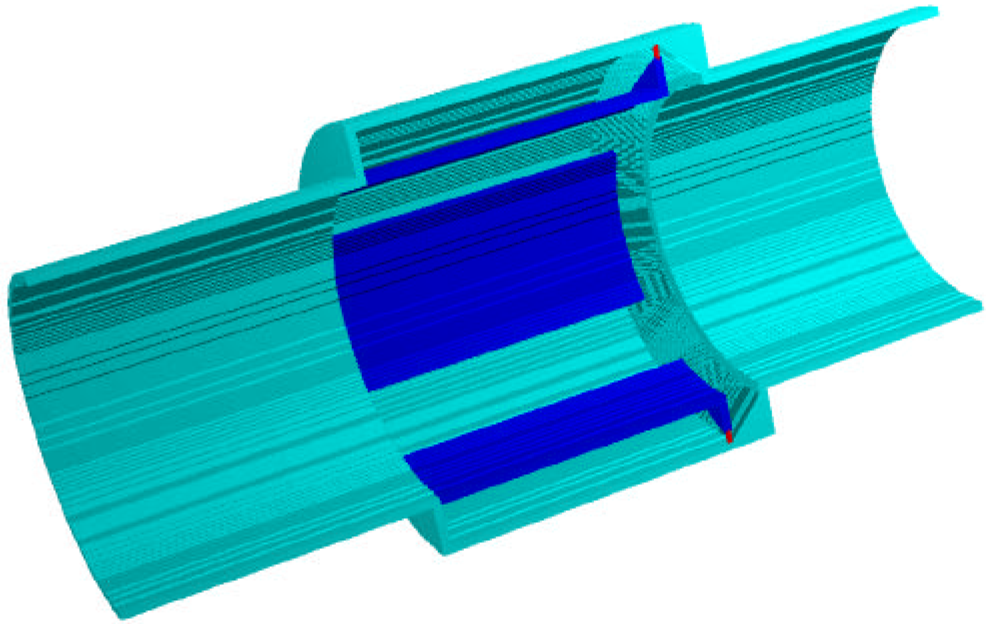
BPM Pickup Responses and Electronics Processing

