Single Board Op-Amp Beam Position Monitors Electronics*

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Abstract

A new approach has been developed for beam position monitors (BPM) [1] in the new 600 keV beamline [2]. A single four layer printed circuit board, attached with short (0.3 m) cables to the electrodes, processes the raw signals and outputs voltages proportional to the beam intensity, horizontal and vertical position, and quadrapole moment. Newly-available high-speed operational amplifiers are used exclusively instead of more conventional rf components. The rf input frequency can be as high as 36 MHz, and the IF frequency is 100 kHz. The output signals from each monitor will be digitized by the VME-based control system which will provide operator displays and use the information as feedback in automatic loops controlling the beam position, envelope, and dispersion. The signal processing at each BPM location eliminates the need for expensive multiplexing and routing of signals to a central processing location. The cylindrical electrode is split into four equal segments allowing both horizontal and vertical information to be obtained at each location thus minimizing the required beamline insertion length.

I. INTRODUCTION

The new high intensity polarized ion source (HIPIOS) [3] being commissioned at IUCF is designed to increase the intensity of the polarized beams by an order of magnitude over that provided by the existing polarized ion source. The 30 m long beam transport system connecting the 600 kV ion source terminal to the cyclotron has been designed with the goal of increasing the transmission efficiency of the beams from the source to extraction from the main stage cyclotron from the present range of 4 - 10% to as high as 20 - 50%. The BUM system is the key diagnostic in this new beamline and will be used for non-destructive monitoring of the beam intensity and measurement and control of the beam position, dispersion, and envelope.

Each BUM electrode will have a dedicated set of electronics contained on a single four layer circuit board. This approach, although requiring more electronics, is more efficient and cost effective than a single processing approach. Radio frequency (rf) signals remain localized to the electrode location thus eliminating costly cable runs and multiplexing systems. The position and intensity information from any electrode is available to the computer at all times, thus eliminating timing complications and increasing the system bandwidth.

This approach is made possible by the use of newly available, low cost operational amplifiers and a custom, high density circuit board. The system (Fig. 1) consists of four major subsystems: (1) the pickup electrode, (2) the rf section, (3) the mixer/intermediate frequency (IF) section, (4) and the

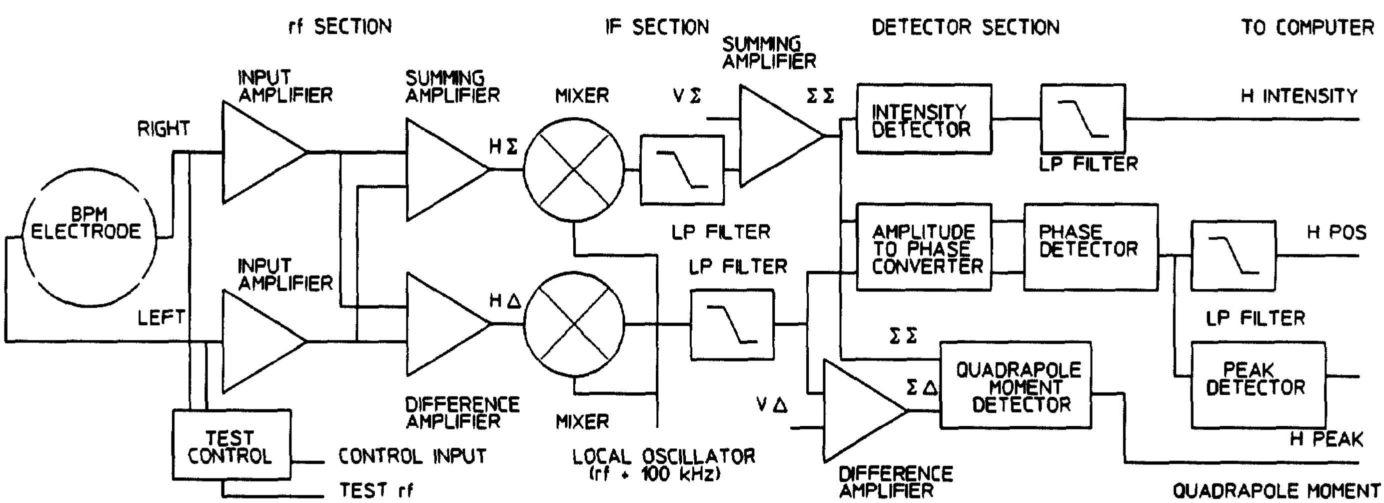

Figure 1. Block diagram of BPM electronics.

