BPM Position Monitor Electronics

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LANL

BPM development team members include:

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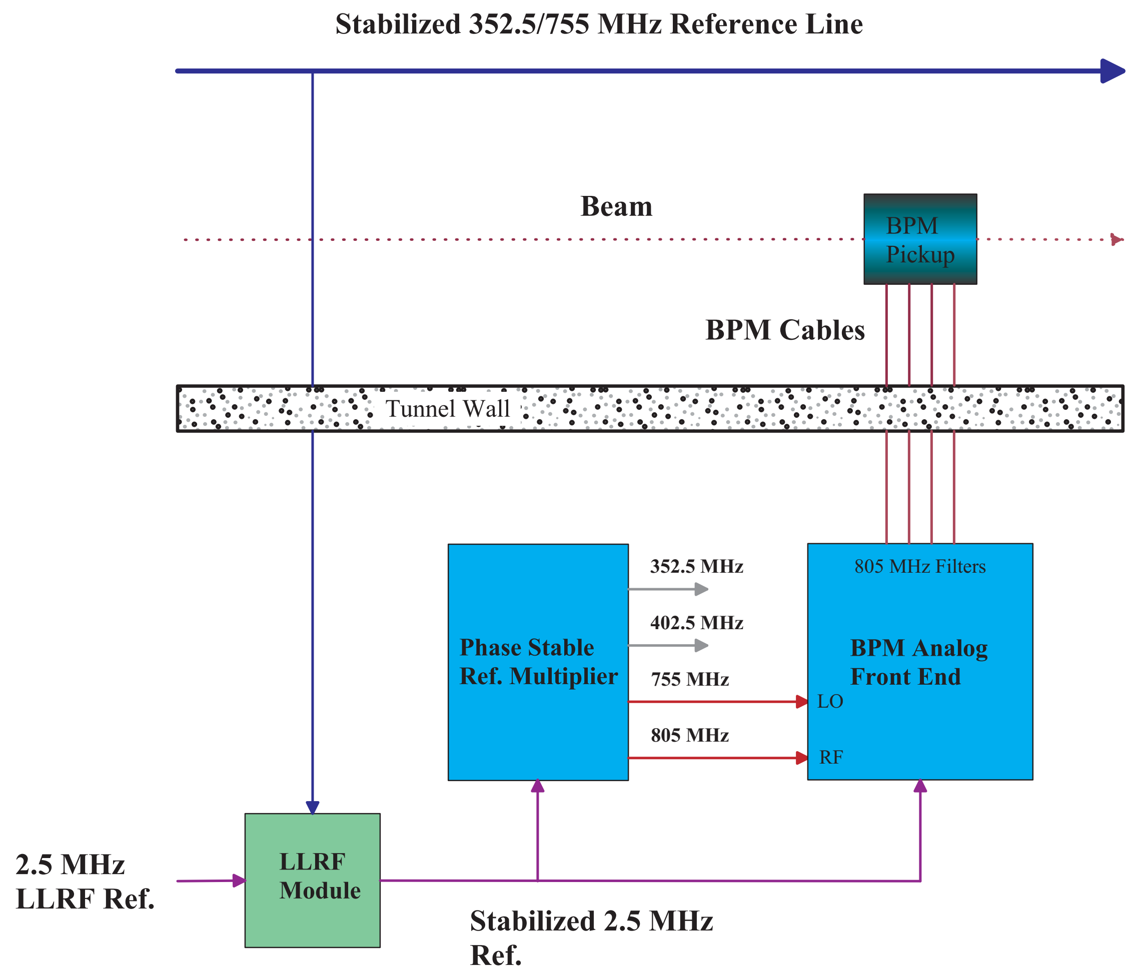
- Matt Stettler
- Lisa Day
- Sergey Kurennoy
- Mike Plum
- Bob Shafer