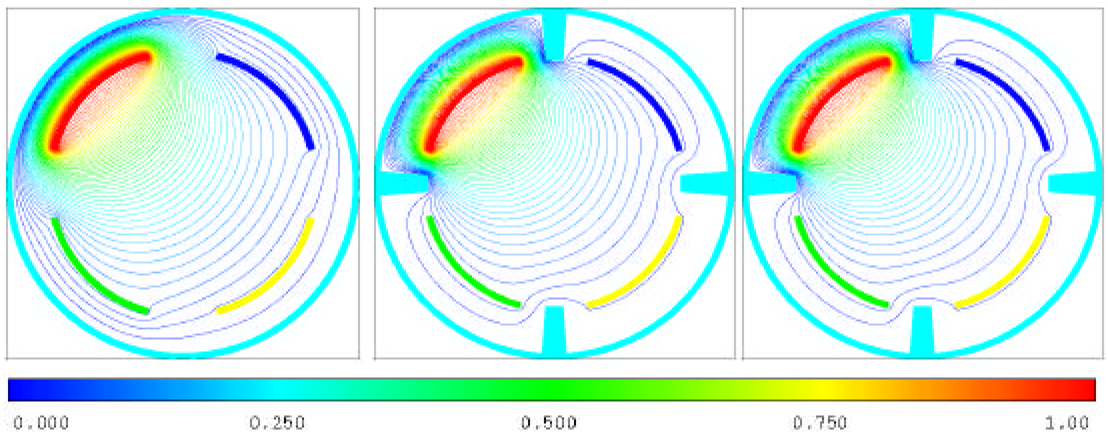
John Power
LANL

BPM MAFIA Model



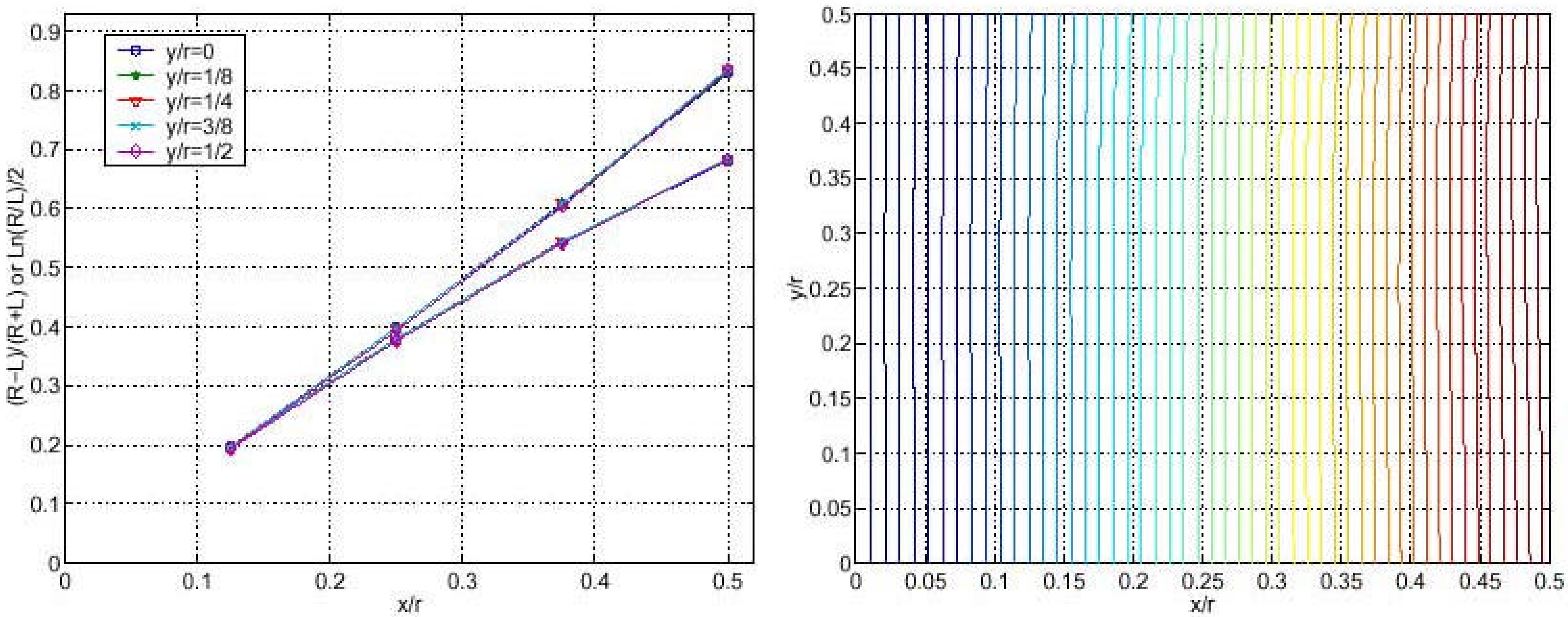
MAFIA model of SNS linac BPM (one-half cutout) with cone tapered box and electrodes (dark-blue) with modified terminations (connectors are shown in red).

Electrostatic Coupling in BPMs



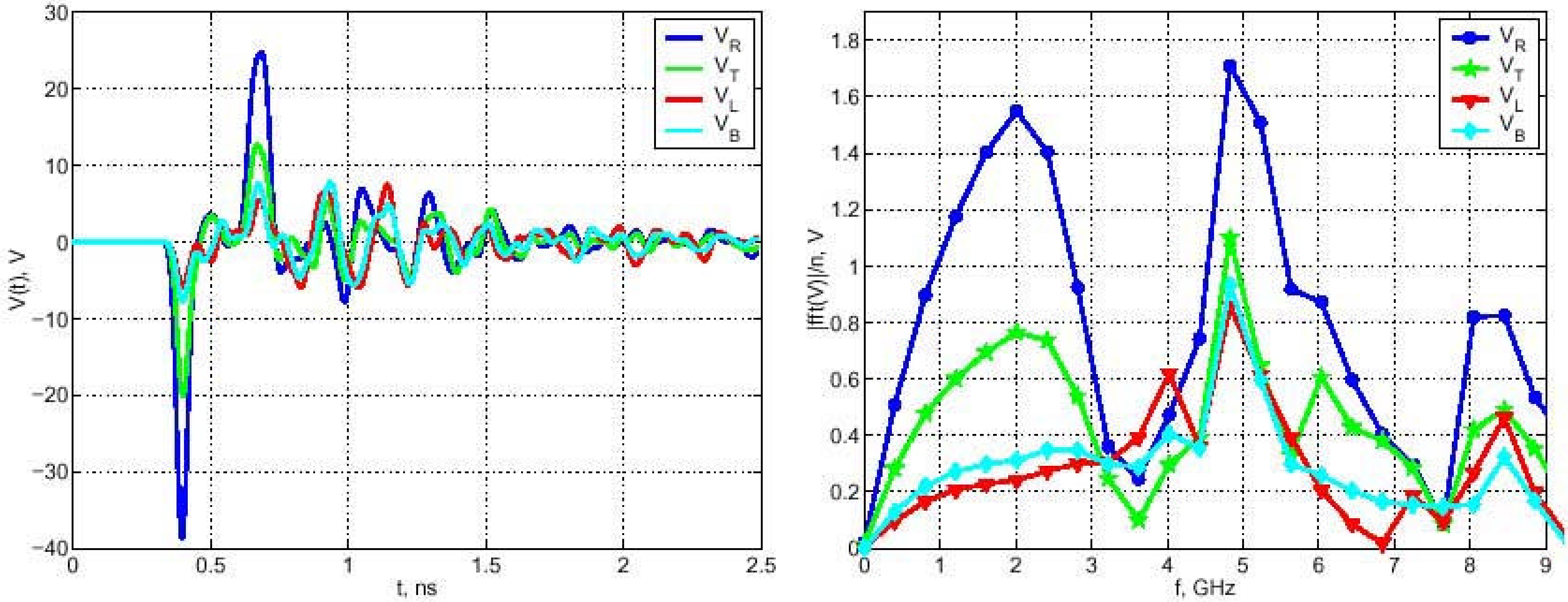
Electrostatic coupling in three BPMs: 60° electrodes (left), the same with separators (center), and 45° electrodes (right). The color of equipotential lines corresponds to the scale below.