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detector section.

The system will operate at rf frequencies in the range from 27 to 35 MHz though operation in the range from < 1 to > 50 MHz is possible; the IF frequency was limited to 100 kHz to ease the gain-bandwidth requirements of amplifiers in the IF section. The four layer circuit board is 7.5 inches wide and 9 inches long. It houses 23 integrated circuit (IC) chips, 250 resistors, 130 capacitors and various other support components. The required supply voltages are $\pm$ 5 and $\pm$ 15 V. Each board has a local oscillator, split 4 ways, and 4 rf test inputs with control bits (left, right, up, and down). The output voltages are proportional to the beam intensity, horizontal and vertical position, and quadrapole moment. Two other outputs provide voltages proportional to the amplitude of low frequency modulation of the beam position in each plane.

II. SYSTEM DESCRIPTION

A. Pickup electrode and rf section

The electrode diameter, D, is 76 mm and length, L, is 50 mm. The total input capacitance, C, which is the sum of the electrode, input cable and amplifier capacitances, is $\approx$ 75 pF. The cable length from electrode to amplifier is as short as possible to minimize the capacitance and maximize the effective electrode impedance, Z, which is given by:

$$Z = \frac{L}{\beta c C} \qquad (1)$$

where c is the speed of light and $\beta = v/c = 0.0357$ for 600 keV protons. Using the above values, we obtain a Z of 62 Ω.

The input buffer amplifier is a Comlinear CLC400, a fast settling, wideband, operational amplifier [3]. Its input noise is 6.3 nV/$\sqrt{\text{Hz}}$. The noise voltage, V_{noise}, signal voltage, V_{signal}, and rms position resolution, δ, are given by:

$$V_{noise} = 6.3\ \frac{\text{nV}}{\sqrt{\text{Hz}}}\ \sqrt{BW}$$

$$V_{signal} = \frac{I Z}{4} \qquad (2)$$

$$\delta = \frac{V_{noise} D}{\sqrt{2}\, V_{signal}}$$

where I is the beam current which will be in the range from 1 to 100 μA, and BW is the output bandwidth (2.8 kHz). For beam currents in this range we expect δ to vary from 1.2mm to 12 μm. Bunching factor is not included in Eq. 2 since the detector is tuned to a single harmonic of the fundamental frequency.

The left and right, or up and down, input signals are both added and subtracted after the input buffer amplifiers. The sum, Σ, and difference, Δ, signals are then converted to IF signals.

Each BUM circuit board has an rf test signal input with computer on/off control. This test signal can be applied to any combination of the four electrode inputs. These signals are used as a system operational and diagnostic test as well as for initial calibration.

B. Mixer/IF section

The IF is derived by mixing the rf beam signal with a local oscillator signal having a frequency 100 kHz higher than the beam signal using a Mini-Circuits SRA-3H [4] level 17 mixer having a maximum rf input power level of 10 dBm. A 100 kHz low pass filter follows the mixer. The amplifiers used in the IF section are Elantec EL2424 high speed op-amps [5]. The EL2424 has a unity-gain bandwidth of 60 MHz. All of the amplifiers in the IF are also used as active filters to further reduce the level of higher frequency products from the mixers.

C. Position detector

The position detection is accomplished using the standard amplitude to phase conversion technique[6]. The two resulting signals are converted to digital signals, or leveled, using a Maxim, Max901 quad, high-speed, voltage comparator [7]. The phase is detected with an exclusive-or gate. The phase detector output is offset and amplified. The sensitivity is 0.26 V/mm, with a fullscale output of $\pm$ 10 V.

A system of 4 steerers operating at 10 Hz will move the beam along an ellipse having the same shape as the measured beam emittance at the beginning of the line. The peak detector section is used to measure the amplitude of the position modulation at each BUM consequently giving the operators an online measurement of the beam envelope. The computer will also use this data to optimize the strength of quadrapoles. The position signals are sent through half-wave rectifiers, then filtered and amplified to produce a dc signal proportional to the position modulation amplitude with less than 2% ripple.

