GOUBAU LINE AND BEAM CHARACTERIZATION OF TURBO-ICT FOR SWISSFEL

S. Artinian, J. Bergoz, F. Stulle, Bergoz Instrumentation, Saint-Genis-Pouilly, France
V. Schlott, P. Pollet, Paul Scherrer Institut, Villigen, Switzerland

Abstract

SwissFEL will be able to operate with electron bunch doublets 28ns apart. Each of the bunches carries 10pC to 200pC of charge with bunch lengths of a few femto-seconds. For charge calibration of the FEL photon pulses, a measurement accuracy of 1% is desired. The Turbo-ICT accomplishes these requirements with negligible beam position and bunch length dependence. It is insensitive to dark current and features high immunity to background noise. We characterize the Turbo-ICT performance on a Goubau line, also known as single-wire transmission line. The Goubau line utilizes electromagnetic fields with frequencies up to many GHz. It allows accurate bench testing including beam position and bunch length dependence. The results are compared to beam measurements performed at the SwissFEL Injector Test Facility (SITF).

SWISSFEL CHARGE MEASUREMENTS

SwissFEL [1, 2] is a compact free electron laser (FEL) user facility presently under construction at the Paul Scherrer Institut in Villigen, Switzerland. The 5.8 GeV accelerator is based on normal conducting C-band technology operating at 100 Hz repetition rate. It is foreseen to accelerate (at least) two electron bunches per RF pulse with 28 ns bunch spacing, in order to provide the full repetition rate to the two experimental end stations [3], which are ARAMIS (hard X-ray) for phase 1 and ATHOS (soft X-ray) for phase 2 of the project. Single-shot bunch charge information with 1% resolution are required for charge calibration of the FEL photon pulses in both, the nominal (Q_b = 200 pC, $\tau_b \sim 20$ fs rms) and the short-pulse (Q_b = 10 pC, $\tau_b \sim 2$ fs rms) operation modes of SwissFEL.

While the requested sensitivity of the Turbo-ICT and BCM-RF as well as its immunity to dark current has been demonstrated experimentally in the SwissFEL Injector Test Facility (SITF) in a first development step [4], the two bunch operation and the absolute (preferably in-situ) calibration of the charge monitor are still major goals for further design optimizations.

Two-bunch TURBO-ICT & BCM-RF

The Turbo-ICT and BCM-RF principle have been explained in a previous paper presented at IBIC'12 [4]. Here we highlight new developments.

While the Turbo-ICT itself has been kept identical, the front-end filter amplifier has been modified (Figure 1). In order to process the 28 ns spaced doublet the filter's resonance duration is decreased by reducing its quality factor. The noise increase due to this larger bandwidth is limited by the resonance magnitude increase. Therefore the signal over noise ratio does not suffer from this modification.

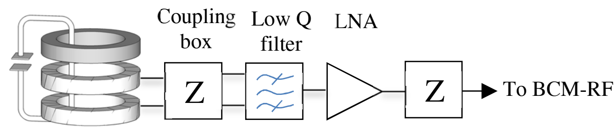

Figure 1: Two-bunch Turbo-ICT.

To measure the two successive bunches simultaneously a two-bunch BCM-RF has been designed based on the previous single bunch release (Figure 2). A faster log detector, the AD8318, is used to process the 28 ns spaced bunches. The demodulated signal is then split in two track and hold paths, such that the two-bunch BCM-RF outputs provide DC voltages which are log proportional to each pulse charge.

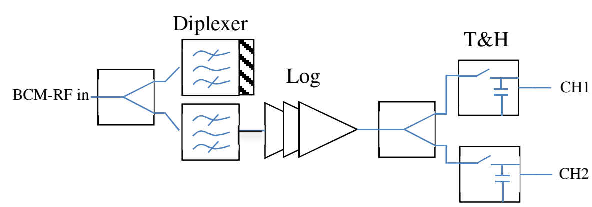

Figure 2: Two-bunch BCM-RF.