CCL BPM Linearity



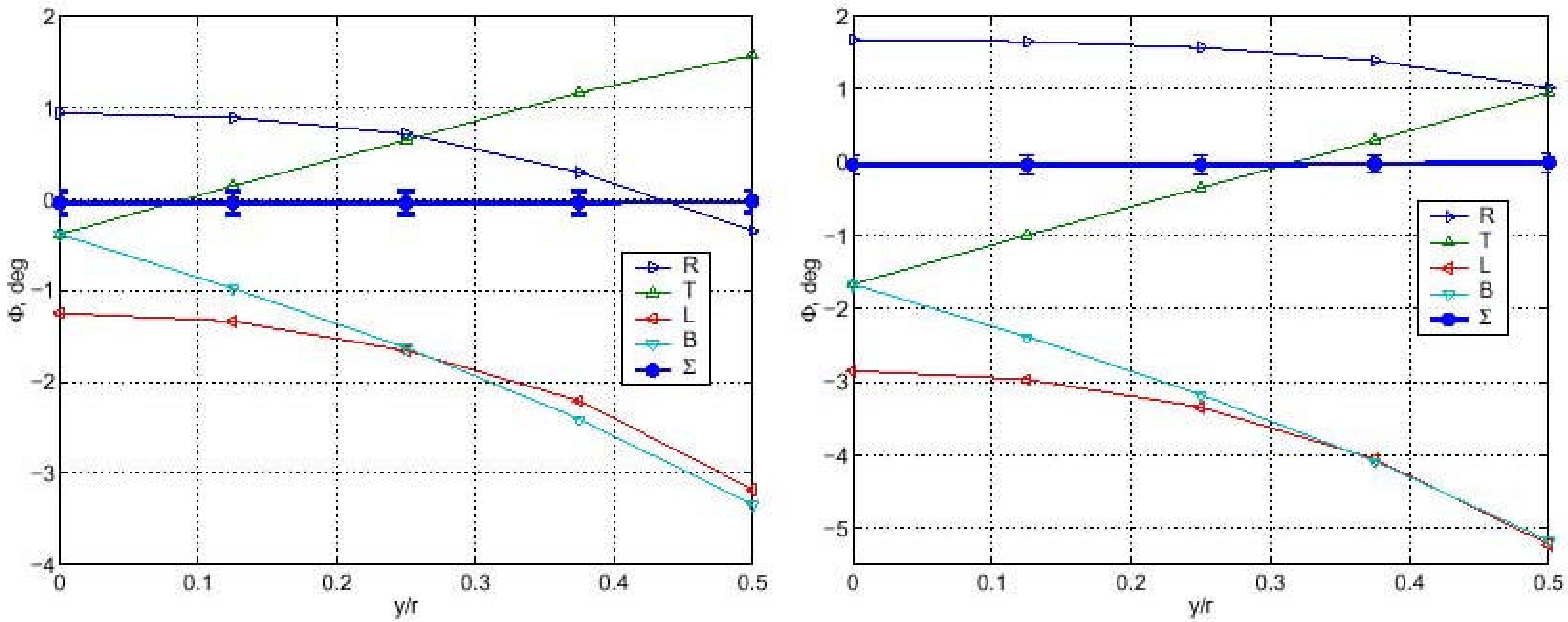
Horizontal ratio S of the signal harmonics at 402.5 MHz (top lines for $S=\ln(\tilde{A}_R/\tilde{A}_L)/2$, bottom ones for $S=(\tilde{A}_R-\tilde{A}_L)/(\tilde{A}_R+\tilde{A}_L)$) versus the beam horizontal displacement x/r_b, for a few values of the beam vertical displacement y/r_b (left, see legend); contours of equal ratio $S=\ln(\tilde{A}_R/\tilde{A}_L)/2$ (right).

CCL BPM Signals



Signals on four BPM electrodes from a passing transversely displaced ($x = r_b/2$, $y = r_b/4$) bunch: left – voltages versus time during one period $T = 1/f_b = 2.4845$ ns; right – normalized Fourier transform amplitudes (V) versus frequency.

CCL BPM Phase Response



402.5-MHz signal phases on four BPM electrodes and for the summed signal versus beam vertical displacement y/r_b, for the beam horizontal displacement x/r_b=1/4 (left) and x/r_b=1/2 (right).

