PAUL SCHERRER INSTITUT

BUNCH ARRIVAL TIME MONITOR CONTROL SETUP FOR SWISSFEL APPLICATIONS

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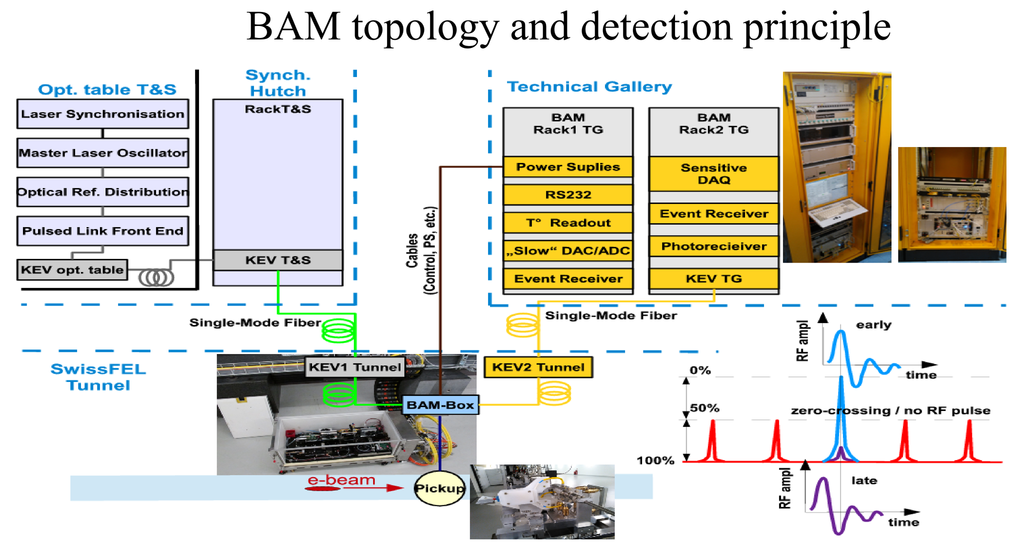
Introduction

SwissFEL is a compact X-ray Free Electron Laser (FEL) newly built at Paul Scherrer Institute (PSI). With total length of ~750 m, optimized to produce extremely bright and short X-rays in the range from 1 to 70 A and pulse duration in the order of 20 fs, it poses challenging demands on the diagnostic instruments regarding stability and sensitivity. The advanced SwissFEL characteristics open unique research opportunities in many disciplines such as medicine, biology, chemistry, electronics and nanotechnology.

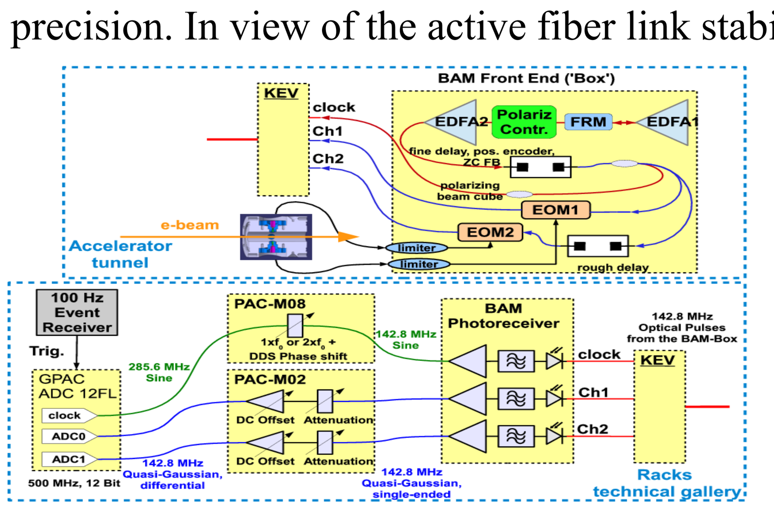
SwissFEL is driven by a warm electron linac, which generates electron bunches with a repetition rate of 100 Hz and charges in the range of 10 pC to 200 pC. The longitudinal bunch stability of the machine is critical for the user experiments. To monitor and control this stability, among other longitudinal and transverse beam diagnostics, the facility is equipped with several stations that provide non-destructive, shot-to-shot electron bunch arrival time information relative to the extremely stable pulsed optical reference system. Such Bunch Arrival time Monitor (BAM) stations are valuable longitudinal diagnostics tools for SwissFEL operations.