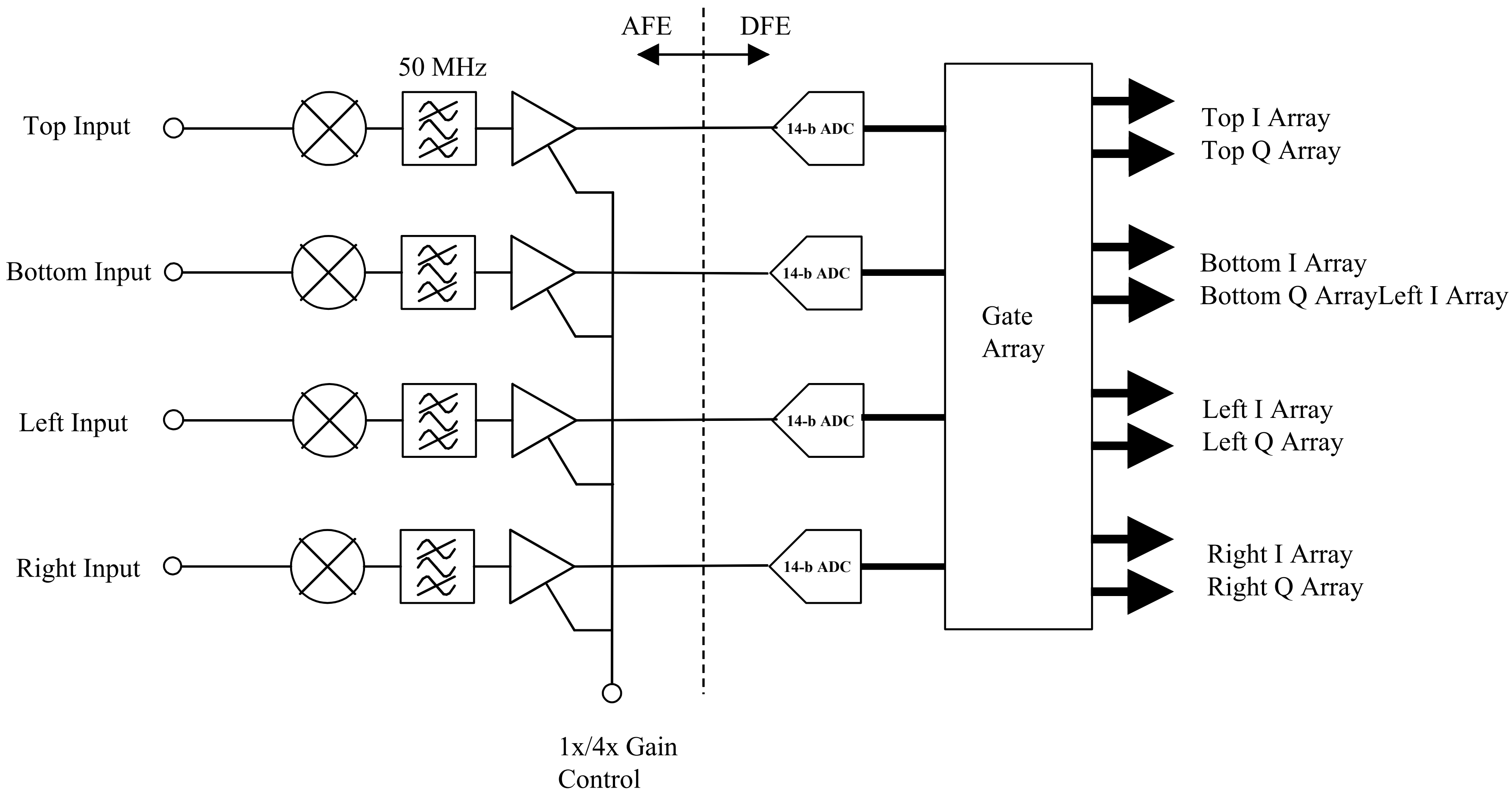
BPM Signal Processing Technique

- Down convert BPM signals to 50 MHz IF
- Sample IF at 40 MHz to generate I and Q data
- Signal vectors calculated from I and Q
- Synchronous L.O. and rf calibration signals required for phase measurements
- Continuous calibration using internal pulsed RF sources