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 Signal Levels and Responses

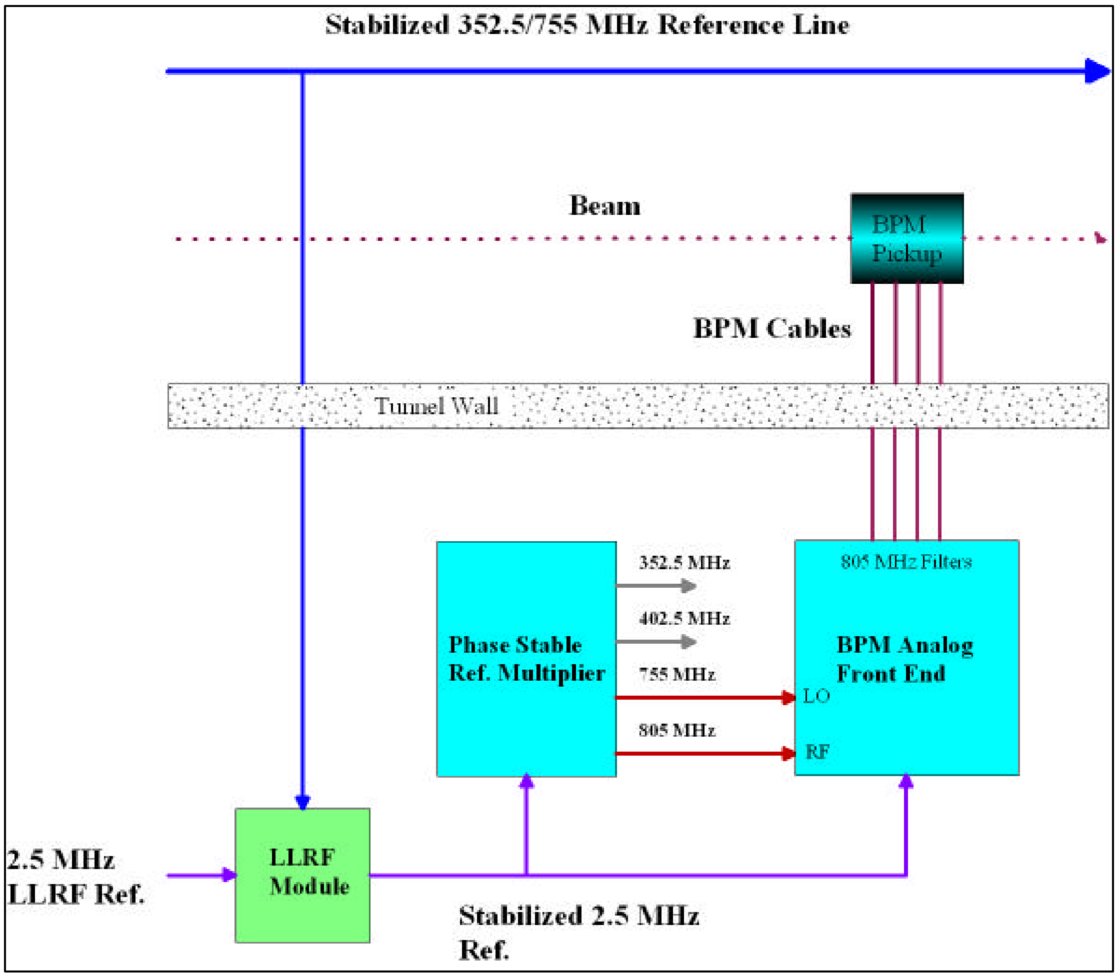
	Freq. MHz	P, b=1 dBm	b Ampl. Corr.	P(Cent) dBm	P(min) dBm*	P(max) dBm*	Dynamic Range*	S, dB/mm
MEBT 1	805	-0.55	0.139	-17.66	-35.31	1.12	36.4	4.76
MEBT 2	805	-0.55	0.051	-26.33	-48.57	-2.86	45.7	4.52
DTL	805	1.03	0.455	-5.8	-18.7	1.4	20.1	3.12
CCL	402.5	-2.42	0.972	-2.7	-11.0	3.6	14.6	1.87
SCL	402.5	-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

