Development of a Low-latency, Micrometre-level Precision, Intra-train Beam Feedback System Based on Cavity Beam Position Monitors

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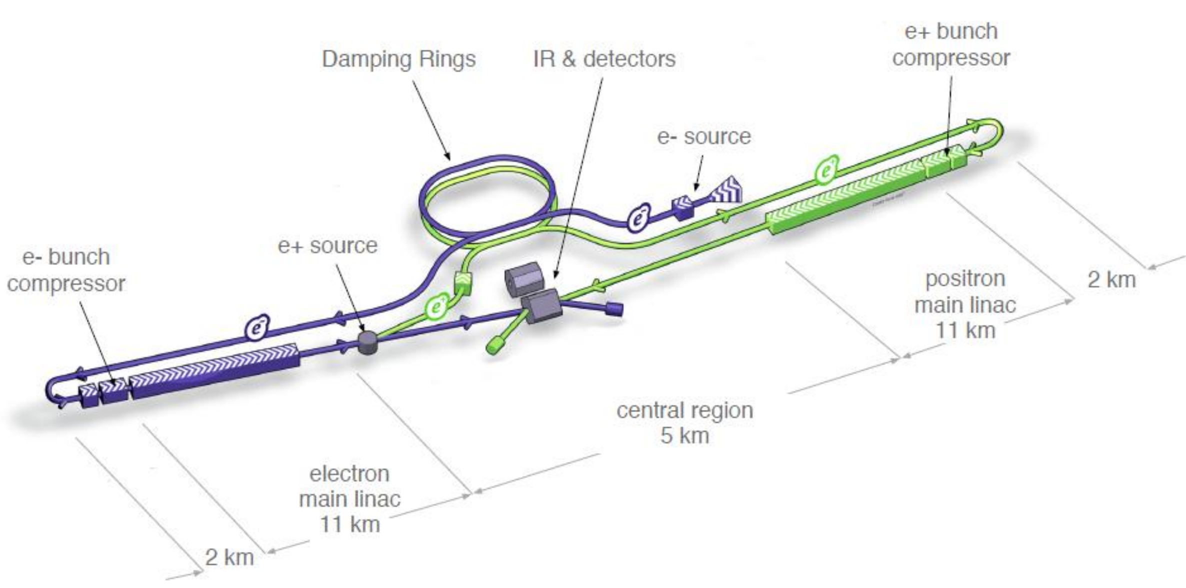
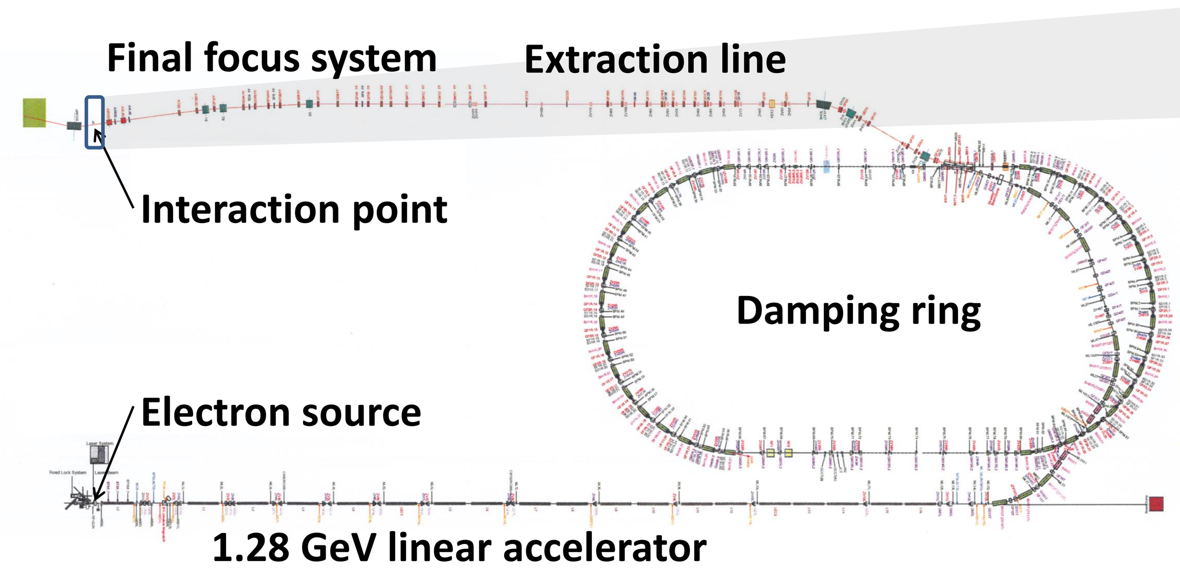
A low-latency, intra-train, beam feedback system utilising a cavity beam position monitor (BPM) has been developed and tested at the final focus of the Accelerator Test Facility (ATF2) at KEK. A low-Q cavity BPM was utilised with custom signal processing electronics, designed for low latency and optimal position resolution, to provide an input beam position signal to the feedback system. A custom stripline kicker and power amplifier, and a digital feedback board, were used to provide beam correction and feedback control, respectively. The system was deployed in single-pass, multi-bunch mode with the aim of demonstrating intra-train beam stabilisation on electron bunches of charge ~1 nC separated in time by c. 220 ns. The system has been used to demonstrate beam stabilisation to below the 75 nm level. Results of the latest beam tests, aimed at even higher performance, will be presented.