Figure 3 shows test pulse signals processed by the two-bunch BCM-RF. The Turbo-ICT integrates and converts the two wideband source pulses successively into two narrow band resonances. Their respective magnitudes are proportional to the source pulse charge. The BCM-RF filters the signal through a 500 MHz diplexer to reject spurious noise picked up by cables and demodulates it. The demodulation is performed by a log amplifier to achieve a sufficiently fast response time and a large dynamic range. Thanks to this successive detection it is possible to measure each pulse charge.

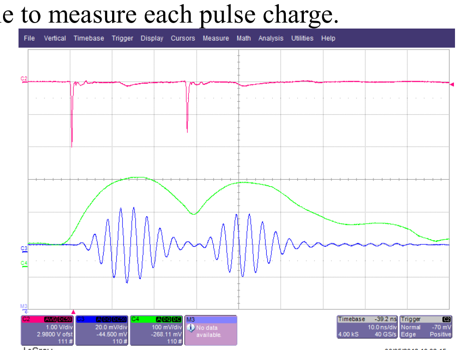

Figure 3: Double input pulses at 28 ns spacing (top trace), log detector demodulation (middle trace), Turbo-ICT narrow-band modulation (bottom trace).

GOUBAU LINE

A major challenge for bench testing in the laboratory is the transmission of the required sub-ns pulses through the Turbo-ICT. Since the pulse spectrum exceeds the GHz range the test bench must be capable of properly transporting these frequencies. A promising idea is to use surface waves traveling along an insulated wire, a so-called Goubau line [5, 6]. The basic principle and its application to beam instrumentation have been discussed in [7, 8, 9].

Due to the dimensions of the wave launcher, the launching efficiency of the surface wave is limited at lower frequencies, i.e., in the range up to some 100 MHz. However, higher frequencies ranging up to many GHz are excited as well. Hence, pulses traveling along the wire loose amplitude compared to the incoming pulse, but their RMS length is preserved or even slightly shortened. Consequently, a Goubau line is very well adapted to the short-pulse measurements required for Turbo-ICT testing.

Several devices can be tested at the same time on the same Goubau line, therefore cross-calibration is possible. Interference of the different devices is minimal.

TEST SETUP

The purpose of the test is to explore the dynamic range and resolution of the two-bunch Turbo-ICT associated with its two-bunch BCM-RF electronics. Figure 4 shows the test setup.

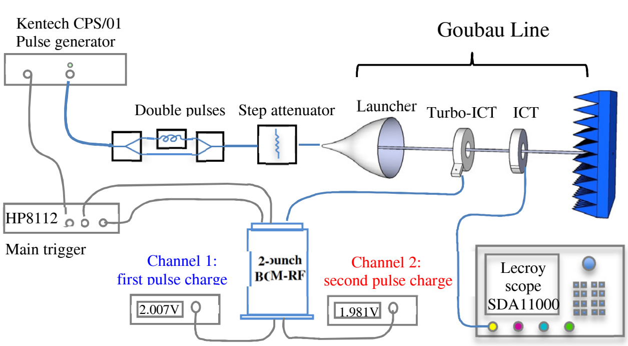

Figure 4: Test setup on Goubau line.

The pulse source is a 250 ps fwhm / 2000 Vpeak pulse generator Kentech CPS/01. The two pulses are created by a splitter, a 28 ns coaxial cable delay line and a combiner. The pulse doublet is fed into a programmable step attenuator then sent into the Goubau line. The Goubau line consists of a wave launcher, the cone and a wave guide, the wire. The Turbo-ICT and a reference ICT are installed on the line. The former is the device under test whereas the latter acts as its reference. The source pulse is converted into an EM field by the wave launcher and travels along the wire. The EM wave is absorbed at the end of the line by RF absorbers to limit reflections.