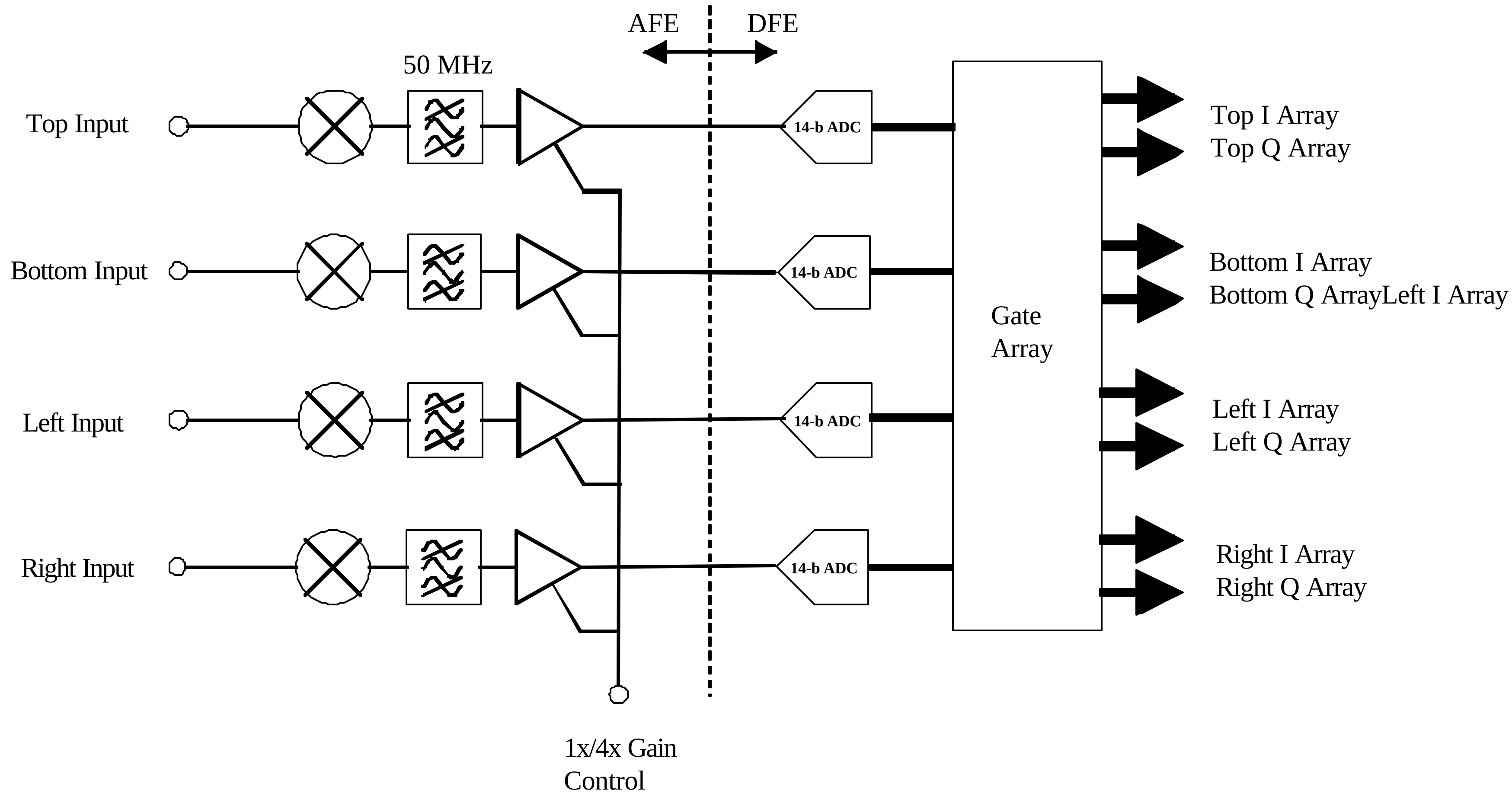
BPM Signal Processing Technique

- **Down convert BPM signals to 50 MHz IF**
- **Sample IF at 40 MHz to generate I and Q data**
  - 14-bit, 65 Msps AD6644 ADC available today
  - Burr-Brown ADS 852 may be released in time with programmable gain for higher dynamic range (4x)
- **Amplitude and phase vector calculated from I and Q**
- **Synchronous L.O. and rf calibration signals required for phase measurements**

BPM Reference Signals



AFE/DFE Block Diagram



Electronics Specifications (preliminary)

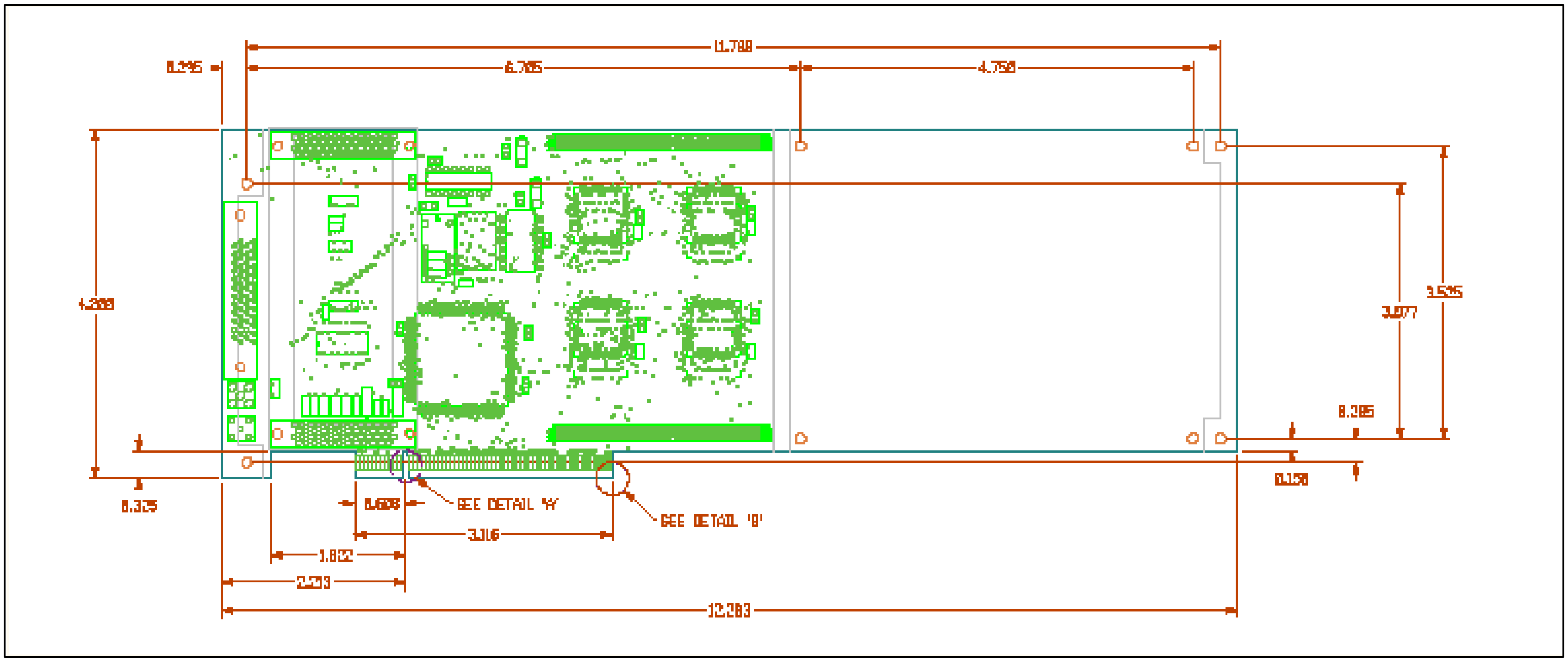
Measurement Freq.	402.5/805 MHz
Intermediate Freq.	50 MHz
Local Oscillator Freq.	352.5/755 MHz
Sampling Frequency	40 MHz
Measurement Bandwidth	5 MHz
Maximum Signal Power	+2 dBm
KTB @ 5 MHz BW	-107 dBm
Electronics Noise Figure	17.5 dB
Cable Loss, ¼” (125 Ft.)	4.6/6.7 dB
ADC SINAD	72 dB
SFDR	85 dB
Max. Calibration Output	6 dBm