International Linear Collider



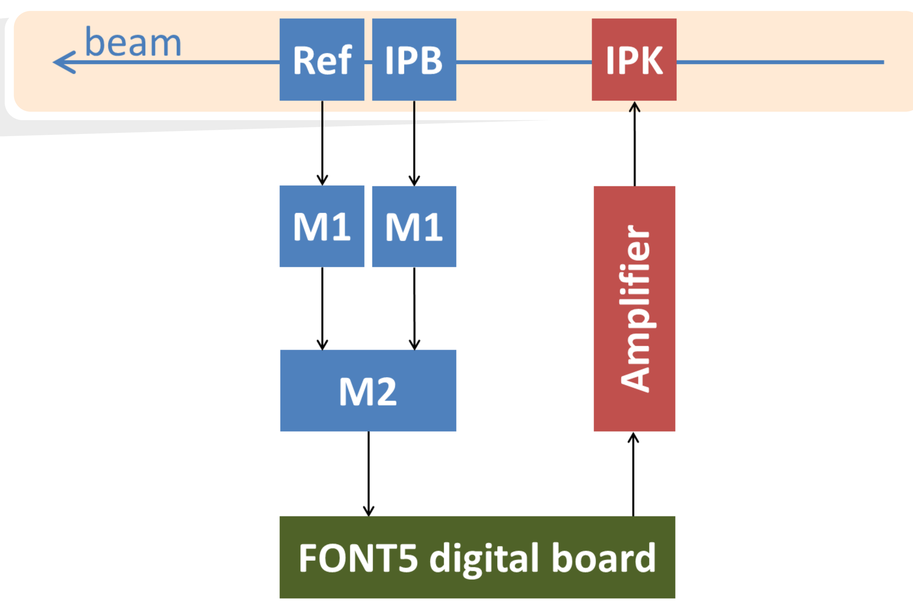
The International Linear Collider (ILC) is a proposed linear electron-positron collider with a centre-of-mass energy of 500 GeV [1]. The schematic above shows the 6.7 km circumference damping rings followed by the 11 km long superconducting main linacs. The ILC is designed to have a vertical beam size at the interaction point (IP) of 5.9 nm and a bunch separation of 554 ns.

