FIRST TESTS OF A PRECISION BEAM PHASE MEASUREMENT SYSTEM IN CTF3

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Abstract

High precision beam phase measurements will be vital for synchronization of main and drive beams in CLIC. Development work is underway with the aim to demonstrate 0.1 degree resolution for a wideband 30 GHz measurement. In order to be able to test this with a beam exhibiting much higher phase jitter, two prototypes have been built so that the difference in their outputs can be measured. Results of measurements made with bunch trains in CTF3 are presented.

INTRODUCTION

Timing jitter between main and drive beams in the Compact Linear Collider (CLIC) [1] will give rise to energy variations that will result in a reduction of luminosity. To achieve the required level of synchronization a feedforward system has been proposed wherein the drive beam timing is measured before, and corrected after, the drive beam turn-arounds [2]. The timing reference for such a system could be the beam in the transfer line between the injector complex and the main linac [3]. This would remove the need for a very precise reference line and would also give the system the potential of directly correcting for the relative timing errors between main and drive beams.

A key component in such a system will be beam timing measurement. The precision required is in the order of 10 fs. In addition, a wideband measurement (±50 MHz or greater) is required so as to be able to correct errors up to the bandwidth of the main linac's accelerating structures.

The present work was undertaken to show the feasibility of achieving the required specification with beam phase measurements at the main linac's RF frequency in both linacs. While such a solution would be very convenient, system requirements make the phase detection electronics challenging.

After a period of development and laboratory tests, first measurements with beam have been performed in CTF3 (CLIC Test Facility 3 [4]). Two systems were made to measure the signal from the same beam pick-up. This way the jitter of the CTF3 beam (which far exceeds the system resolution) is removed when the two outputs are compared.

SYSTEM OVERVIEW

A simplified block diagram of the set-up used for the CTF3 beam tests is shown in Fig. 1. It consists essentially of two 30 GHz front-ends that down-convert the beam signal to an IF (intermediate frequency) of 750 MHz for phase and amplitude detection. The 3 GHz master oscillator is common to both systems, removing an important jitter source that would be present in the intended application [3] in CLIC. Oscillators are available commercially with low enough jitter (3 fs over the bandwidth of interest) to make them suitable for keeping time between the passage of the main beam in the transfer line and the drive beam. However, they are very expensive and their purchase is unjustifiable for the present feasibility tests.

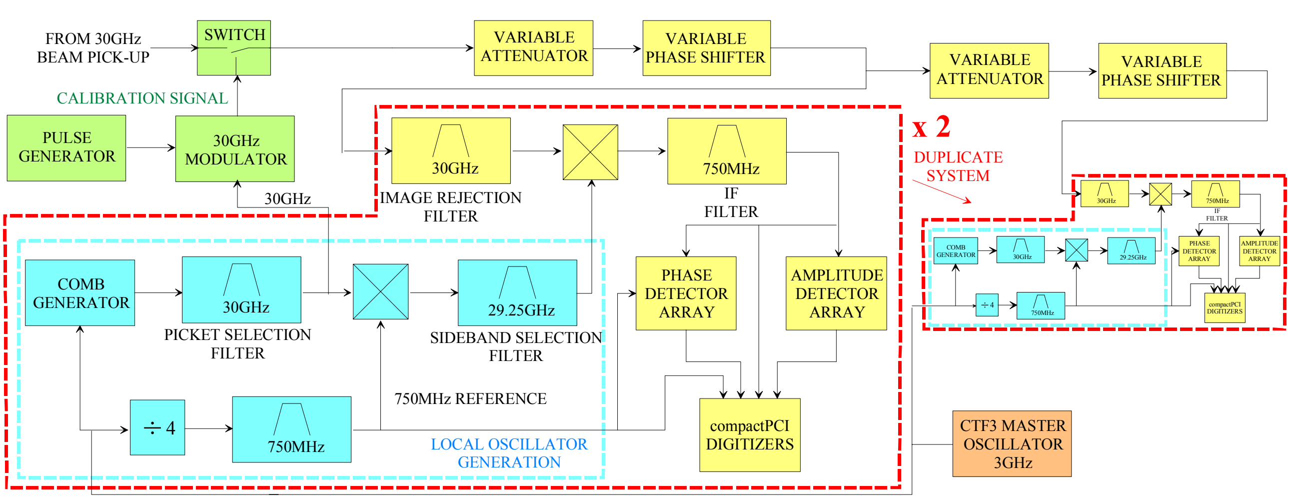

Figure 1: Set-up for beam tests in CTF3.