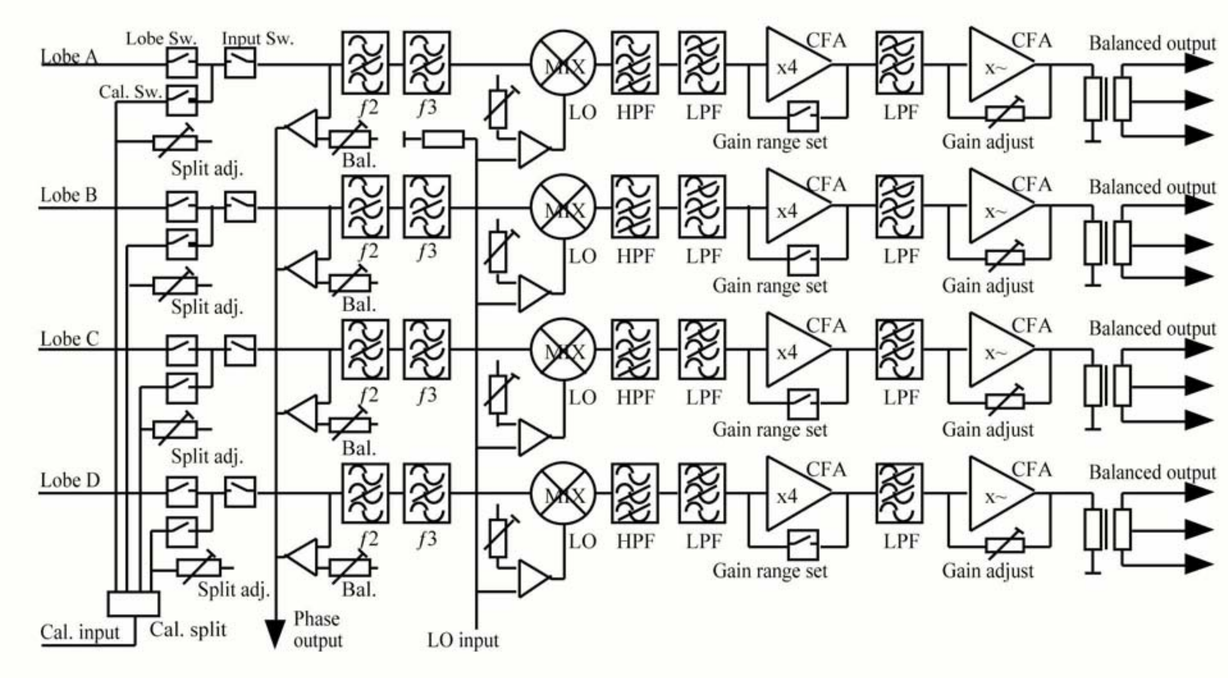
BPM Reference Signal Diagram



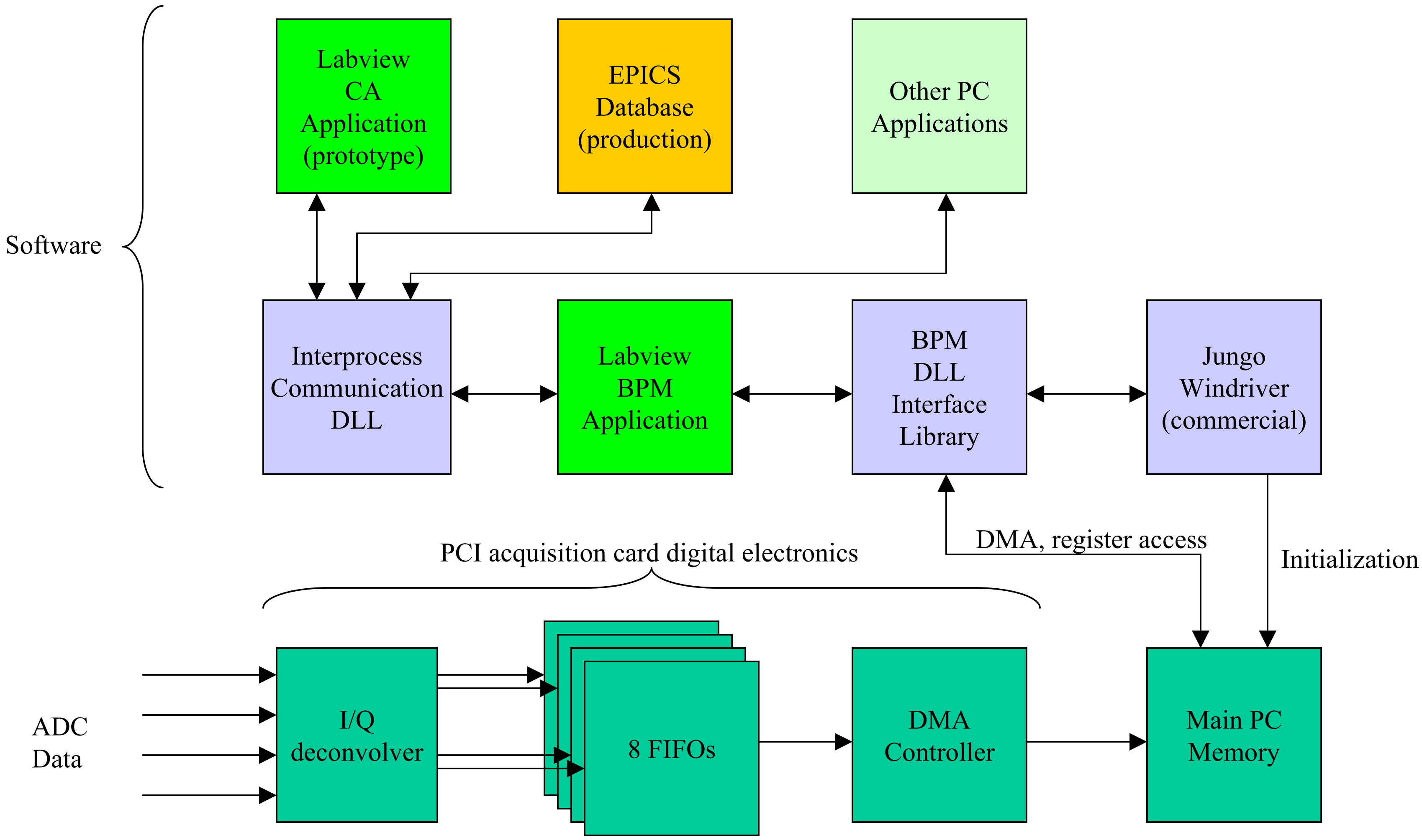
AFE/DFE Block Diagram



AFE Prototype Block Diagram

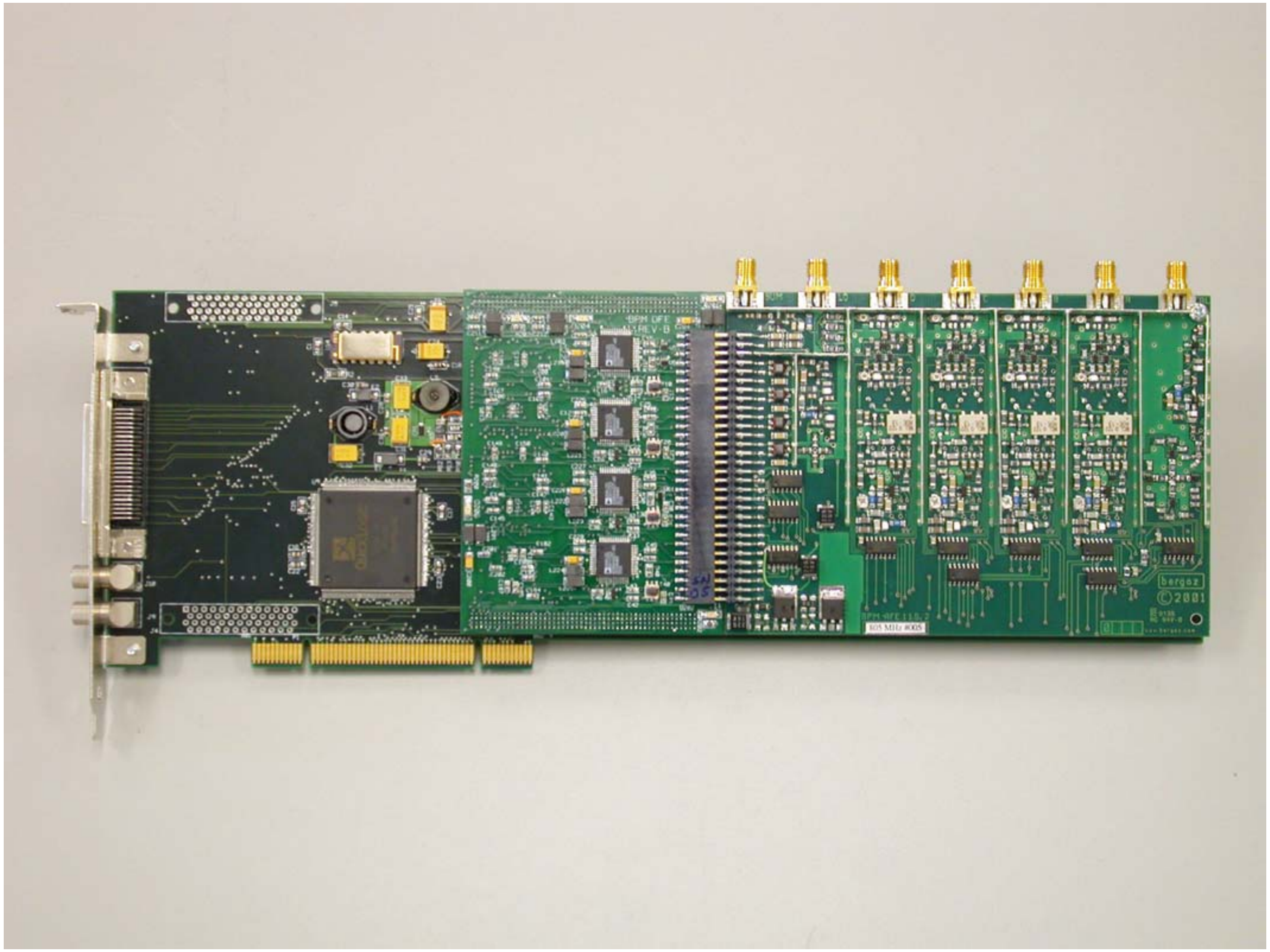


BPM Digital Data Flow

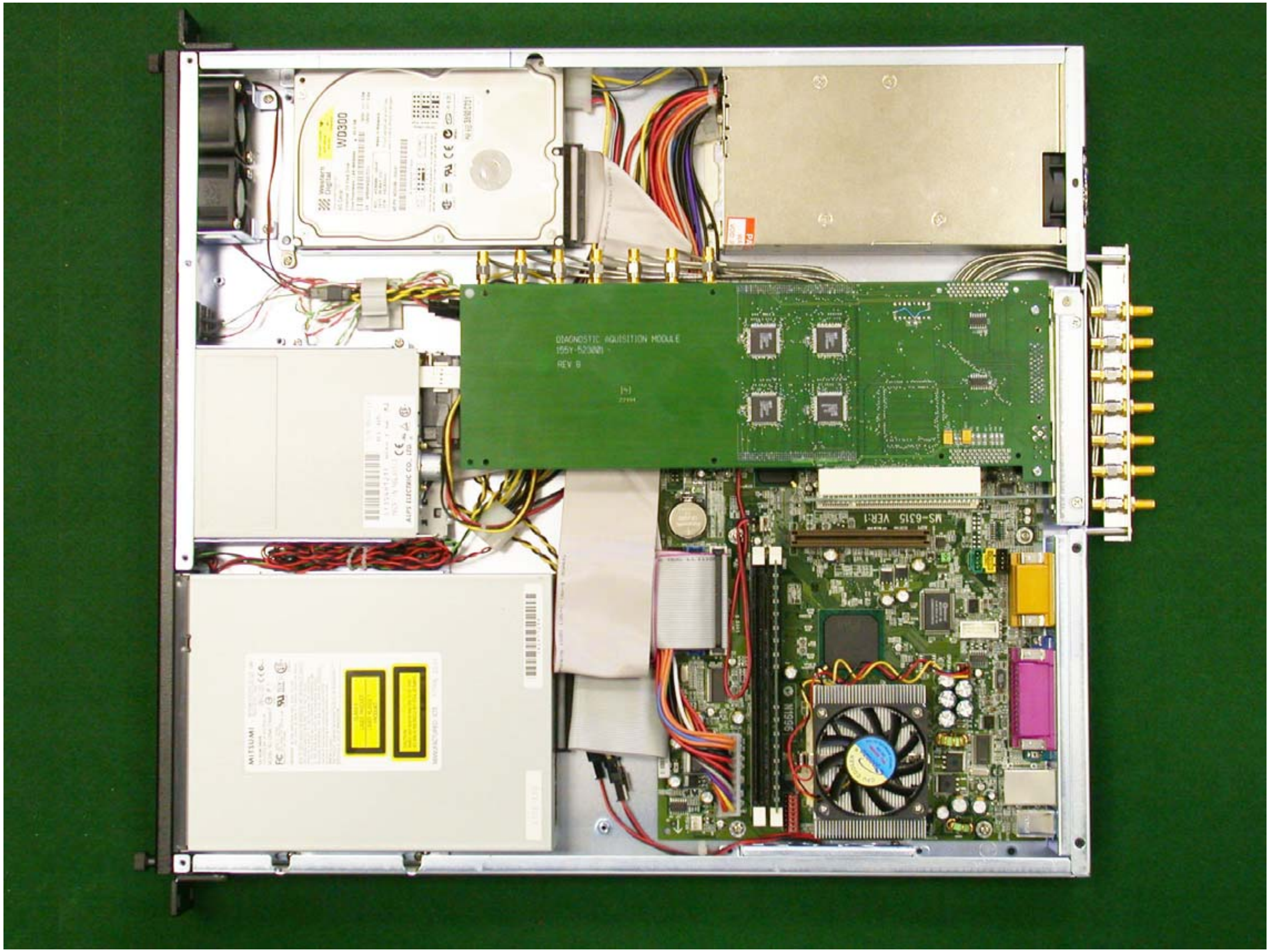


1U BPM Processor Chassis

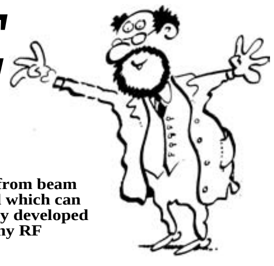
PCI Hardware



Chassis Interior

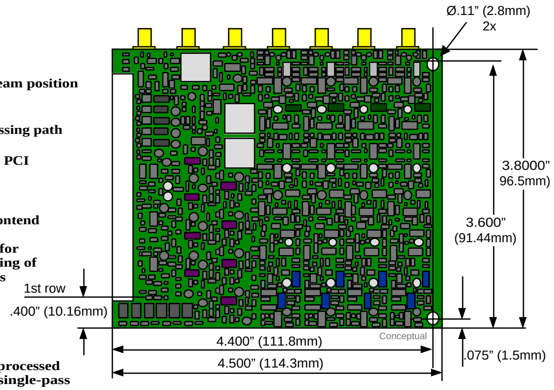


BPM-AFE



BPM Analog Frontend

BPM-AFE is an analog frontend to process RF signals from beam position pickup electrodes. It delivers an output signal which can be directly entered into fast 14-bit ADCs. It is specially developed for transfer lines and linacs. It can be customized to any RF frequency up to 1 GHz.



Non-interceptive beam position measurement

Four parallel processing path

Mezzanine board to PCI specifications

