SLAC-PUB-8445
April 2000

The Logarithmic Beam Position Monitor*

Evgeny A. Medvedko, Stephen R. Smith

Presented at 9th Beam Instrumentation Workshop, 5/8/2000 – 5/11/2000,
Cambridge, MA, USA

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94039

* Work supported by Department of Energy contract DE-AC03-76SF00515.

The Logarithmic Beam Position Monitor

Evgeny A. Medvedko, Stephen R. Smith

Stanford Linear Accelerator Center
Stanford, CA 94309, USA

Abstract. Modern logarithmic amplifiers offer wide dynamic range, high bandwidth, good logarithmic conformance, and low cost making them attractive for beam position measurements. A log-ratio beam position monitor has been designed and built at SLAC for use at the PEP-II B-Factory. An integrated circuit logarithmic amplifier from Analog Devices, the AD8307, recovers the envelope of the 476 MHz harmonic of the beam signal. A log BPM board with two logarithmic and one differential amplifier performs the basic function of forming an output voltage proportional to the difference of the logarithms of the signal amplitudes on opposite electrodes. This voltage is approximately linear with beam position. For this application, we have limited the video bandwidth of the log amps to 50 kHz in order to remove fill pattern dependence. The log BPM board has an interface for testing and simulating beam offsets. The log BPM's were developed for a PEP-II ring protection chassis. Here the log BPM's function to identify dangerous orbit excursions. These excursions are signaled to a system, which can dump the beam. Two such chassis serve to protect the PEP-II rings.

INTRODUCTION

The rf logarithmic BPMs (log BPM) are designed to measure signals from two opposite electrodes and to form a difference of the logarithms of these signals. The log BPM has high dynamic range and is used to measure a beam position offset up to half the aperture of the beam pipe.

Two log BPMs measure signals from four electrodes. The log BPM board plugs into the motherboard of the ring protection module. The motherboard sum and differential amplifiers derive the *X* and *Y* beam position.

The motherboard provides test signals to the log BPM board to simulate beams of various currents and position on demand.

LOG BPM DESIGN DESCRIPTION

The logarithmic board (Fig. 1) has two inputs. Input signals come from two opposite electrodes and go through test signal power combiners (C) to bandpass filters (BPF) with center frequency 476 MHz and 5 MHz 3 dB bandwidth. Logarithmic amplifiers demodulate the filtered signal. The signals from LOG AMP1 and LOG AMP2 go to the differential and sum amplifiers. The differential amplifier output signal is proportional to the beam position and goes through the lowpass filter (LPF), a 1 dB ripple four-pole Chebyshev type, designed to suppress 136 kHz (the revolution frequency) by at least 45 dB. By analyzing the DIFF OUT and SUM OUT signals it is possible to verify the board input connections to the electrodes.