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The beam pick-up consists of a PETS structure [5] that is installed in CTF3 for 30 GHz power production (dedicated pick-ups will be developed at a later date). A waveguide switch enables the beam signal to be replaced by a test signal consisting of a 30 GHz pulse. Intended for calibration, this signal proved invaluable for offline debugging. The switch is followed by two sets of waveguide variable attenuators and phase shifters that allow for common as well as independent adjustments of the two systems.

For frequency multiplication from 3 GHz to 30 GHz both step recovery and edge compressor diodes were evaluated. The former was found to be more suitable. The jitter of the local oscillator generation was measured to be 2.5 fs in a ±50 MHz bandwidth. The image rejection, picket and sideband selection filters are made from invar in order that their group delay variations with temperature remain tolerable.

The IF phase detection system consists of a set of power splitters feeding arrays of eight analogue multipliers and eight logarithmic amplitude detectors. This parallelisation and summation achieves the necessary noise reduction through averaging. The analogue signal is then acquired with a 10 bit, 2 GHz digitiser, yielding numerical results to which computational corrections of non-ideal behaviour can be applied. The system has a phase measurement range of ±5^{o} (equivalent to ±460 fs). This limitation is due to the digitiser.

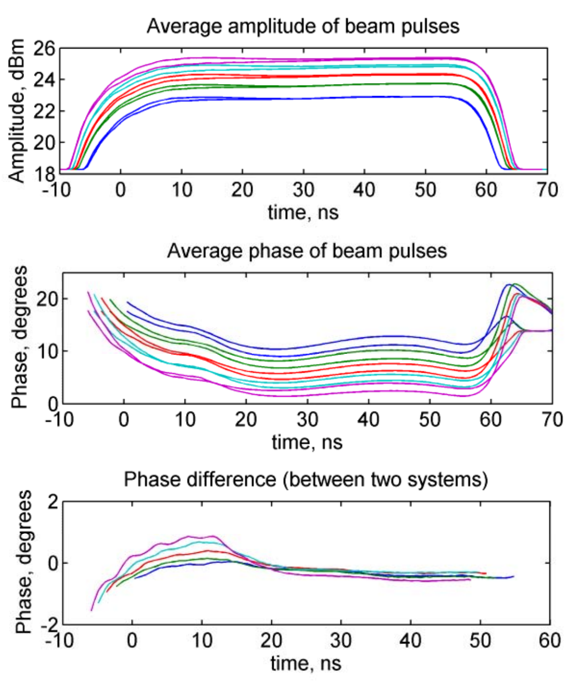

Figure 2: Beam measurements, averaged data, two systems.

MEASUREMENTS WITH BEAM

First Results

Measurements were made in CTF3 with a beam pulse train of length 70 ns, a bunch spacing of 333 ps and a repetition rate of 50 Hz.

Pulse to pulse beam phase jitter was about 2^{o} (at 30 GHz). However the variation of phase across the pulse (about 8^{o}) was fairly constant from shot to shot. Data averaged over many pulses are shown in Fig. 2 where each colour represents a setting of the common 30 GHz attenuator (steps of 1 dB). The phase data contain no correction for the amplitude dependent offset due to the unavailability of a sufficiently powerful amplifier for the 30 GHz calibration signal synthesis at the time of these tests. However, the third graph indicates that the two systems are reasonably well aligned even without correction.

