensating charge may be coupled through a small capacitor into this input. We found the compensation to be temperature dependent largely due to the track-and-hold circuit and chose a negative-temperature-coefficient thermistor configured as a self-regulating heater to maintain a constant chip temperature. While bench tests yielded quite acceptable results, live beam results from three production processors resulted in one unit with unacceptable low level response.

Our present preferred track/hold circuit choice is the SHM-45. This is a version of the 4860 with a single hold command input allowing the manufacturer to trim the circuit for a typical pedestal offset of less than 1 mV. The trimming is relatively insensitive to temperature fluctuations and with careful selection the SHM-45 will provide the desired results.

V. NOISE CHARACTERISTICS

Overall system noise will ultimately limit the usable dynamic range of any position processing system. Figure 5 gives the measured noise characteristics of our processing system. RMS displacement data for live beam and bench tests for high sensitivity and low sensitivity settings are given. At high input signal levels, the observed noise is at the limits of our measurement system

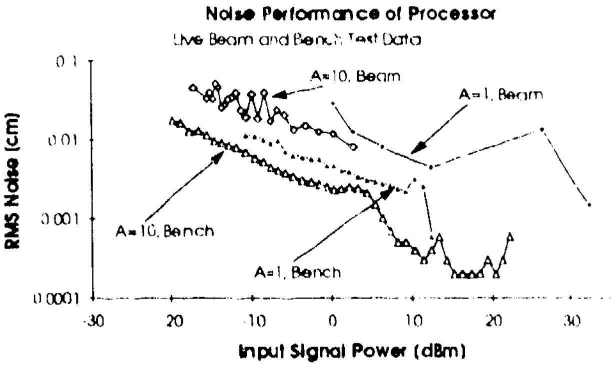

Figure 5: Processor Noise Performance.

VI. CONCLUSIONS

We have produced three versions of our Integrating Log-Ratio processor. Tests with live beam have been encouraging resulting in an observed dynamic range in excess of the desired 40 dB. There remain some circuit difficulties, which we now feel can be controlled. We are constructing a full complement of processors and plan a complete conversion of the PSR extracted beam line in the near future.

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