The Beam Position Monitor Analog Frontend (BPM-AFE)) is an electronics module for fast analog processing of beam pickup signals

Customizable to any bunch frequency up to 1 GHz

Four input signals processed in parallel, allows single-pass position measurement

Input signals are down-converted by independent superheterodyne receivers to an intermediate frequency (IF)

IF output signals are differential and galvanically isolated, for direct input into fast ADC (e.g. AD6644)

Output signals are adjustable up to ±1V to take advantage of full ADC input aperture

High phase accuracy and low harmonic distortion by current feedback amplifiers

IF bandwidth adjustable by separate independent high-pass and low-pass filters provide flexibility

Low power dissipation and temperature drift are achieved with passive mixers

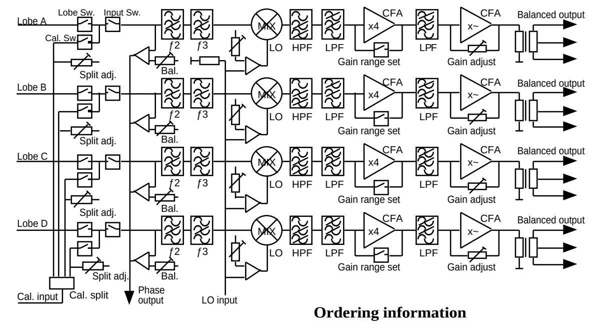
Excellent in-band transient response

Abuse-tolerent, by design. Hot-swap.