BAM DATA ACQUISITION AND PROCESSING MODEL

BAM topology and detection principle



A pulse train from a mode locked laser at 1560 nm and 142.8 MHz repetition rate is sent to the BAM front end ("Box") via length stabilized single mode optical fiber links. In the BAM front end the amplitude of all reference laser pulses is modulated to the half with a Mach-Zehnder intensity modulator, biased at quadrature for maximum linearity. One reference laser pulse coincides with the zero-crossing of the S-shaped RF transient from the button pickup. With such an overlap there is no amplitude modulation, but any arrival-time change causes modulation by the non-zero voltage from the RF transient. Thus the arrival time information is encoded in the amplitude modulation with a fs precision. In view of the active fiber link stabilization, BAM has also a very low intrinsic drift..



Each BAM station has the following components.

- An RF vacuum pickup consisting of four cone-shaped buttons, tapered to 50 Ohm vacuum feedthroughs with 40 GHz bandwidth.
- Two Mach–Zehnder type electro-optic intensity modulators (EOM).
- Two erbium-doped fiber amplifiers (EDFA) with their controllers from Photop (II-VI).
- Reference laser pulse polarization control components (PCC), which include a Faraday rotating mirror, a polarization scanner, and a fiber polarizing beam cube.
- A high precision linear servo motor positioner MX80 from Parker with a controller from Copley Controls. The MX80 has a built-in incremental encoder with a 10 nm resolution. The controller can output the raw quadrature signals to external electronics for further processing.
- A motorized variable optical delay stage MDL-002 and a controller from General Photonics.
- Eight Peltier elements driven by a PTC10K controller (TEC) from Wavelength Electronics.
- A set of temperature, humidity, and air pressure measurement sensors.
- An in-house designed triple photo-receiver (PRX).
- Fast ADC bunch synchronous readout with an RF front end for pulse shaping, DC offsetting and clock shifting.

These components and their operational conditions define the SwissFEL BAM data acquisition and processing model.

With a high-accuracy delay line, the amplitude modulation can be calibrated with time. The time resolution is proportional to the slope of the RF pickup signal at zero crossing.

The BAM-box is temperature stabilized and is located close to the beam pipe (this reduces losses and drifts in the RF cables). The box also accommodates the end of the optical fiber link and two EDFAs.

The first EDFA is an actuator for fiber link amplitude feedback loops. The second EDFA (out-of-loop) controls the power of the signal sent to the PRX. The first delay stage in the BAM box is used for zero-crossing feedback: each time the bunch arrival time exceeds a predefined limit determined by the slope of the RF transient signal, the reference pulse is shifted back to the zero-crossing, thereby keeping the BAM acquisition within the proper dynamic range of the transient. The second delay stage matches the zero crossing of the second BAM channel with the first one.

The modulated optical pulses from two BAM channels are transferred to a data acquisition back-end. They are conditioned in the BAM PRX and read out by the in-house developed fast (500 MHz) 12-bit analog-to-digital converter (ADC) unit. The unit is a Generic PSI Analogue Carrier (GPAC) board that is clocked with a signal generated from the same optical pulses. The optimal ADC dynamic range in view of a better time resolution is ensured by the use of a complementary PSI Analogue Carrier (PAC) module, which provides additional DC offset, amplitude control, and clock shifting functions.