Accelerator Test Facility



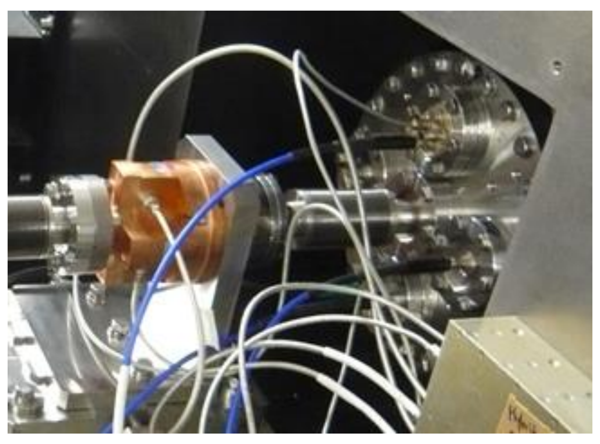
The Accelerator Test Facility (ATF) at KEK, Tsukuba, Japan is a test bed for the ILC. The ATF consists of a 1.28 GeV electron linac, a super-low emittance damping ring and a scaled version of the ILC's final focus system. ATF's current goal is to achieve a 37 nm beam size with nanometre beam stability as measured at the IP [2].

Feedback on Nanosecond Timescales



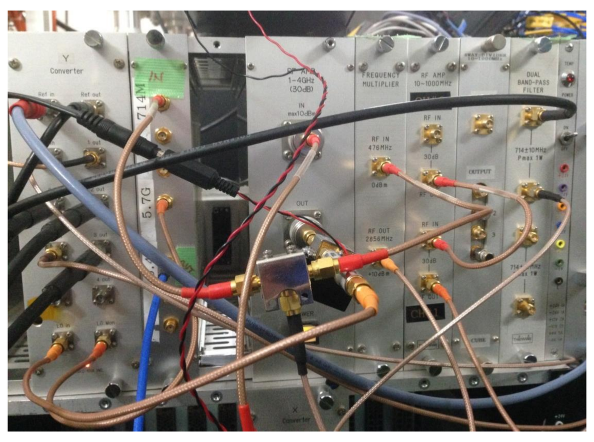
The Feedback on Nanosecond Timescales (FONT) [3] project works towards ATF's high stability goal by performing intra-train beam-based feedback. Operating with 2-bunch trains at a bunch separation of 215.6 ns, the FONT system uses a beam position monitor (BPM) to measure the path taken by the first bunch in order to then correct the path of the second bunch.

Ref IPB Cavities



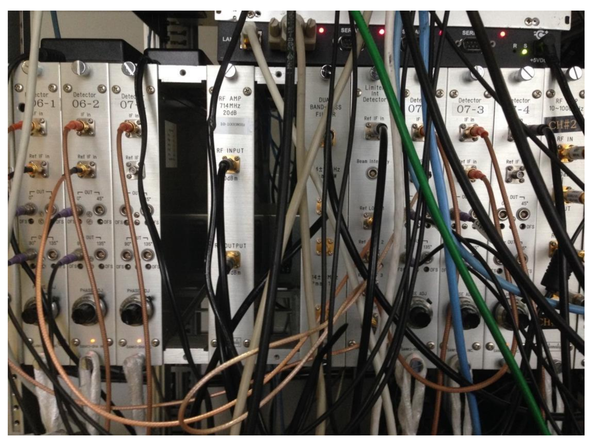
IPB is a C-band cavity BPM on an x, y mover system [4] with a 6.4 GHz dipole mode for the y signal. The reference cavity has a 6.4 GHz monopole mode and is used for phase detection and charge normalisation [5].

M1 M1 Stage 1 mixer



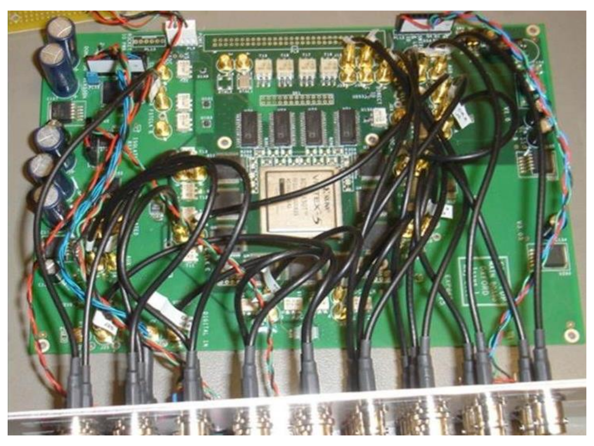
The first stage downmixer takes the 6.4 GHz reference and IPB signals and mixes each with an external common 5.7 GHz local oscillator (LO) to produce downmixed outputs at 714 MHz [6].