In order to check the pulser's charge stability, a first measurement is done by directly connecting the source to a fast digital oscilloscope. Figure 5 shows that the charge standard deviation is within 1% down to 2 pC. Below this value, the signal over noise ratio becomes too small to be properly measured by the oscilloscope. As a consequence, the source noise limits the charge measurement accuracy. However this limit is close to the 1 % accuracy aimed at.

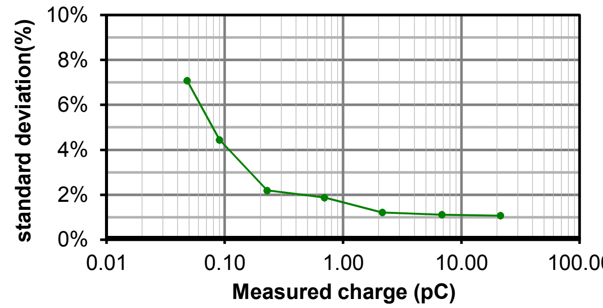

Figure 5: Charge stability of source pulser.

MEASUREMENTS & RESULTS

A charge scan from 40 pC to 0.04 pC is performed by changing the programmable attenuator in 2 dB steps. Figure 6 shows the reference ICT linearity error versus input charge. The measured charge is within +/- 1 % down to 2 pC input charge. Below this value the linearity error increases drastically due to the oscilloscope resolution limit. To overcome the oscilloscope resolution limitation, the pulse charge range is extended below 2 pC by extrapolation of the first fifteen measurements.

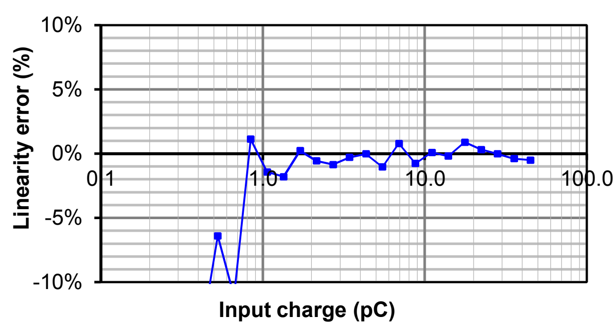

Figure 6: Reference ICT linearity error.

Figure 7 shows measurements by the two-bunch Turbo-ICT and BCM-RF with limited linearity error from 0.04 pC to 20 pC, i. e., 54 dB dynamic range. The instrument is able to measure 2 pC with 1% resolution (figure 8). This performance is better than the previous 5 pC @ 1 % measurement obtained at STIF with the single bunch BCM-RF. Saturation can be observed above 30 pC. It is mainly due to the Turbo-ICT front-end electronics which receives more voltage signal thanks to a lower Q filter. For higher charge measurement it is always possible to change the front-end gain. Since the preliminary analysis has been done by applying a linear fit, the signal over noise ratio artificially increases above 20 pC.

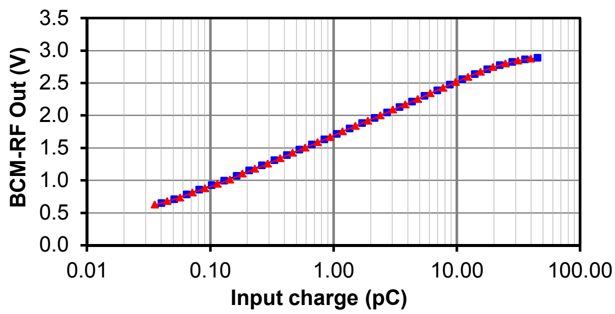

Figure 7: Turbo-ICT and BCM-RF transfer function, first pulse (blue squares trace), second pulse (red triangles trace).