The ADC data are processed by the GPAC FPGA software and then read out by a BAM control computer. Based on this information, the electron bunch arrival time is calculated and used for SwissFEL operations tasks.

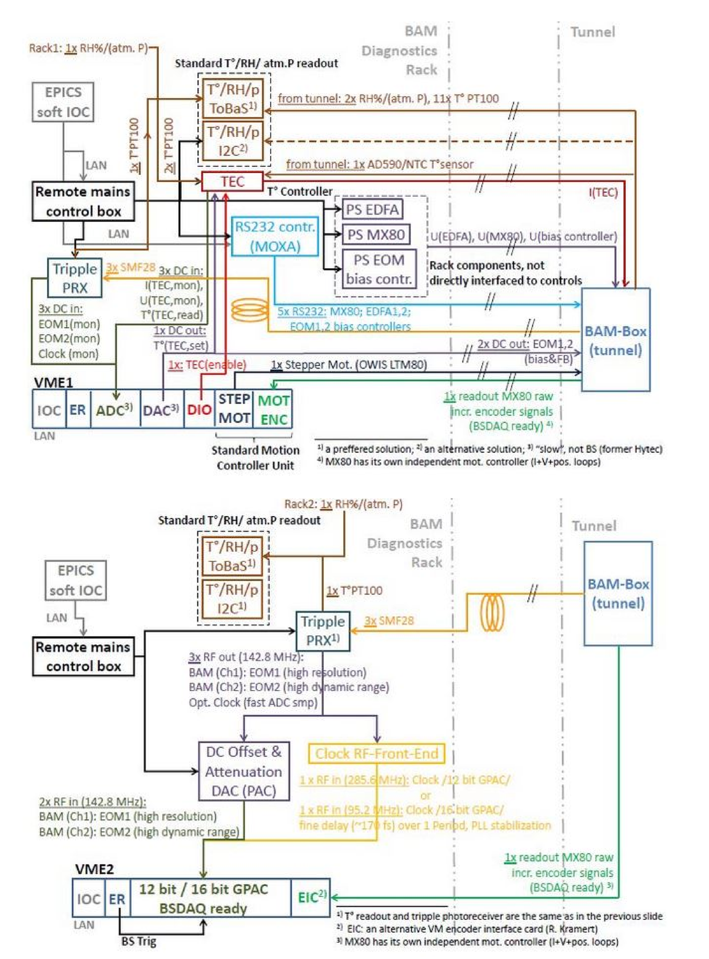
Each of the three PRX channels has DC photocurrent outputs, which are actively used in the polarization and bias control feedbacks.

The above formulated data acquisition and processing model demands the development of a very efficient data acquisition and control system.

BAM DATA ACQUISITION AND CONTROL SYSTEM

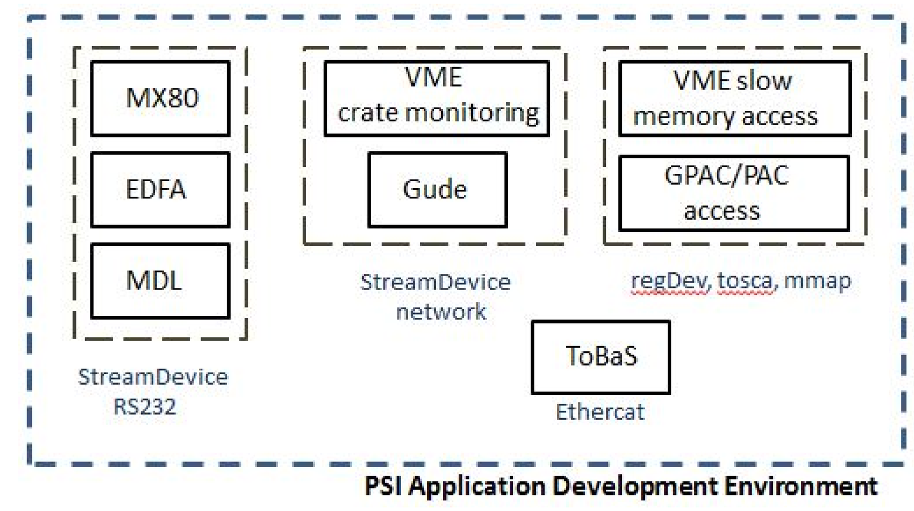
The SwissFEL BAM data acquisition and control system is integrated into the facility controls, which is based on EPICS. The system is implemented as a generic BAM Control Setup (BCS), which can easily be extended to include any additional functionality, if needed.

