CLIC DRIVE BEAM POSITION MONITOR*

S. Smith, CERN, Geneva, Switzerland and SLAC National Accelerator Lab, Menlo Park CA, USA
A. Cappelletti, D. Gudkov, L. Søby, I. Syratchev, CERN, Geneva, Switzerland

Abstract

CLIC, an electron-positron linear collider proposed to probe the TeV energy scale, is based on a two-beam scheme where RF power to accelerate a high energy luminosity beam is extracted from a high current drive beam. The drive beam is efficiently generated in a long train at modest frequency and current then compressed in length and multiplied in frequency via bunch interleaving. The drive beam decelerator requires >40000 quadrupoles, each holding a beam position monitor (BPM). Though resolution requirements are modest (2 microns) these BPMs face several challenges. They must be compact and inexpensive. They must operate below waveguide cutoff to insure locality of position signals, ruling out processing at the natural 12 GHz bunch spacing frequency. Wakefields must be kept low. We find compact conventional stripline BPM with signals processed below 40 MHz can meet requirements. Choices of mechanical design, operating frequency, bandwidth, calibration, and processing algorithm are presented. Calculations of wakes and trapped modes and damping are discussed.

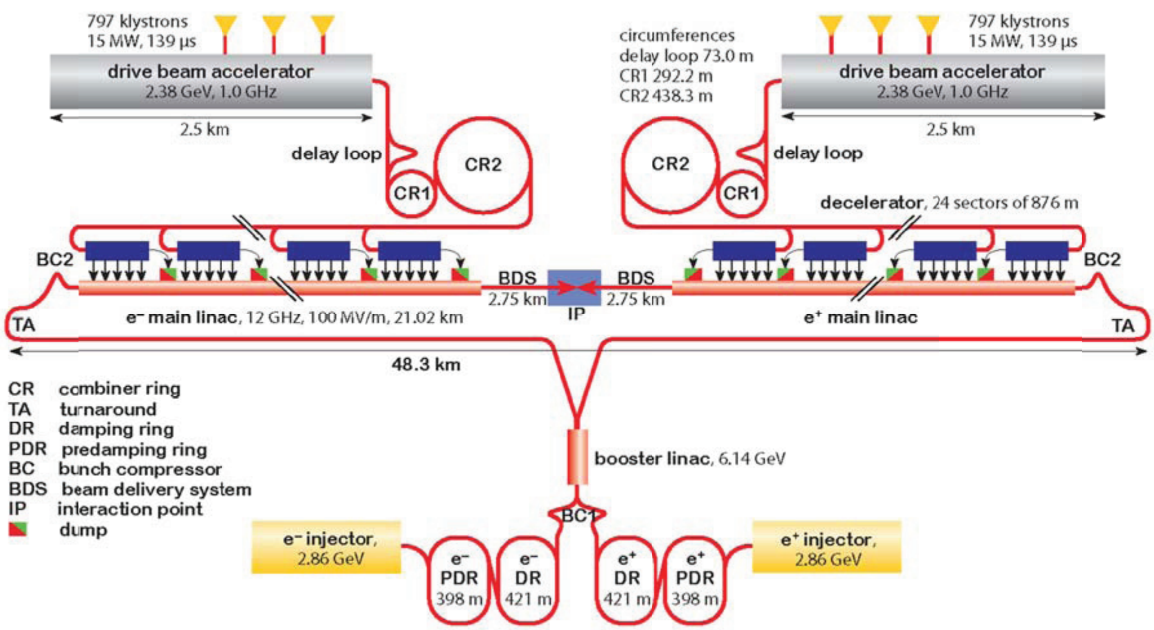

Figure 1: CLIC layout.

CLIC Beam Position Monitors

CLIC will contain roughly 200 km of beam line requiring a variety of beam position monitors[1,2]. Main linacs require about 4000 BPMs of better than 50 nm resolution. The drive beam decelerators, due strong focussing and large energy spread, require far more BPMs. Waveguide modes propagate in the 23 mm diameter beam duct at the 12 GHz bunch frequency; the TE_{11} cutoff is at 7.6 GHz. Processing BPM signal here would be sensitive to non-local signals confounding the position measurement. An example of non-local signal propagating in the beam duct is the ~130 MW of 12 GHz RF power intentionally extracted by the neighbouring Power Extraction Structure (PETS), though little of this power should be present at the location of the BPM. We plan to implement compact stripline BPMs, 25mm long, built into the quadrupole vacuum chamber as shown in figure Fig. 2, with baseband signal processing in a bandwidth of 4 to 40 MHz.