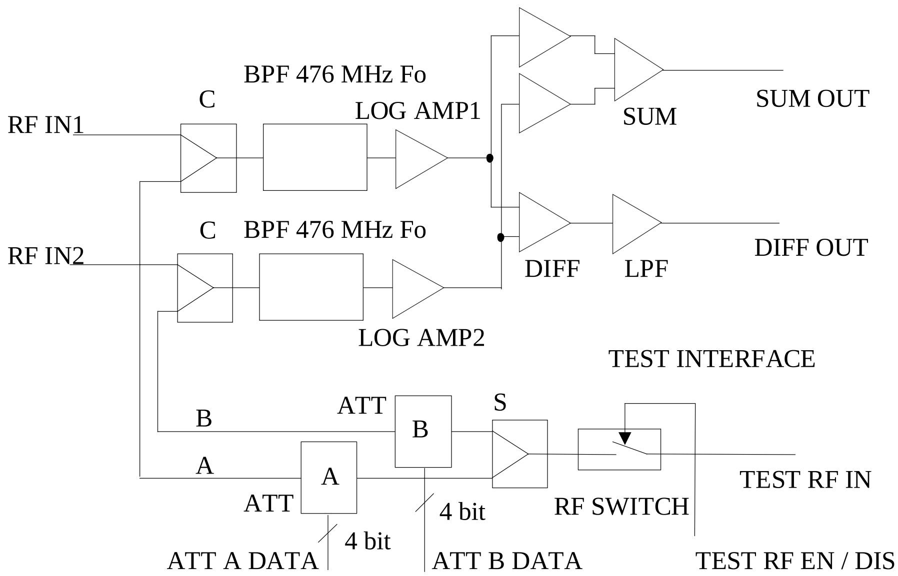

FIGURE 1. Logarithmic rf board diagram. C - combiner, BPF - band-pass filter, Fo - central frequency, LOG AMP - logarithmic amplifier, DIFF - differential amplifier, SUM - summing amplifier, LPF - low-pass filter, ATT – attenuator, S - splitter.

The externally generated test signal (frequency 476 MHz) goes to the TEST RF IN. If the board is selected for test, the rf switch is closed and the test signal goes through a splitter to the A and B attenuators. The attenuation can be programmed individually in a range from 0 dB to 30 dB in 2 dB steps. By varying the *A* and *B* attenuators, beam position offsets can be simulated.

The log BPM board size is 4.7" x 2.7". There are two signal layers and three layers of ground and power. The log amplifier chips are Analog Devices, type AD8307 [1], 92 dB dynamic range; 10 Hz to 500 MHz usable frequency; logarithmic conformance ± 0.5 dB to ± 1 dB; nine cells; 14.3 dB cell gain. The board has a rf connector (Harting, Mini Coax Module) and mixed analog and digital connector (AMP, PCB Receptacle).

REQUIREMENTS

The requirements for the ring protection module related to the log BPM performance are:

1. The measurements must be averaged over one beam turn (the revolution frequency is 136 kHz) to respond to the total current in the ring and to avoid fill pattern sensitivity.
2. Must measure current in a range from 3 A to 100 mA.
3. Must measure the beam *X* or *Y* orbit position up to ± 20 mm off center.
4. The minimum dynamic range should be 45 dB.
5. The position measurement accuracy should be ± 2 mm or better.

DYNAMIC RANGE – BEAM POSITION

At large beam offset from the center, the electrode response to the beam motion is not linear. It is important to know the relation between the beam position and the electrode output signal, especially if the BPM must measure the large beam excursion.

Assume the beam has offset δ from the center in a cylindrical beam pipe, with the monitor electrodes rotated 45° from horizontal and vertical (Fig. 2).

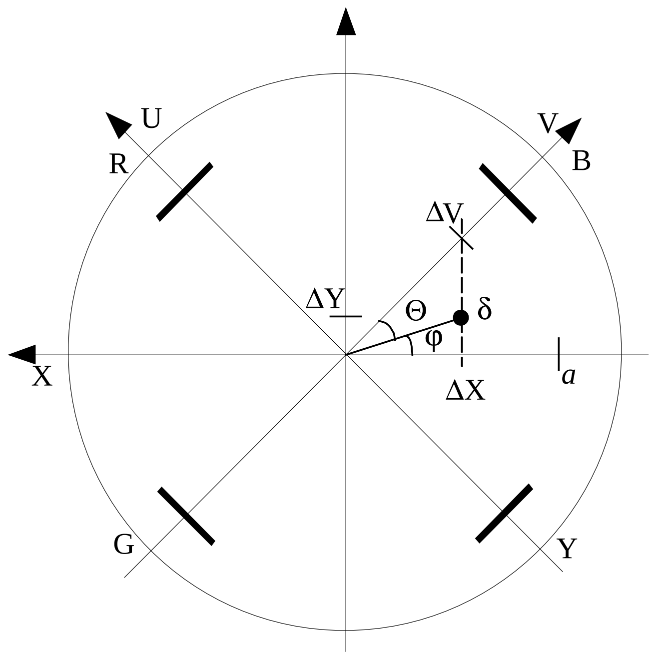

FIGURE 2. Beam offset from the center.

