High Position Resolution and High Dynamic Range Stripline Beam Position Monitor (BPM) Readout System for the KEKB Injector Linac Towards the SuperKEKB

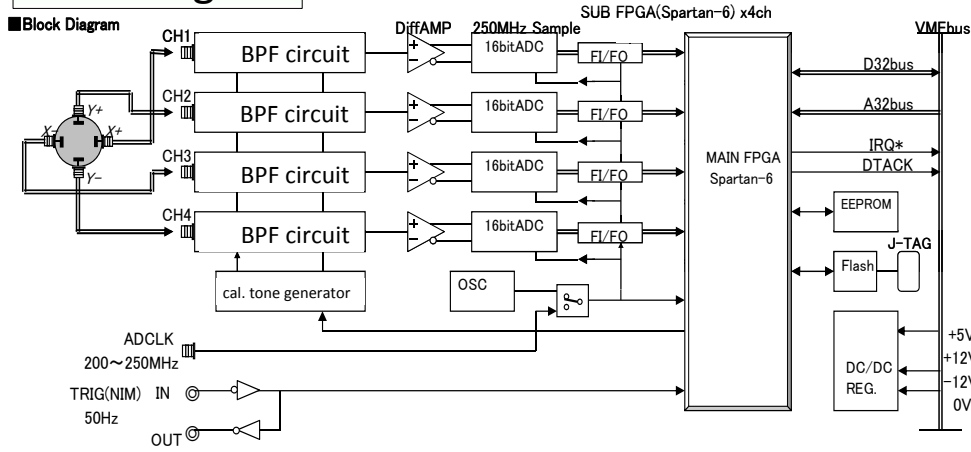R. Ichimiya#, T. Suwada, M. Satoh, F. Miyahara, K. Furukawa (KEK)
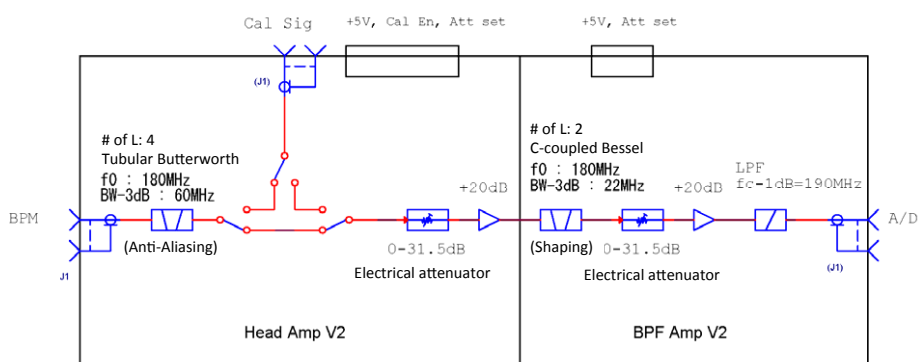
(e-mail: ryo@post.kek.jp)

Specifications

- Position resolution <10 μm. Same order accuracy.
- High dynamic range (0.1 nC – 10 nC), large precise aperture (± 5mm with σ < 10 μm).
- Under-sampling with Narrow Band Pass Filters (BPFs)
  - 16-bit 250 MSa/s ADC (AD9467-250).
  - F$_c$=180 MHz, Bw=22 MHz (Bessel).
  - Measures two bunches with 96 ns interval.
- Equipped Calibration tone generator to compensate position drift due to channel gain drift.
  - > 40 dBm output.
  - Between beam injection (20 ms interval), calibration tone is output to the BPM electrodes.
- Design non-linearity is within ±0.02 dB.