Fig. 3 shows the pulse to pulse phase jitter of one measurement system (1/√2 of the jitter between the two systems) as a function of the setting of the common attenuator. It is well within the 10 fs requirement. It should be noted that when correction for amplitude dependence is incorporated the noise performance will degrade somewhat [3].

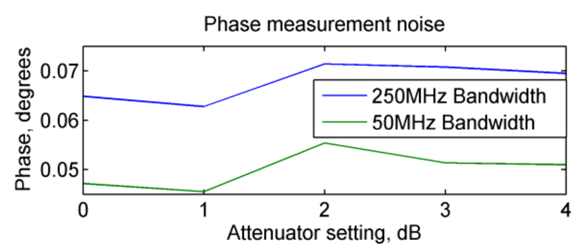

Figure 3: Jitter of beam phase measurement system.

Modifications Required Before Future Tests

As a result of the experience gained with these first beam measurements, several hardware modifications will be made to the set-up before further beam tests:

- More powerful amplifier for the 30 GHz calibration signal. This will allow offline characterization over the amplitude range of interest. It has already been incorporated for the measurements described in the following section.
- More powerful IF amplifier. The compression observable in Fig. 2 is due to the IF amplifier.
- Better IF filtering. Some distortion is due to baseband signals produced in the down-mixing passing into the amplitude detectors.

OFFLINE CALIBRATION

The output signals from the phase detector integrated circuits do not conform to the response expected from ideal multipliers. In particular, there is an amplitude dependent offset, as well as a multiplicative factor that is not strictly linear with the input amplitude. These imperfections can be overcome via a calibration routine using data from the amplitude detectors for 30 GHz carrier wave input signals over a range of amplitude levels. Fig. 4 illustrates this static correction applied to 200 ns RF pulses for verification of the scheme in a pulsed system. The ability to align two independent systems is shown to be very good. The first set of curves represents six different amplitude levels in 1 dB steps, with the phase difference of the statically corrected curves plotted. The second plot shows the same curves, but with the average of all curves subtracted (for the purpose of illustrating the very low variance around the mean obtained for the range).

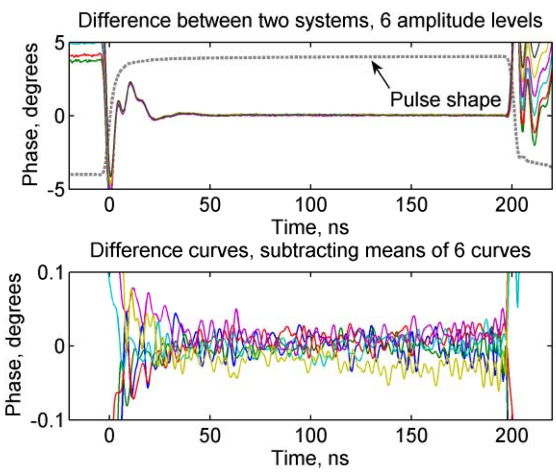

Figure 4: Static correction applied to pulse.

As well as a static correction, the difference in dynamic behaviour, notably at the beginning of the pulse, also needs to be addressed. Work has begun to characterize this effect and develop a model for correcting the discrepancy.

CONCLUSIONS

These first beam tests have successfully demonstrated a beam timing measurement with a resolution well under 10 fs in a 50 MHz bandwidth and have gone a long way towards establishing the feasibility of using this system for the precision timing measurement needs in CLIC. They have also brought to light a few shortcomings in the prototype that are now being addressed. Some relatively minor hardware changes are being made to the electronics. Work is now underway to produce calibration procedures to characterize both static and dynamic performance.

Another round of beam tests in CTF3 is scheduled for later this year. These are intended to demonstrate a slightly larger dynamic range and also the use of the offline characterization as a means of aligning the responses of the two systems with beam.

In a recent parameter change [6], the CLIC main linac frequency has been reduced from 30 GHz to 12 GHz. Nevertheless, precision timing is still a key issue and the results obtained with this present R&D programme remain very relevant.

ACKNOWLEDGEMENTS

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