Minimum BPM Electronics Requirements

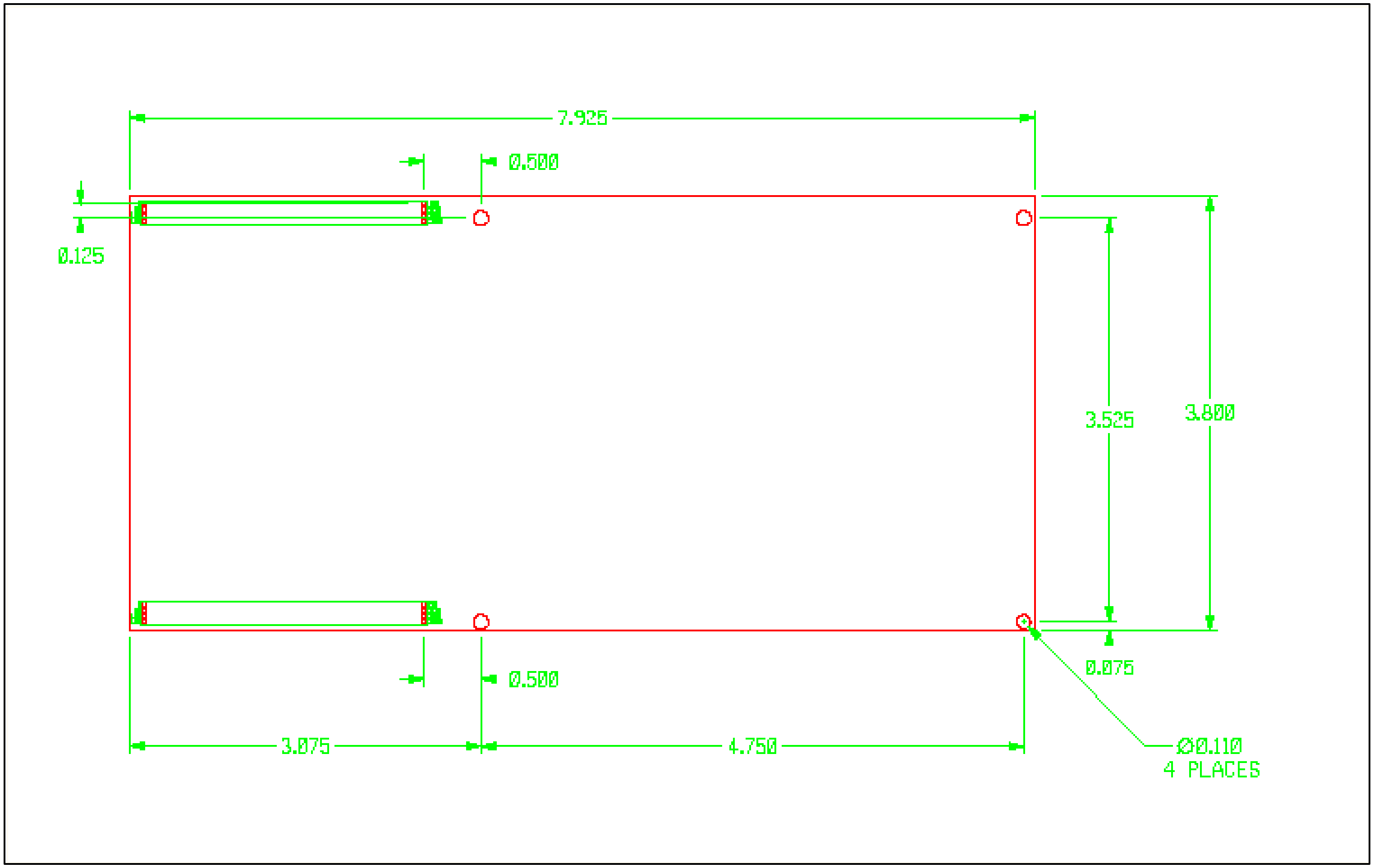
	S (dB/mm)	Accuracy (dB)	Res. (dB)	Headroom (dB)	Nominal ADC Count	Pos. ADC counts	Phase ADC counts
MEBT 1	4.76	4.3	0.7	7.9	758	39	6.6
MEBT 2	4.52	5.4	0.9	11.9	281	23	2.5
DTL	3.12	2.3	0.4	7.6	2981	73	26.0
CCL	1.87	1.7	0.3	5.4	4260	81	37.2
SCL	0.79	1.7	0.3	3.9	4618	90	40.3
D-Plate	1.25	3.8	0.6	22.9	850	36	7.4