R, G, Y, B represent the PEP-II cables color code (red, green, yellow, blue), $a \approx 45$ mm is the aperture, $\delta = \sqrt{\Delta x^2 + \Delta y^2}$, $\Theta_{R,B,Y,G} = n\frac{\pi}{4} - \tan^{-1}\left(\frac{\Delta y}{\Delta x}\right)$, where n = 3,1,7,5 respectively.

The normal component of the electric field at the monitor electrode [2]:

$$E_n \cong F(\delta, \Theta), \tag{1}$$

where

$$F(\delta, \Theta) = \frac{a^2 - \delta^2}{a^2 + \delta^2 - 2a\delta\cos(\Theta)}. \tag{2}$$

For the worse case $|\Delta x| = |\Delta y|$ (beam moves toward button) $\Rightarrow \delta = x\sqrt{2}$, at $n = 1$,

$$F(\delta, \Theta) = \frac{a + \delta}{a - \delta} = \frac{a + x\sqrt{2}}{a - x\sqrt{2}}. \tag{3}$$

The function $F(\delta,\Theta)$ versus the X beam position is shown below (Fig. 3).

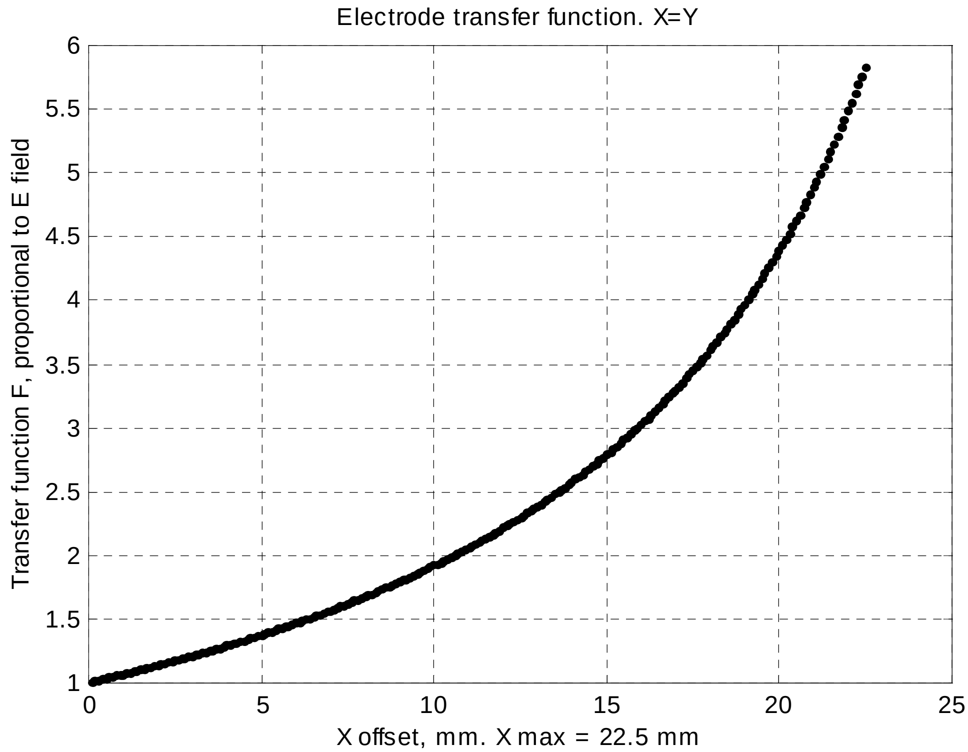

FIGURE 3. The monitor electrode transfer function.