The intensity output of the BUM is the rectified sum of the horizontal and vertical Σ channels. The intensity range is 1$-$ 100 μA.

The quadrapole moment is a test circuit yet unproven in design or usefulness. This circuit calculates the ratio of the difference in the Σ signals to the sum of the Σ signals using a circuit identical to the position measurement circuit.

III. SYSTEM PERFORMANCE

The dynamic range of the position detector is greater than 50dB. The normal range of operation is 1 $-$ 100 μA. Within a 35 dB normal operating range, position gain errors of less than 300 μm (Fig. 2) and zero offset errors of less than

200 μm (Fig. 3) have been observed under bench test conditions. The output bandwidth of the position detector and intensity detectors are 2.8 and 1 kHz respectively.

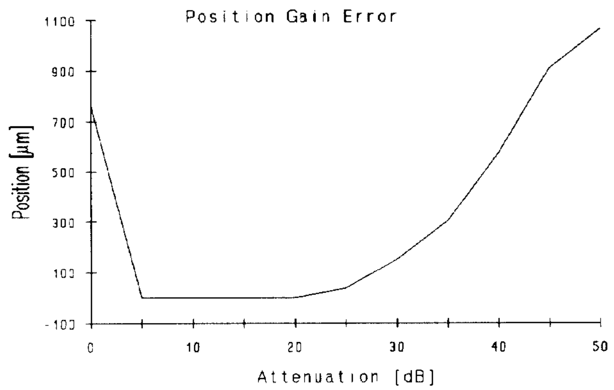

Figure 2. Position gain error (in μm) as a function of input level over a 50 dB range.

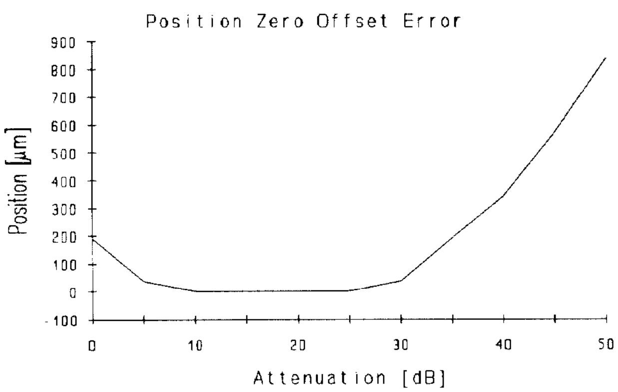

Figure 3. Zero offset error (in μm) as a function of input level over a 50 dB range.

IV. Conclusions

With the introduction of high speed, wide bandwidth, and low cost op-amps, design of accurate and reliable beam position detectors has been made simpler for. Although many of the ideas of beam position measurement have been used before in the laboratory they have not been carried out using this technology.

V. Acknowledges

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V. References

[1] Timothy JP Ellison, C. Michael Fox, Steven W. Koch, Liu Rui, "Nondestructive diagnostics for measuring the phase, position, and intensity of 15 nA beams for IUCF cyclotron", *Proc. 11th Int. Conf. on Cyclotrons and their Applications,* edited by M. Sekiguchi, Y. Yano, K. Hatanaka (Ionics, Tokyo, Japan, 1986)279-283.

[2] W.P. Jones, T.J.P. Ellison, M.S. Ball, J.C. Collins, D. DuPlantis, D.L. Friesel, B. Hamilton,J.W. Hicks, and P. Schwandt,"Beam Transport System For The IUCF High Intensity Polarized Ion Source",*Proc. 13th Int. Con. of Cyclotrons and their Applications,* edited by G.Dutto, M.K. Craddock, (Vancouver, B.C.,1992)609-611.

[3] M. Wedekind, R. Brown, V. Derenchuk, J. Hicks, P. Schwandt, "The IUCF High Intensity Polarized Ion Source Project", these proceedings.

[4] Comlinear Corporation 1991 Databook, *"Amplifiers and Data Conversion"*

[5] Mini-Circuits 92/93 Databook, *"RF/IF Designer's Handbook"*

[6] Elantec 1992 Databook, *"High Performance integrated Circuits"*

[7] R.E. Shafer and R.E. Gerig, *"Proc. of 12th Int. Conf. on High Energy Accel."*(Fermilab, 1983),pg. 609

[8] Maxim 1992 New Releases Databook, *"1992 Analog Design Series"*