Block diagram

■Block Diagram

CH1 → BPF circuit → DiffAMP + → 250MHz Sample 16bitADC → FI/FO
CH2 → BPF circuit → + → 16bitADC → FI/FO
CH3 → BPF circuit → + → 16bitADC → FI/FO
CH4 → BPF circuit → + → 16bitADC → FI/FO

SUB FPGA(Spartan-6) x4ch

MAIN FPGA Spartan-6

cal. tone generator
OSC

VMEbus
D32bus
A32bus
IRQ*
DTACK
EEPROM
Flash J-TAG

ADCLK 200~250MHz
TRIG(NIM) IN 50Hz
OUT

DC/DC REG.
+5V
+12V
-12V
0V

- BPF circuit block diagram

Cal Sig   +5V, Cal En, Att set   +5V, Att set

# of L: 4
Tubular Butterworth
f0 : 180MHz
BW-3dB : 60MHz
(Anti-Aliasing)

# of L: 2
C-coupled Bessel
f0 : 180MHz
BW-3dB : 22MHz
(Shaping)

BPM
0~31.5dB
Electrical attenuator
+20dB
0~31.5dB
Electrical attenuator
+20dB
LPF
fc-1dB=190MHz
A/D

Head Amp V2   BPF Amp V2

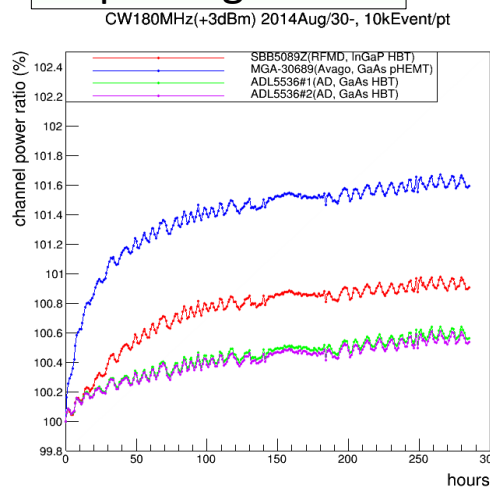- Latter amplifier is the critical device that limits overall linearity. Hence, we tested below three devices.

Device	P1dB	Gain	OIP3	NF	technology
SBB5089Z(RFMD)	20dBm@200MHz	20.8dB@200MHz	37.5dBm@200MHz	4.3dB@200MHz	InGaP HBT
ADL5536(AD)	19.6dBm@190MHz	19.8dB@190MHz	45.0dBm@190MHz	2.6dB@190MHz	GaAs HBT
MGA-30689(Avago)	22.4dBm@900MHz	14.3dB@900MHz	43.0dBm@900MHz	3.0dB@900MHz	GaAs pHEMT

Waveforms

20 ns

200 mV

ADC (under sampling) →

ADC waveform event#1

Under sampled waveform.
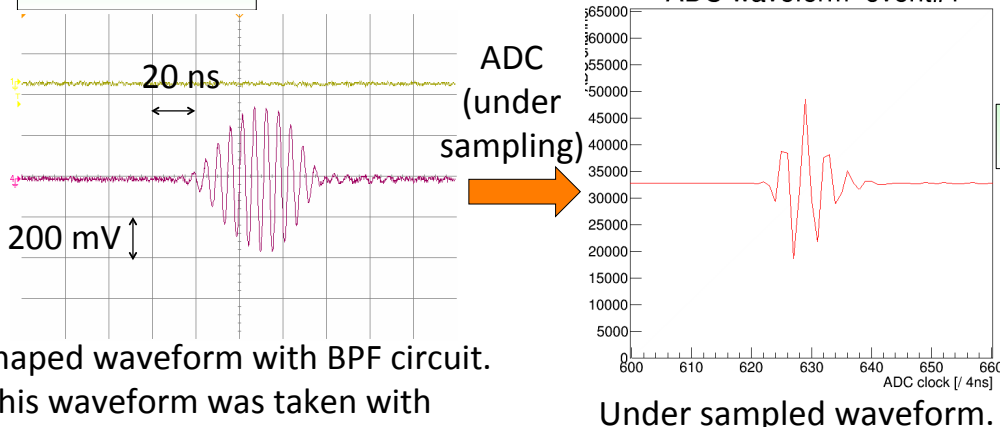
Shaped waveform with BPF circuit. (this waveform was taken with calibration tone generator.)