The requirements state that the log BPM should measure position up to a 20 mm beam offset. According to the equation (5) at $\Delta x = 20$ mm $F(\delta,\Theta) = 4.38$ or 12.8 dB, at $\Delta x = \frac{a}{2} = 22.5$ mm (the log BPM margin) $F(\delta,\Theta) = 5.83$ or 15.3 dB. So a 45 dB dynamic range is the sum of the 30 dB ratio between 3 A and 100 mA current and 15 dB due to the beam-position monitor electrodes' transfer function.

LOG BPM PERFORMANCE

The basic expression for the beam position, measured by the logarithmic method [3] is:

$$X = \frac{1}{S \cdot G_{STM}} \cdot 20 \cdot \log\left(\frac{R}{L}\right) = \frac{1}{S \cdot G_{STM}} \cdot 20 \cdot (\log R - \log L), \qquad (4)$$

where $S = \frac{80}{\ln(10)} \cdot \frac{1}{a}$ (dB/mm) is the sensitivity [4], a (mm) is the aperture; G_{STM} (mV/dB) is the system gain which includes gains of the logarithmic amplifier, the differential amplifier and the rest of the system; R and L are the right and left electrode potentials. The difference between logarithms is proportional to the beam position signal. So the expression for beam position in *mm* versus position in *Volts* is:

$$x = \frac{1}{S \cdot G_{STM}} \cdot V_{OUT}, \quad (5)$$

where V_{OUT} is the differential amplifier output.

For the aperture $a \approx 45$ mm the sensitivity is S = 0.77 dB/mm. The AD8307 unadjusted gain is 25 mV/dB, and the differential amplifier and the rest of the system gains are about unity. So the beam position is:

$$x(mm) \approx \frac{1}{19.25\,(mV/mm)} \cdot V_{OUT}\,(mV). \quad (6)$$

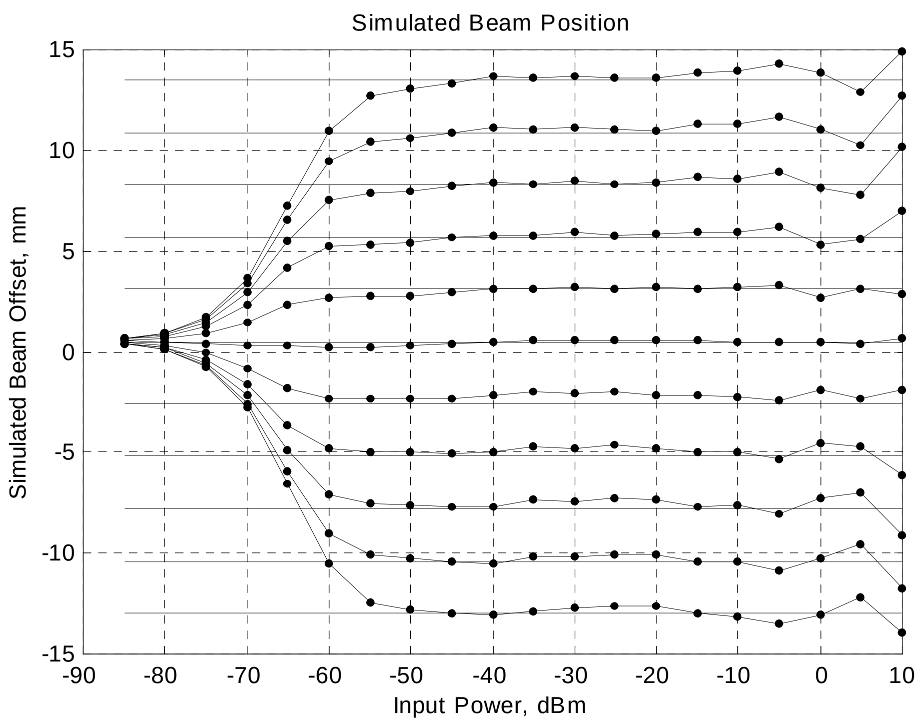

FIGURE 4. Simulated beam position.