M2 Stage 2 mixer



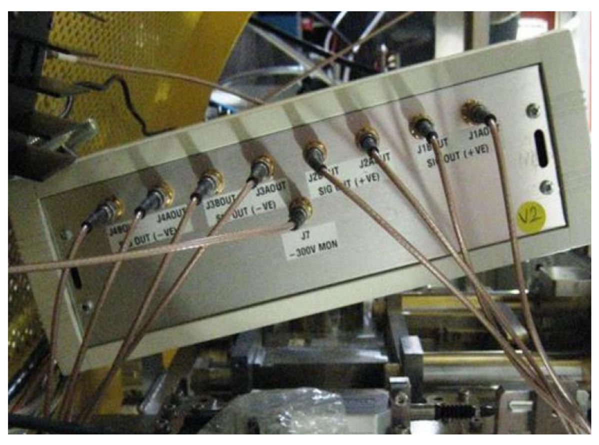
The second stage downmixer mixes the 714 MHz IPB signal using the 714 MHz reference as the LO [7], giving 2 signals at baseband: I (IPB and reference mixed in phase) and Q (mixed in quadrature).

FONT5 digital board



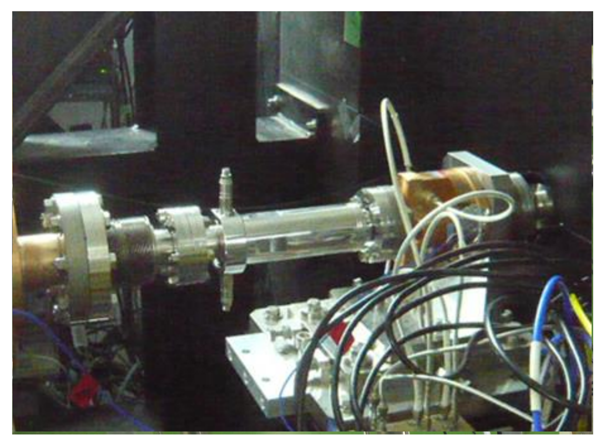
The FONT5 digital board has a Virtex-5 Field Programmable Gate Array (FPGA) [8]. The I, Q and charge signals are digitised at 357 MHz and used to compute the beam position and generate the kick signal.

Amplifier



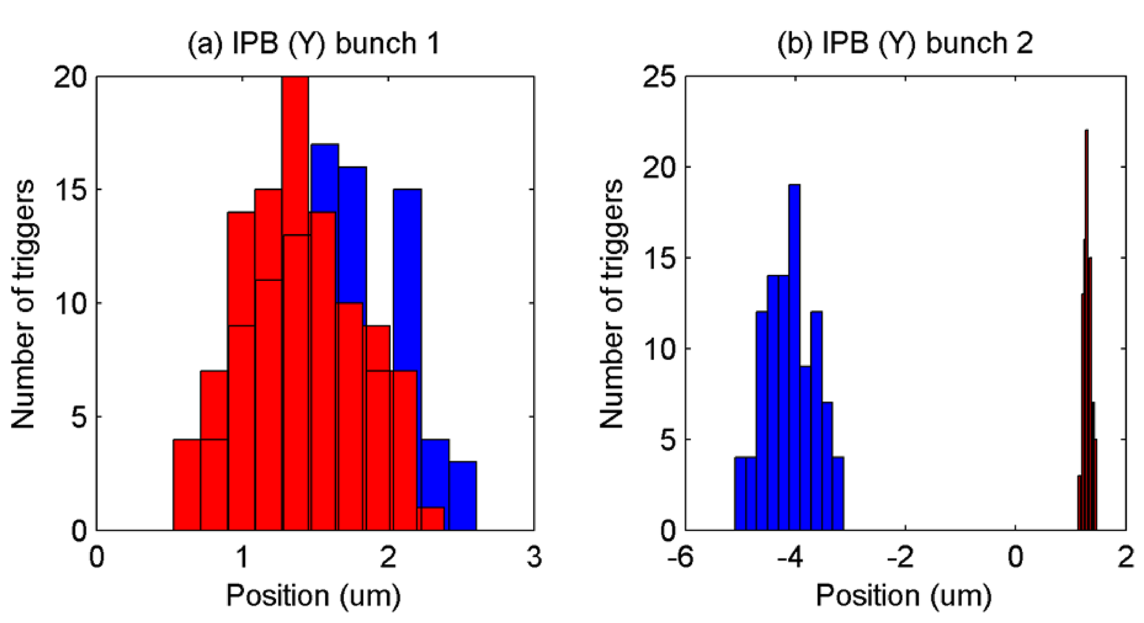
The kick signal from the FONT5 board is amplified by an amplifier manufactured by TMD technologies [9]. The amplifier provides ±30 A of drive current and takes 35 ns to reach 90 % of peak.