Signal processing

Input signals into each superheterodyne channel can either be the Calibration signal or the signal from the lobe, controlled by the Lobe, Input and Calibration switches. Each channel switches are controlled individually. Calibration signals are balanced to identical level for each receiver, and can be sent to any lobe for detection by another channel, under the control of the switches. Calibration signal frequency is independent of the superheterodyne receiver frequency.
Switch-selected input signals are summed to produce a phase reference signal. Each channel is otherwise processed independently. Two successive trap filters reject unwanted harmonics. A passive double-balanced mixer processes the signal with a common Local Oscillator (LO) signal. The common LO signal is distributed to each mixer after buffering. The resulting Intermediate Frequency (IF) is filtered by two cascaded high-pass and low-pass filters to reject the unwanted mixing products.
The IF filtered signal is amplified by two stages of high gain x bandwidth current-feedback amplifiers. The first stage can be switched between two gain levels, while the second stage gain is adjustable by potentiometer in a range 1:4.
A balun at the output produces a balanced signal with floating ground reference from each single-ended IF signal.v.0.1

Block Diagram



Specifications

Board size:	3.800" (96.5mm) high 4.500" (114.3mm) wide with 2 mounting holes per PCI specifications
Operating frequency	Customizable 60 MHz < ƒ0 < 1 GHz
RF input signal	+2 dBm max
IF output signal	±1V max
Overall gain	Pot adjustable in 1:4 range Fixed range switching x1/x4 by TTL control
Intermediate frequency	Customizable 10 MHz < IF < 100 MHz
IF output bandwidth	Customizable 10 kHz < IFBW < 1 MHz
IF harmonics distortion	< 50 dBc
Sum output	Pot adjustable 0-4 dB above input level Sum balanced to 0.1 dB. On option, sum balanced to 0.01 dB
Sum phase error	< 3 degrees
Calibration	By external calibration signal
Calibration switching	< 50-ns switching, >50 dB isolation
Calibration signal	+13 dBm max
Calibration balancing	Splitter and switches compensated to <0.1 dB error. On option: <0.01 dB.
RF harmonics rejection	> 60dB ƒ2, ƒ3 rejection
Crosstalk	Channel to channel: < 50 dB Calibration to channel: < 60 dB
Connectors	Male HE10 60 pins (30x2) right angle header SMA jack right angle 50-ohm for RF signals (7)
Power supply	+5V, -5V regulated
Temperature drift	< 10^{-3} per degree

V0.1

Ordering information

BPM-AFE-xxxMHz BPM Frontend PCI mezzanine

On-board factory-installed options:

BPM-AFE/CLM Calibration signal level matching error <0.01dB

Maintenance accessories:

BPM-AFE/KIT Table-top test kit featuring
AC-DC power supply
Single-ended 50-ohm output
SMAs for each channel

SUPERHET/04-xxxMHz
Superheterodyne detector with 4 inputs. Resolves 0.001 dB channel-to-channel difference
Phase independent !
Incl. 4 Cannon pin probes

BPM-AFE/SCH Schematics and test procedures, full set with copyrights

One-time Customizing:

BPM-AFE/CUS-xxxMHz
Customize BPM-AFE to xxxMHz operating frequency

Distributors

U.S.A. : GMW Associates
955 Industrial Rd.
San Carlos, CA 94070, U.S.A.
Fax: (650) 802-8298 - Tel.: (650) 802-8292
sales@gmw.com

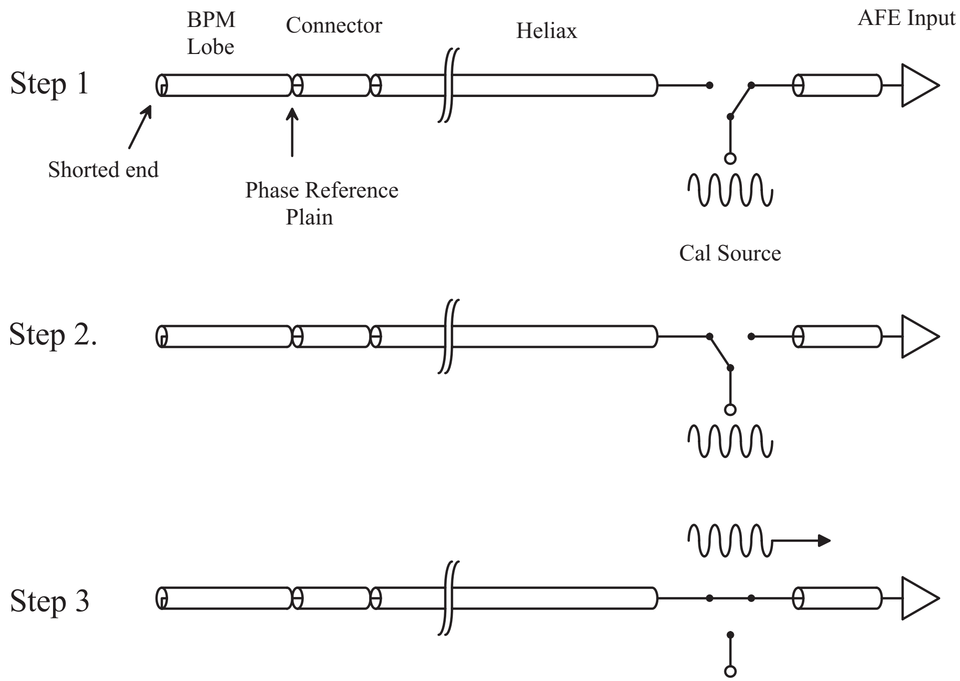
Japan : REPIC Corporation
28-3 Kita Otsuka 1-Chome
Toshima-ku, Tokyo 170-0004, Japan
Fax: 03-3918-5712 - Tel.: 03-3918-5326
sales@repic.co.jp

Manufacturer

BERGOZ Instrumentation
Espace Allondon Ouest
01630 Saint Genis Pouilly, France
Fax: +33-450.426.643 - Tel.: +33-450.426.642
sales@bergoz.com