amplifier gain drift

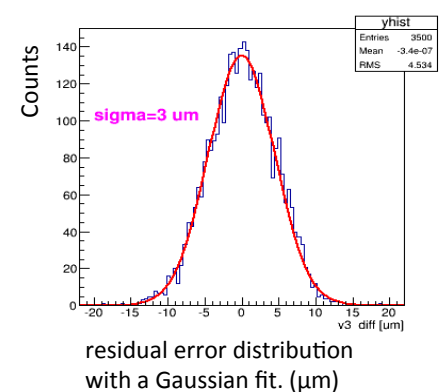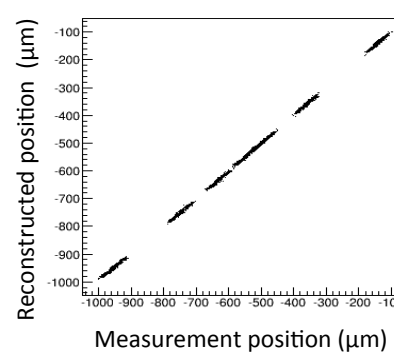CW180MHz(+3dBm) 2014Aug/30-, 10kEvent/pt

SBB5089Z(RFMD, InGaP HBT)
MGA-30689(Avago, GaAs pHEMT)
ADL5536#1(AD, GaAs HBT)
ADL5536#2(AD, GaAs HBT)

- We measured amplifier gain drift of the BPF circuits in a thermostatic chamber (25±0.1 °C) for 286 hours (11.9 days).
  - MGA-30689 (Avago) shows largest gain drift (1.6% (0.14 dB)/11.9 days).
    - pHEMT: FET structure.
  - ADL5536 (Analog Devices) shows smallest gain drift (0.6% (0.05 dB)/11.9 days).
    - HBT: Bipolar structure.
- HBT devices seem to have better power drift characteristics.
- We employed ADL5536.

Resolution /Linearity

CW: linearity check: main:no1, BPF:no1, (2014/5/31) NACal/25degC

Wy1(AD)
Wy2(AD)

0.02 dB
0.02 dB

24 dB
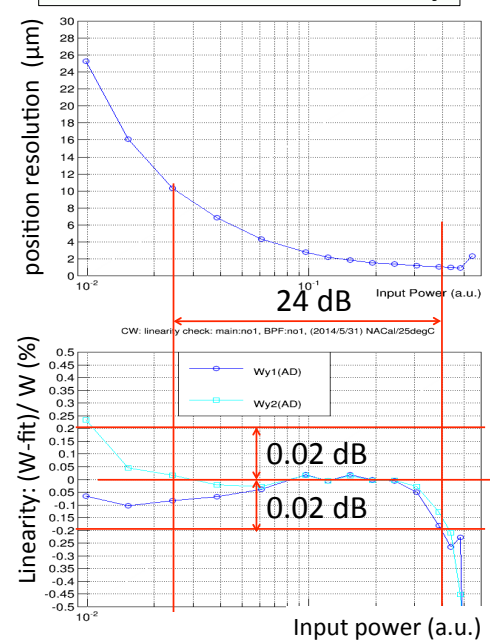
- Instead of beam signal, 180 MHz CW signal is equally divided into four channel (to reduce source jitter/noise).
- 96 ns (same with beam gate) Hanning window is applied to extract a pseudo-beam signal.
- Upper plot shows position resolution and lower plot shows linearity.
- Requires >14 dB dynamic range to ensure ± 5mm precise aperture.
  - Keeps 24 dB in dynamic range that meets both
    - position resolution <10 μm,
    - linearity within ±0.2%(=0.02 dB).
- We can set an operation point with about 2 μm or less.

3–BPM resolution tests

yhist
Entries 3500
Mean -3.4e-07
RMS 4.534

sigma=3 um

residual error distribution with a Gaussian fit. (μm)

- At KEK Linac, beam from 3T thermionic gun (0.8 nC, 1 ns bunched) is used.
- Adjacent three BPM output are readout by these readout systems: 3,500 events with 12.5 Hz have been readout.
- During the experiment, steering magnet current was changed in each 500 events.
- With a multiple regression analysis, 3rd BPM positions were estimated, and we obtain σ = 3 μm from residual error distributions.

Summary and future plan

- We have developed a BPM readout system with high position resolution (σ < 10 μm) and a gain calibration system.
- 3-BPM resolution test has been done with KEK Linac beam (0.8 nC) and proved that it meets all requirements.
- We plan to fabricate total 100 units within this fiscal year (till March 2015) and install at 2015 summer shutdown.