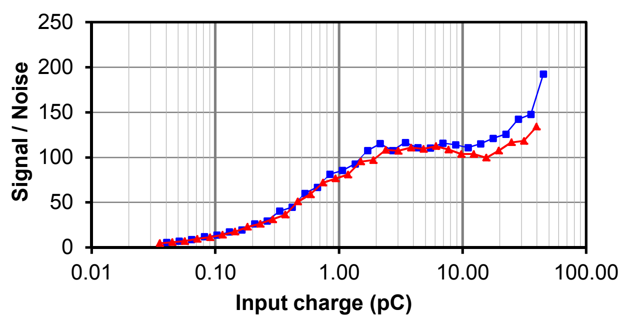

Figure 8: Turbo-ICT & BCM-RF signal over noise ratio, blue squares trace: first pulse, red triangles trace: second pulse.

Figure 9 shows the Turbo-ICT and BCM-RF linearity error versus input charge. A significant log conformance error was expected but has not been observed during the test measurements. The BCM-RF shows good linearity (within 1 %) over more than one decade: from 0.2 pC to 4 pC. This systematic non-linearity will be corrected over the whole range by the on-board microcontroller, using a look-up table.

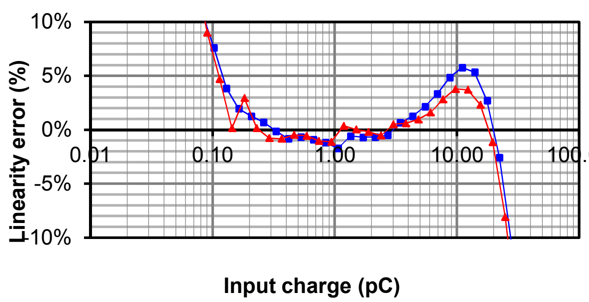

Figure 9: Turbo-ICT & BCM-RF linearity error, first pulse (blue squares trace), second pulse (red triangles trace).

Absolute calibration of the laboratory test set-up has been performed using the reference ICT. The accuracy error is below 10 % (estimated), taking into account uncertainties in the test setup and the oscilloscope performance. Further measurements are required to achieve 1 % absolute accuracy.

CONCLUSION

A new beam charge monitor is under development for the SwissFEL's two-bunch operation mode. The two-bunch Turbo-ICT and BCM-RF have been improved to measure the 28 ns spaced pulses. The first tests on the Goubau Line have shown a 54 dB dynamic range and 1 % resolution for bunch charges of 2 pC, which matches the SwissFEL requirements. Although the linearity is better than expected, post-processing correction is necessary to keep the accuracy better than 1 % over the full dynamic range. The next challenge is to achieve 1 % accuracy by improving the test setup and to develop an in-situ absolute charge calibration. Further measurements on a real beam will take place at SITF in fall 2013 in its two-bunch operation mode.

REFERENCES

[1] R. Ganter (Ed.), SwissFEL Conceptual Design Report, PSI report 10-04 (2009)
[2] for more information see: http://www.psi.ch/swissfel/
[3] B.D. Patterson (Ed.), Ultrafast Phenomena at the Nanoscale: Science Opportunities at the SwissFEL X-ray Laser, PSI report 90-10 (2009)
[4] S. Artinian et al., Development and First Tests of a High Sensitivity Charge Monitor for SwissFEL, in Proc. of IBIC'12, 2012.
[5] A. Sommerfeld, "On the propagation of electrodynamic waves along a wire" (in German), Ann. Phys. 303, 1899.
[6] G. Goubau, "Surface Waves and their Application to Transmission Lines", J. Appl. Phys. 21, 1950.
[7] J. Musson et al., "Application of Goubau Surface Wave Transmission Line for improved Bench Testing of Diagnostic Beamline elements", Proc. of PAC09, 2009.
[8] F. Stulle, J. Bergoz, "The Goubau line - Surface Waves for Bench Testing of Beam Instrumentation at high Frequencies", in Proc. of BIW12, 2012.
[9] F. Stulle, J. Bergoz, "Surface Waves for testing of Beam Instrumentation", in Proc. of IPAC12, 2012.