IPK Kicker



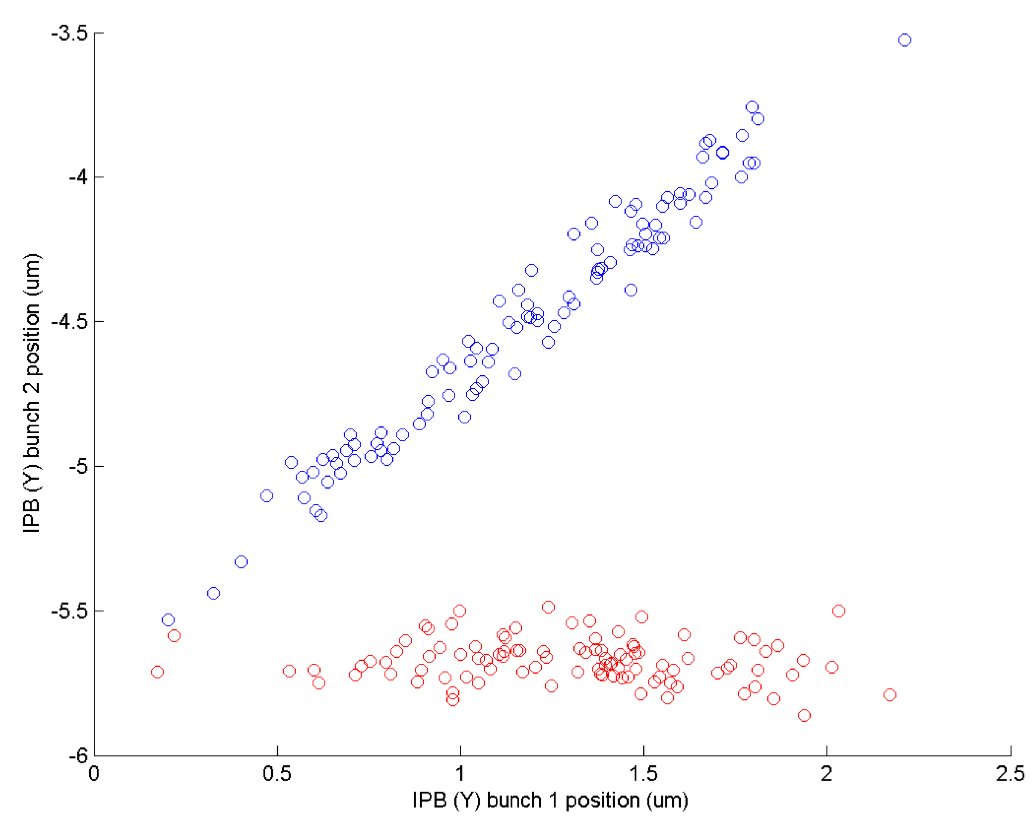
The IP stripline kicker consists of a pair of top and bottom electrodes connected to the corresponding amplifier at its downstream end and shorted together at its upstream end, forming a transmission line.