bergoz
Instrumentation

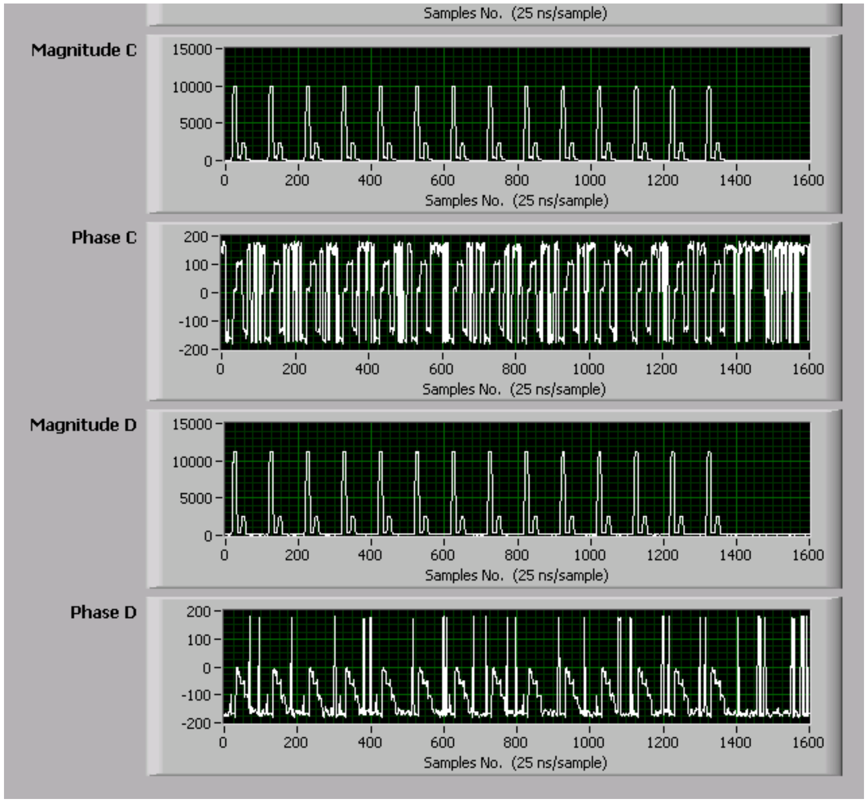
BPM Electronic Calibration

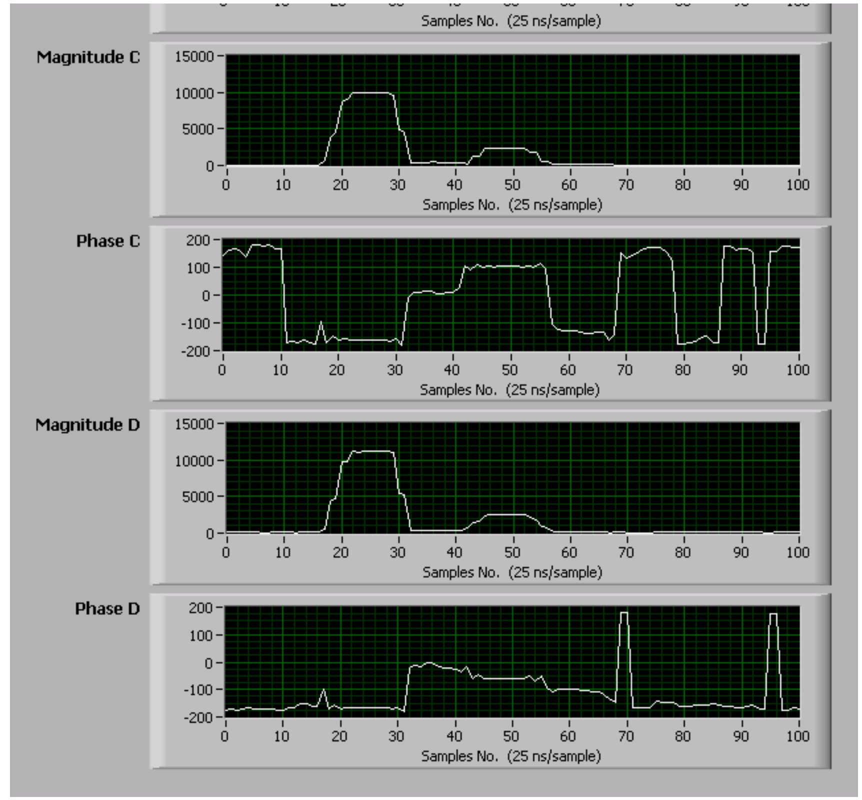


- Step 1. Characterize AFE inputs
- Step 2. Launch pulsed rf cal pulse into BPM cables
- Step 3. After Heliax double-transit delay, disconnect cal source and connect BPM cables to AFE inputs. Measure amplitude and phase of rf reflected off shorted BPM lobes.
- Step 4. Calculate calibration constants

* Note cables must be phase matched to < ± 90 deg.

Calibration Pulse Sequences





Calibration Features

- Calibration data may be taken every macropulse
- 1-2 usable measurements per cal pulse
- Calibration constants could be updated with a rolling average every few seconds
- Cal signal amplitude is near top of dynamic range for optimum S/N. Single amplitude point calibration with system assumed to be linear (gain switching on AFE requires new calibration data).
- Calibration phase is only absolute between BPMs that share a calibration source.
- Second generation AFE should improve the amplitude and phase absolute accuracy (prototype is adequate but can easily be improved)

BPM Signal Levels and Responses

	Freq. MHz	P, β=1 dBm	β Ampl. Corr.	P(Cent) dBm	P(min) dBm*	P(max) dBm*	Dynamic Range*	S, dB/mm
MEBT 1	805	-0.55	0.139	-17.66	-35.31	1.12	36.4	4.76
MEBT 2	805	-0.55	0.051	-26.33	-48.57	-2.86	45.7	4.52
DTL	805	1.03	0.455	-5.8	-18.7	1.4	20.1	3.12
CCL	402.5	-2.42	0.972	-2.7	-11.0	3.6	14.6	1.87
SCL	402.5	-1.42	0.933	-2.0	-9.8	5.1	14.9	0.79
D-Plate	402.5	2.55	0.108	-16.7	-21.7**	-13.9**	7.8**	1.25

*beam displaced at 1/2 of pipe radius
** beam displaced at 1/8 of pipe radius

Power levels are for 52 mA beam current, reduce by 2.7 dB for 38 mA.

BPM Dimensions

	Min. Energy, MeV	Beta, Min.	Diameter, mm	Length,mm	Lobe Angle
MEBT 1	2.5	0.0728	30	71.5	22
MEBT 2	2.5	0.0728	40	71.5	22
DTL	7.5	0.126	25	32	60
CCL	87	0.404	30	40	60
SCL	186	0.55	73	50	60
D-Plate	7.5	0.126	100	90	60

BPM Position Requirements/Measurements

	Sen. (dB/mm)	Position Accuracy Requirement (μ m)	Position Accuracy (μm, based on isolation)	Position Resolution Requirement (μm)	Measured Position Resolution (mm)
MEBT 1	4.76	150	62	15	7*
MEBT 2	4.52	200	110	20	7*
DTL	3.12	130	3.1	13	6**
CCL	1.87	150	19	15	10**
SCL	0.79	370	4.9	37	26**
D-Plate	1.25	500	93	50	32*