Beam position simulation measurements (Fig. 4) are performed on a test bench. A 476 MHz signal, split into two channels goes through the programmable attenuators to the logarithmic amplifiers (log amp) inputs. The differential amplifier derives a simulated *X* position signal from the log amp outputs.

The data were taken at attenuations of 10 dB to 0 dB in 2 dB steps. At each attenuation step twenty measurements of the output signal versus the input signal were made, by varying input power from 10 dBm to –85 dBm in steps of 5 dB. When one attenuator is changing, the other one is set to 0 dB. Gain adjusting, matching of log amp offset and adjusting of log amp slope were done in software.

The measured offset is +0.5 mm. Straight lines show filled positions, corresponding to fixed attenuation differences. The lines' position includes the measured log amps offset. The expected log amp slope is 25 mV/dB. Fitting the data to straight lines gives a slope of 26 mV/dB, a 4 % difference. The dynamic range is about 55 dB. The jump at 5 dBm corresponds to the AD8307 specification at 500 MHz input frequency.

Two different techniques were used to measure the log BPM noise. The oscilloscope measurements give about 3.4 mVrms at the LPF output. The LPF bandwidth is 50 kHz and gain is 4, so the noise at the LPF input is 0.85 mVrms or –48 dBm. The Spectrum Analyzer measured data is –112 dBm/Hz, so at 50 kHz (47 dB) it is –65 dBm or 126 μV rms. The noise was measured at 0 dBm, –30 dBm, -50 dBm and -60 dBm input signal level. The data above corresponds to –30 dBm input signal. The noise figures at 0 dBm and –30 dBm are the same, at –50 dBm and –60 dBm noise goes up to –104 dBm/Hz and –92 dBm/Hz respectively. The log BPM noise response at the inputs connected to ground is about –46.4 dBm, referred to the LPF input.

The log BPM resolution is

$$\sigma_X = \frac{1}{SG_{STM}} \cdot 126\,\mu Vrms \approx 2\,\mu m \tag{7}$$

The log BPM performance summary is shown on the table below (Tab. 1)

TABLE 1. Log BPM performance.

Parameter	Conditions	Data
LPF bandwidth	1 dB bandwidth	50 kHz
Noise	@ LPF bandwidth	- 48 dBm
Noise	@ 50 kHz	- 65 dBm
Resolution	0 dBm to –30 dBm input signal	2 μm
Log amp rise time	@ pulse modulated 476 MHz	454 ns
Log amp fall time	log amp in, out is 2.14 V p-p	626 ns
Dynamic range	-	55 dB

These log BPMs operate without adjustment for logarithmic slope or offset. The offset requirements were met by simple pairing of log amp chips. Tighter position offset requirements might necessitate logarithmic slope and offset adjustments.

CONCLUSION

Twelve log BPMs were fabricated. All were tested on the test bench. Two PEP-II ring protection chassis, carrying four log BPM each, were installed in July and August of 1999 on the Low Energy Ring and High Energy Ring. The beam position measurements were checked at different beam offsets by moving the beam locally up to 5 mm off center. The measured data correspond to the beam position and satisfy the requirements.

The ring protection chassis have been commissioned and are in operation.

ACKNOWLEDGMENTS

We would like to thanks all involved in commissioning the PEP-II protection chassis and to all who gave us a fruitful advice.

Work supported by U.S. Department of Energy, contract DE-AC03-76SF00515.

REFERENCES

1. Analog Devices, "Low Cost DC-500 MHz, 92 dB Logarithmic Amplifier". www.analog.com
2. J.-L. Pellegrin, "Intrinsic Nonlinearity of Position Monitor", SPEAR-149, November 1972, SLAC note.
3. G. R. Aiello and M. R. Mills, "Preliminary Evaluation of AD640 Logamp Detector for BPM Electronics", SSCL-N-787, February 1992.
4. Robert E. Shafer, "Beam Position Monitoring", AIP Conference Proceedings 212, Upton, NY: American Institute of Physics, 1990, pp. 33-34.