Table 1: Drive Beam BPM Requirements

Parameter	Value	Comment
Beam Current	100 Amp	
Bunch Spacing	12 GHz	
Train Length	240 ns	
BPM quantity	>40000	Total drive beam BPM
Duct aperture	23 mm	In decelerator
Resolution	2 micron	Single bunch to full train
Accuracy	20 micron	
Temporal Resolution	< 10 ns	BW > 20MHz

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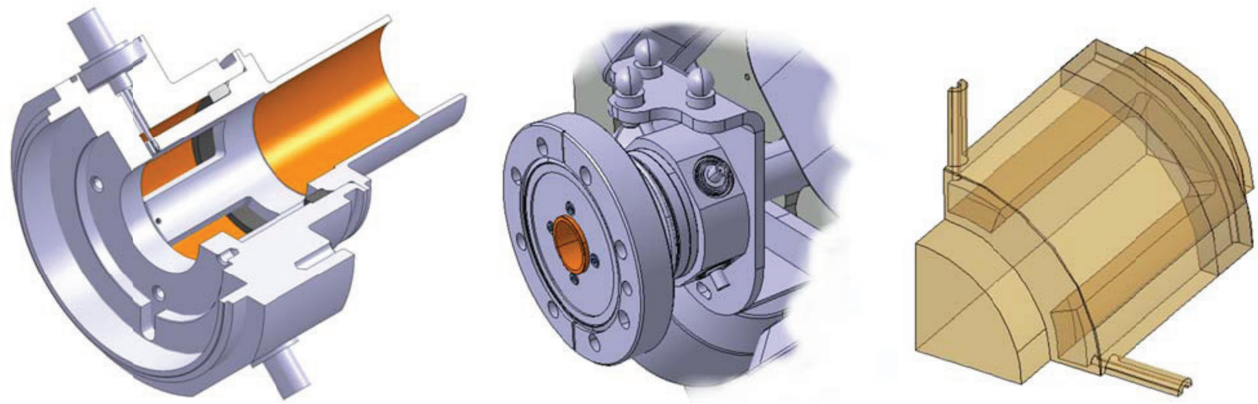

Figure 2: Drive Beam BPM, BPM inserted into drive beam quadrupole, and GdfidL model.

Table 2: Drive Beam BPM Specifications

Parameter	Value	Comment
Diameter	24 mm	Stripline ID
Strip Length	25 mm	
Width	12.5%	of circumference
Impedance	50 Ohm	
Duct aperture	23 mm	In decelerator
Resolution	< 2 µm < 1 µm < 2 µm	Single bunch Train average 10 ns resolution
Accuracy	20 micron	
Temporal Resolution	< 10 ns	BW > 20MHz

Signal Processing

The BPM processor acquires signals in a bandwidth of 4 to 40 MHz from the four BPM strips. Signals are processed (Fig. 3) by lowpass filters, programmable attenuation, low-noise amplification, anti-alias filtering and a high-resolution, fast-sampling ADC per channel.

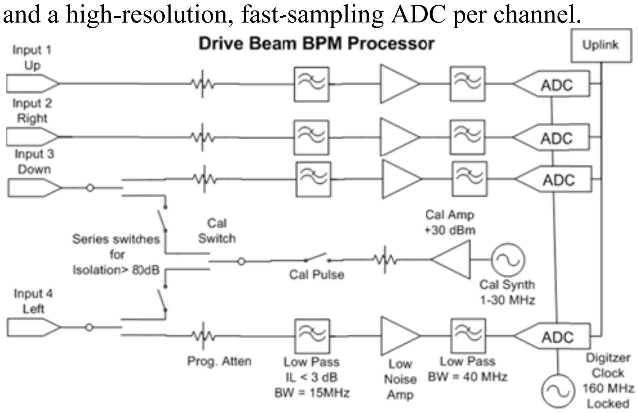

Figure 3: Drive Beam BPM Processor.

Further processing is performed digitally, including digital filtering, amplitude estimation, with a position estimate of $Y = R/2 \cdot \Delta/\Sigma$ where R is the duct radius, Δ and Σ are respectively the difference and sum of opposing stripline amplitudes. Assuming at least an 160M samples per second digitization rate, position can be reported in 6 ns intervals, though successive measurements at this rate are highly correlated due to the bandwidth rolloff, typically about 20 MHz.

Striplines couple to the derivative of the product of beam current and position, rolling off response at low frequencies. For the baseband processing scheme used here, this makes difficult the extraction of beam position through the length of the bunch train, up to 240 ns. The need for adequate signal at the low frequency end of the bandwidth is what drives the requirement for stripline pickups rather than, for example, buttons.