Results



Feedback	Bunch 1 jitter (nm)	Bunch 2 jitter (nm)
Off	412 ± 29	420 ± 30
On	389 ± 28	74 ± 5

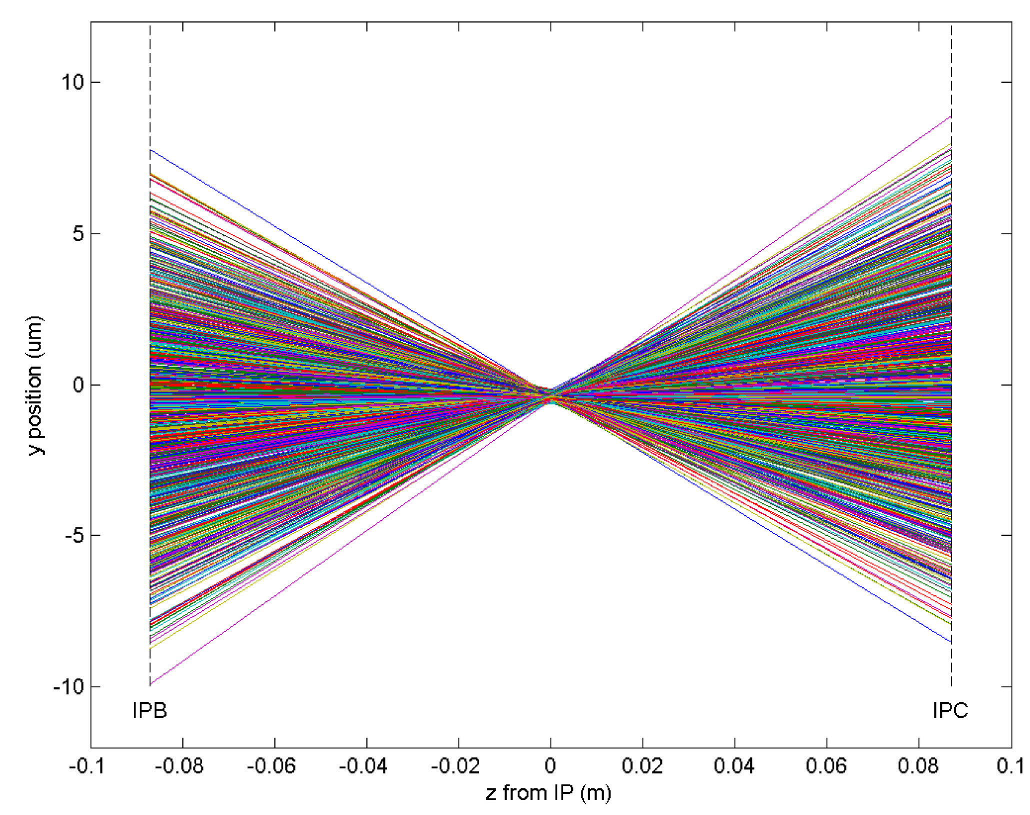
Operation of the feedback system stabilises the position jitter of the second bunch from 420 nm to 74 nm. Given the incoming values for the jitter of the two bunches and the bunch-to-bunch position correlation, the feedback is expected to stabilise the beam jitter to 79.4 nm [10], which agrees with measurement.



Feedback	Bunch-to-bunch position correlation (%)
Off	$+98.2^{+0.3}_{-0.4}$
On	-13 ± 10

For best feedback performance, a high incoming bunch-to-bunch position correlation is required. This was measured to be 98.2 % with feedback off. The feedback then removes the correlated component between the bunches, reducing the bunch-to-bunch position correlation to approximately zero.

Outlook



	Interpolated waist
y jitter (nm)	82
z (mm)	0.3

The use of two BPMs (IPB and IPC) located either side of the IP beam waist, in order to stabilise the beam at the waist, may improve the position resolution available to the feedback system as the error on the interpolated position would be $\sigma_r/\sqrt{2}$ where σ_r is the resolution of either BPM [10].

Acknowledgements

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