- Based on 3% absolute position accuracy, 0.5% absolute position resolution and 0.5 degree phase resolution
- Assumes all processors set to +9 dBm = ADC Top (16384)
- No averaging shown
- Phase requires 4-point average by definition, not reflected in above table

PCI Card Dimensions

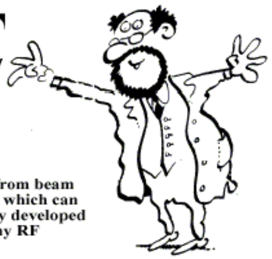


Front End Daughter Card Dimensions



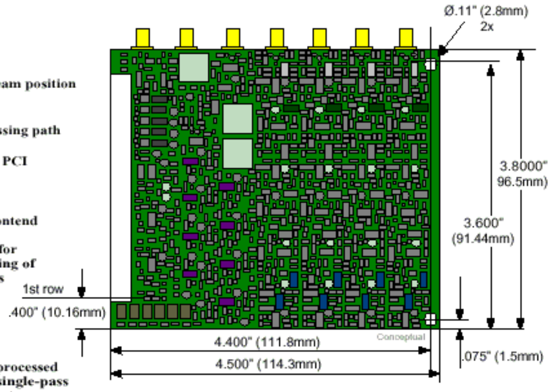
BPM AFE Preliminary Data Sheet

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

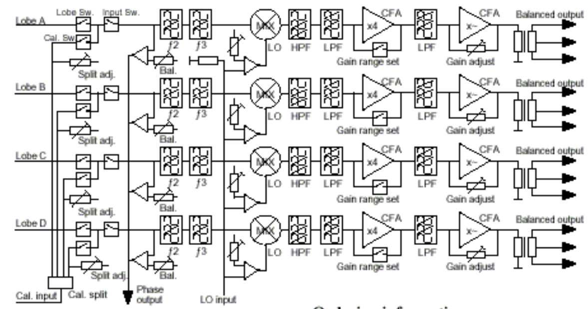
Excellent in-band transient response

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 < $f0$ < 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 $f2$, $f3$ 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