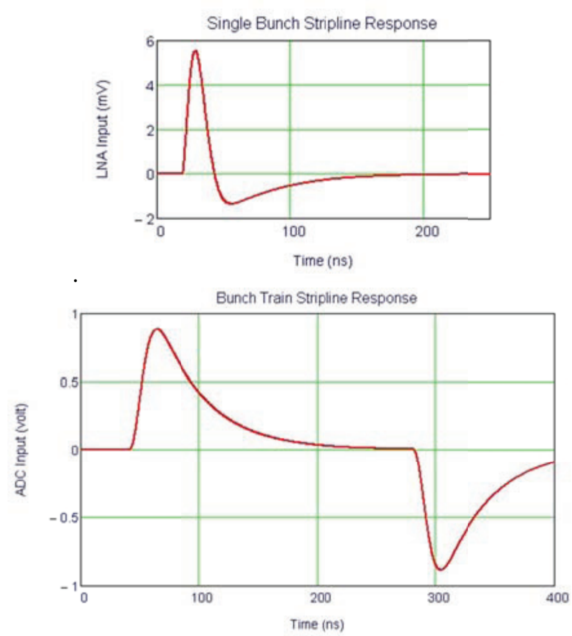

Figure 4: Simulated single bunch and train response after processing filters.

We expect to extract position within the train by deconvolution of the measured single bunch (impulse) response from the bunchtrain response. This requires occasional acquisition of single bunch response, probably acquired during the MPS-required restart procedure after any interruption of beam. The accuracy of this approach is mostly limited by dynamic range of the digitizer, where we can expect future improvements.

Calibration

A stripline BPM depends on extracting a position signal as a small difference between signal amplitudes on opposing electrodes. This makes calibration crucial to accuracy. These BPMs will be calibrated continuously during operation. Between machine pulses a calibration tone is transmitted from one processor input. The ratio of its coupling to adjacent striplines calibrates the BPM offset for one axis. Then the other axis is calibrated, all transparent to operation. This scheme has been very successful at LCLS, the free-electron laser at SLAC[3].

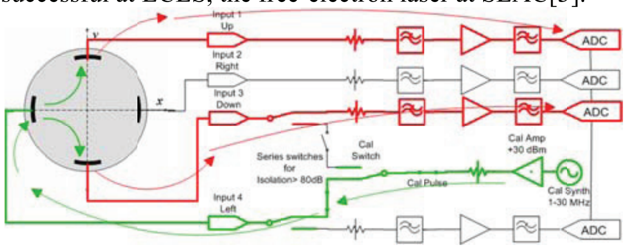

Figure 5: Y axis calibration signal flow.

Finite-Element Analysis

The BPM is modelled in GdfidL (Fig, 2) for beam response and wakes. Initial analysis indicated trapped modes; in particular a resonant mode close to the 12 GHz bunch spacing apparent in the transverse wake. Addition of a ring of SiC RF damping material at the base of the striplines damps this resonance without significantly affecting the beam position signal as depicted in Fig. 6 and Fig. 7. Analysis with GDFIDL also showed that the longitudinal wake/impedance is strongly suppressed in a wide frequency range.

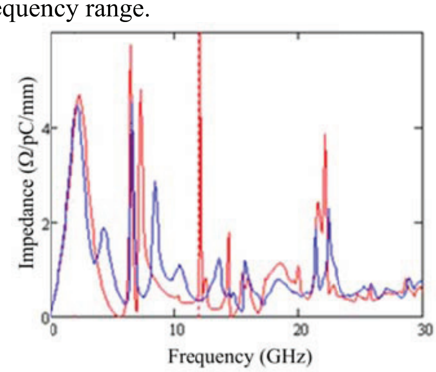

Figure 6: Transverse impedance for undamped (red) and damped (blue) stripline.

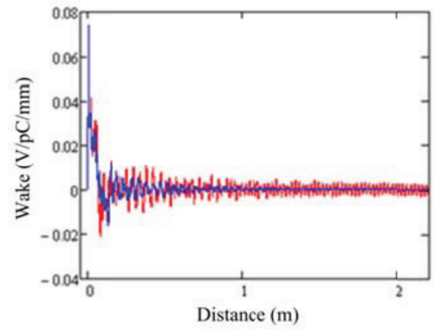

Figure 7: Wake, damped (blue) and undamped (red).

We then analyze the damped BPM for beam response and wakes comparing the time-domain analysis with an analytic model for an idealized stripline and find excellent agreement. Transverse wakes are calculated for the analytical model from the beam voltages induced on the striplines, integrated over the number of bunches in the round-trip time of the stripline signal and find wakes acceptable.

Conclusions

A conventional stripline BPM processed at baseband should satisfy requirements. This solves the potential problem off non-local signals inherent in signal processing at the bunch frequency or its harmonics, but at the cost of processing complexity of deconvoluting the single bunch response from the bunch train response to get intra-train position information. Simulations suggest that requirements can be met. Finite-element analysis simulation show potential trapped modes, which may be damped with RF absorbing material. The simulation of signal response and wakefields agree with analytic calculations. Calibrations must be done online transparently to operation.

REFERENCES

[1] http://clic-study.org/.
[2] J.P. Delahaye, “Toward CLIC Feasibility”, IPAC’10, Kyoto, May 2010, FRXCMH01, (2010).
[3] E. Medvedko, et al., “LCLS Stripline BPM System Commissioning”, PAC’09, Vancouver, May 2009, TH6REP036, p. 4027 (2009).