*measured at –19 dBm input
** measured at –13 dBm input

Best and Worst Case Channel Noise Spectra

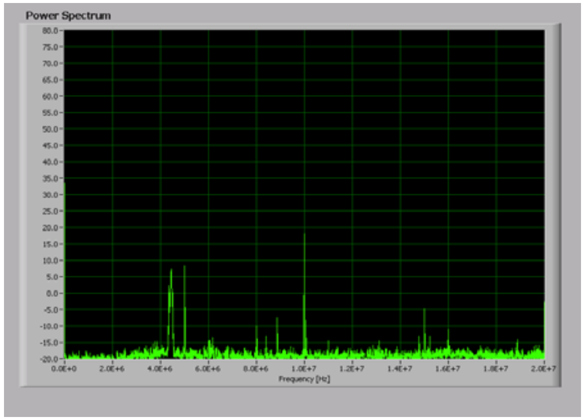
No Input | 74 dB Input

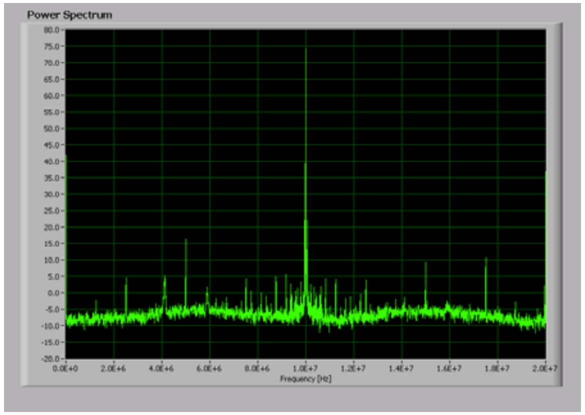
Best Case:

Non-Synchronous Free

DR 67 dB

Synchronous Error Free
DR 57 dB



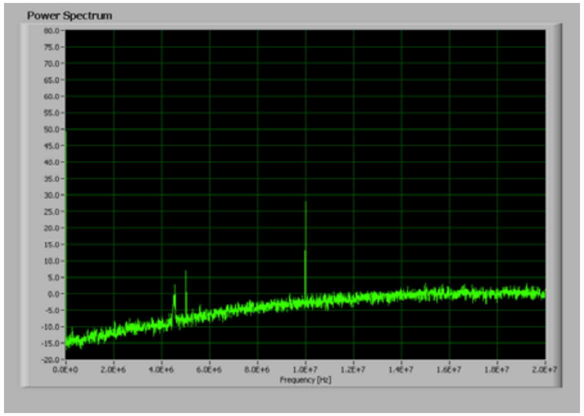


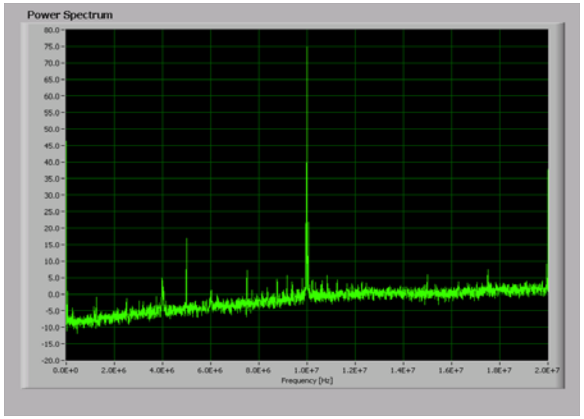
Worst Case:

Non-Synchronous Free

DR 68 dB

Synchronous Error Free
DR 48 dB – need to improve by 10 dB





20 MHz FS, 5 KHz Res, -20dB to +80 dB Amplitude

BPM Amplitude Requirements/Measurements

	Amplitude Accuracy Requireme nt (%)	Amplitude Accuracy (%, based on isolation)	Amplitude Resolution Requirement (%)	Measured Amplitude Resolution (% RMS)
MEBT 1	1	3.7	0.5	0.31
MEBT 2	1	5.7	0.5	0.5
DTL	1	0.9	0.5	0.14
CCL	1	0.8	0.5	0.12
SCL	1	0.9	0.5	0.14
D-Plate	1	0.9	0.5	0.14

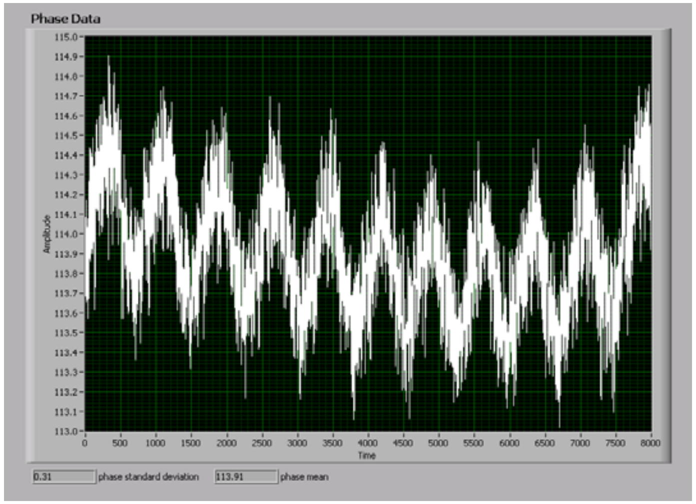
Amplitude accuracy is improved by 2X by turning off the calibration source. Improvements to the second-generation AFE should reduce LO bleadthrough resulting in an additional 2X improvement.

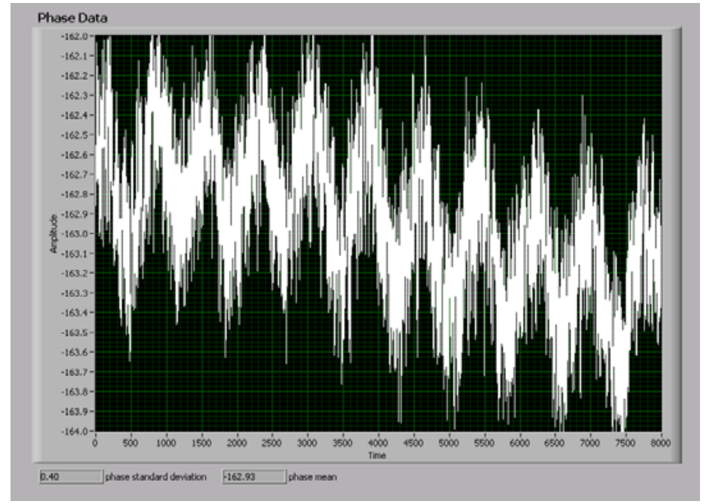
BPM Phase Requirements/Measurements

	Phase Accuracy Requirement (±deg)	Phase Resolution Requirement (deg RMS)	Measured Position Resolution (deg RMS)
All BPMs	2	0.2	0.3

Resolution measurements are based on 10 samples/minipulse with 20 minipulses averaged (20 μs of chopped beam). Phase resolution shown includes the phase noise of 5 different sources, four of which are test instrumentation. Additional averaging may be done to reach the required resolution. The final resolution may ultimately be limited by phase noise in the LLRF reference distribution line.