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Toshima-ku, Tokyo 170-0004, Japan
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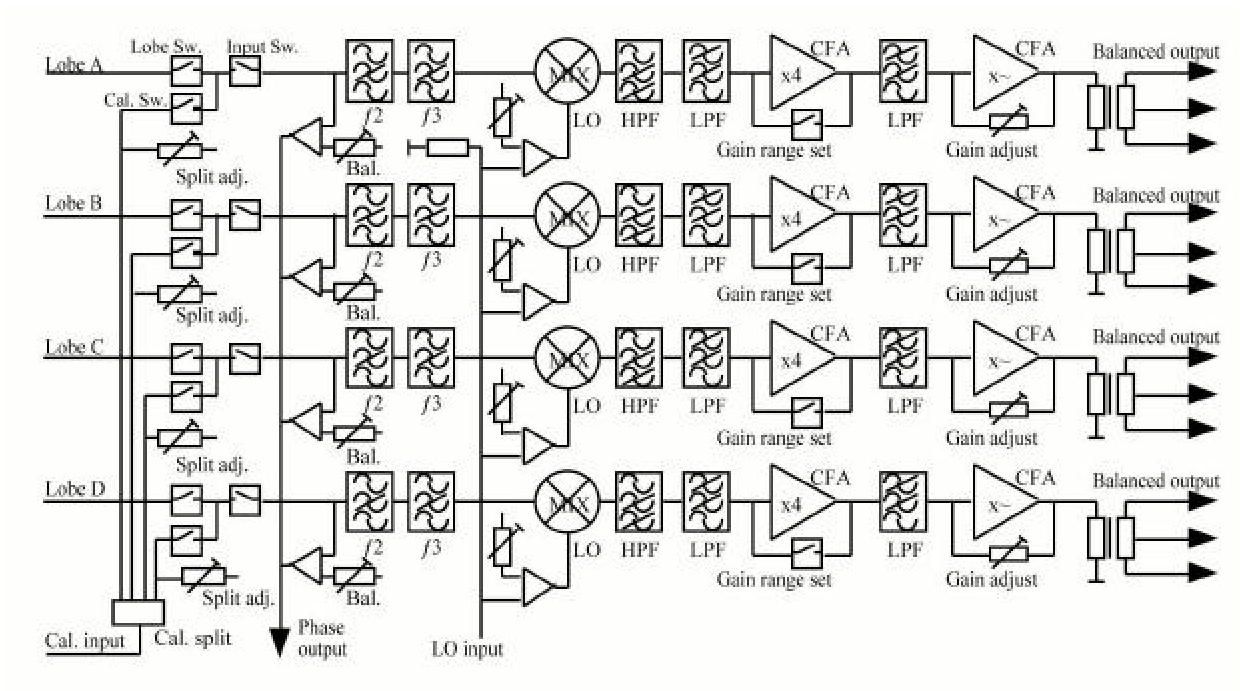
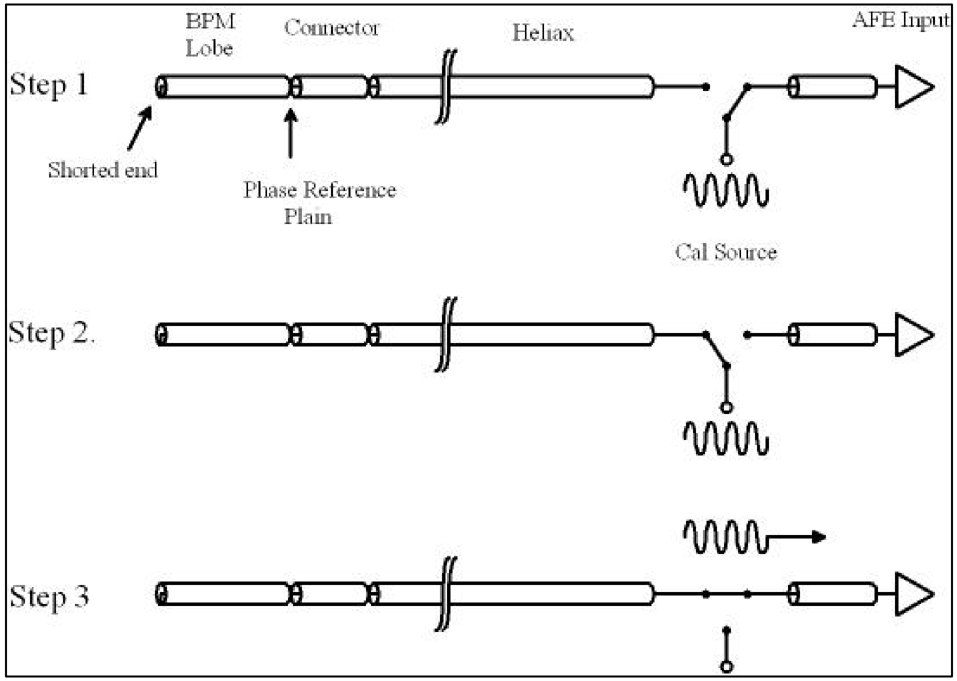
bergoz
Instrumentation

AFE Preliminary Block Diagram



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**

Calibration Features

- Calibration data may be taken as often as every macropulse
- At least 100 ns worth of good data per cal pulse with four data points (I, Q -I, -Q) for amplitude and phase calculation
- Calibration constants could be updated with a rolling average every few seconds
- Cal signal amplitude is near top of dynamic range for good S/N. Single amplitude point calibration with system assumed to be linear (gain switching on AFE requires new calibration data).
- RF interference from cavity fields can be measured just prior to beam injection and, in theory, subtracted from each lobe signal. This is not expected to be necessary in the linac or HEBT. Possibly beneficial in MEBT BPMs where the dynamic range of signals is largest.
- Calibration is only absolute between BPMs that share a calibration source.

Software Benchmarks

- **Assume 1.2-ms long macropulses**
  - 1 ms beam data
  - 200 μs calibration period plus rf turn-on transient
- **192000 data points**
  - 8 channels of I and Q
  - 40 MSPS ADC clock gives 20 MHz I/Q data pair rate
- **Data can be read into LabVIEW at over 230 Hz**
  - 933 MHz CPU
- **Typical linac application runs at over 600 Hz**
  - 100 millipulses of data processes
  - Average beam position calculated
  - Average amplitude and phase calculated
  - Doesn’t include time stamp, continuous calibration or channel access, but this requires time
- **More work needed**

Electronics Hardware Cost Estimates (Preliminary)

Computer w/rf hardware	$1,050
PCI motherboard	$670
AFE	$960
DFE	$400
Cal sources 10 ch/unit	$800
Total*	$3,880

*Timing IP module cost not included. Computer costs based on one BPM channel per computer, which increases costs. Funding is based on 3 BPMs/computer.

Summary

- **BPM responses modeled**
- **Preliminary design of BPM electronics in progress**
  - Digital I/Q processing of down-converted signals
    - Prototype analog front end ordered and due in March
    - Prototype PCI motherboard due in March
  - Prototype RF reference oscillator chassis received
- **System software development and testing in progress**