Typical Channel Phase Noise





- **Typical phase noise of two channels (C and D)**
- **8000 samples at 25 ns/sample (200 μs)**
- **Primary oscillations at 50 KHz**
  - Probable source is in instrumentation, expected to be significantly reduced
- **RMS phase noise is 0.31 and 0.40 degrees**
- **Sum of all four channels is 0.3 degrees RMS**

Software Benchmarks

- **1 GHz PIII, 256 MB SDRAM, Intel 815 motherboard**
- **1.2-ms long data acquisition**
  - 1 ms beam data
  - 200 μs calibration period plus rf turn-on transient
- **384,000 data points/cycle (768 KB)**
  - 8 channels of I and Q
  - 40 MSPS ADC clock with 40 MHz I/Q data pair rate
- **MEBT prototype application runs at over 10 Hz**
  - Calibration with 14 pulses/cycle takes 5 ms
  - Copying data into LV App. Arrays takes about xx ms
  - 250 minipulses of data processed and served in about 2 ms
    - Only limited to 250 points due to EPICS limitations
  - Average beam position, amplitude and phase of each minipulse calculated
  - Average beam position, amplitude and phase of macropulse calculated
  - Includes time stamp from PC's time. Timing IP module will be incorporated when ready.

PDR Comments and Responses

Committee Observation - System **requirements not yet defined** include interface to low level RF system, scope of required absolute vs. relative beam phase measurements (exactly which BPM locations will be involved), and cable plant flexibility. These impact signal handling at the very front end of the BPM/Phase electronics, cable phase matching requirements, potential electrical interference, temperature effects, and hardware layout options affecting phase measurement accuracy.

Suggestion - Strive to **reach resolution** on these and other outstanding requirements issues as early as possible. BPM locations are being studied.

Response - The only interface to the low level RF system now is the 2.5 MHz reference. No BPM RF signals are exchanged between systems. See additional discussion of the 2.5 MHz reference following.

Committee Observation - Requirement for and range of **adjustable gain** stage(s) required in BPM/Phase measurement front-ends seems as yet unresolved. Does one requirement apply to all BPM locations?

Suggestion - Proceed to **resolve** this uncertainty.

Response - A single programmable gain adjustment with a 1x/4x range is included in the AFE design. This is not required, but may be useful. Variation of the fixed gain is easily done on the existing design by changing component values. The gains of the BPMs, MEBT, DTL, CCL and SCL, can be preset in groups as appropriate.

PDR Comments and Responses, continued

Committee Observation - **Phase measurement accuracy and resolution** depend on the stability of the 2.5Mhz reference signal and on higher frequency signals derived from that.

Suggestion - Establish quantitative **specifications** for amplitude stability and phase noise characteristics of the 2.5Mhz signal received by the BPM/Phase electronics.

Response - The 2.5 MHz reference will be a TTL-level signal. The amplitude should be between 3.5 and 5 volts peak with a short-term stability of 1% RMS. Amplitude changes over periods longer than a few hours are unimportant. The phase stability needs to be as good as can be obtained. This is currently thought to be on the order of 0.1 degrees RMS at 352.5 MHz/755 MHz. Long-term (several hour) thermal drifts are not important. The creation and utilization of the LLRF 2.5 MHz reference is under review by the LLRF team.

Committee Observation - BPM/Phase measurement design depends critically on the analog **front-end boards** to be supplied by BERGOZ.

Suggestion - Plan a thorough **qualification testing program** for the first boards to be received and begin testing as soon as possible. Testing should be performed with test signals of the same spectral energy density as anticipated beam signals and over the full signal level dynamic range. Mate to digitizer and PCI board as soon as possible so as to do testing in final system environment.

Response -We are characterizing the complete system at this time. Duplicating the spectral energy density of the beam signal is difficult, but we can make CW tests at all appropriate frequencies. There are improvements that we need to make in the next-generation AFEs to reduce isolation of the calibration signal and L.O. bleedthrough.

PDR Comments and Responses, continued

Committee Observation - BPM/Phase measurement accuracy and resolution depends critically on the performance of the **built-in calibration system.** There are many potential problems. Analog RF switches on front-end electronics are a critical part of calibration system. The calibration system described depends on a minimum cable length between electronics and pick-up, yet MEBT apparently does not satisfy this minimum length. Cable plant specifications have yet to be determined as civil construction plans become finalized.

Suggestion - Proceed at full speed with **quantitative testing of calibration scheme** as soon as electronics assemblies become available.

Suggestion - Don't base design of **critical element** of BPM/Phase measurement system on unknown, perhaps uncontrollable, parameters.

Suggestion - Electronics **packaging issues** should begin to be addressed with the goal of a design that will facilitate performance, trouble-shooting, maintenance, and replacement. Available rack space and cable entry options should be considered in packaging design.

Response – Testing of the calibration method is under way, and the results are promising. No known show-stoppers exist. Some modifications to the next-generation AFE will be required, but are straight-forward. The packaging of the BPM system inside a 1U computer chassis has been demonstrated and we are pleased with the results. All systems will use the same length of cables between the BPM pickup and the electronics. The MEBT cable plan includes the appropriate lengths.

PDR Comments and Responses, continued

Committee Observation - It appears that there is already a **commitment** to a PCI based data acquisition path and that considerable work has been completed to assure the feasibility of this design. The committee agrees that the plan seems acceptable and sounds promising.

Suggestion - At this point, we can only recommend getting a complete **prototype acquisition system up and running** coupled with a real analog front end as soon as possible. This will allow maximum time to resolve any problems that may be encountered. Good Luck.

Response: The prototype system is currently operational. Six have been built and are functional.

Summary

- **Prototype design of BPM electronics built**
  - All position measurements meet requirements
  - All phase measurements expected to meet requirements with PLL multiplier improvements and measurement averaging
  - Improvement in the amplitude measurements are required. Modifications to the AFE design are expected to meet requirements.
  - Calibration technique demonstrated. Improvements identified for final design.
  - 1U computer packaging meets requirements

- **Initial instrument software ready for MEBT testing**
  - Position, amplitude and phase measurements exceed the 6 Hz operational mode requirement
  - Includes calibration, time stamping and data serving