BAM Control Hardware and IOCs



BAM Equipment Control Software

BAM equipment control software is implemented as a set of equipment control software modules created and supported in the frames of the PSI application development environment. The environment uses Git for software revision controls and a powerful PSI inventory database together with its complementary application installation and loading tools.



Data Acquisition and Processing Software

The main tasks of BAM data acquisition and processing software are:
- to evaluate the bunch arrival time and jitter and
- to set up and maintain BAM equipment operational conditions, which are required by the data acquisition and processing model.

The first task is performed on a shot-to-shot basis by the used GPAC/PAC set and the IOC, which hosts it and communicates with it over the VME bus. As a part of the EPICS database, current bunch arrival time estimates are always available for users.

The second task is done by applications written in MATLAB and interfacing EPICS channels with the use of the PSI MOCHA/CAFE library. By handling channels, which are in charge of particular BAM equipment components, these applications ensure that the parameters of such components do not introduce any distortions that make BAM data incompatible with the model. The applications are mostly implemented as classic closed control loops. For instance, to make sure that the EOM DC is biased in quadrature, one such application performs EOM bias scans. Based on BAM tuning signals, this application determines the EOM transmission curve by changing the EOM bias voltage by "slow" DAC and measuring the resulting DC photocurrent by "slow" ADC. When the scan is complete, the working point is defined in accordance with the BAM data acquisition and processing model.

To minimize periods when bunch arrival time estimates become invalid, the second task must be performed as fast as possible. Usually MATLAB applications at PSI are deployed on PC consoles running Linux. The loop execution time of such high level applications is strongly affected by natural latencies introduced by the network and general purpose operating system. In some BAM related cases this time can reach one minute and more, which is certainly not a good performance for SwissFEL operations. To improve the situation, with the use of a special MATLAB conversion tool developed at PSI all such applications were embedded into the IOCs directly handling the corresponding control equipment. The results are clearly noticeable. An average execution time of control loops was reduced by up to 5-10 times, which was especially impressive when dealing with the corresponding absolute time values. For instance, for the above mentioned EOM bias scan this time was reduced from 75 to 15 seconds

BAM Beam Synchronous Data Collection

Each electron bunch produced by the SwissFEL machine is assigned a unique ID number, which is generated by the timing system and distributed by this system all over the facility. An in-house developed beam synchronous data acquisition system (BSDAQ) provides a powerful mechanism for collecting and saving control system data, which are also associated with some EPICS records and referenced as channels, in the form of metadata tagged with such a bunch ID. This allows one to easily restore all facility parameters associated with each produced bunch sometimes later (off-line) and to use this information for a variety of applications. The list of all channels, which have to be collected and saved by BSDAQ, is requested by control system users. Based on this list, each IOC gets those channels that are handled locally.

In its IOC default setting for 100 Hz, one bunch operations, the BSDAQ data collection software is activated in the last 1 millisecond of the available 10 millisecond interval between two produced bunches. It obtains the bunch ID number from the timing system (via a standard or embedded EVR card), collects the requested data and tags them with this number. This default setting assumes that all data processing associated with each particular bunch ID is done before the corresponding BSDAQ data collection starts. However, if this data processing is not done, then the data and bunch ID consistency will be violated. In case of BAM, such violations were observed on very rare occasions and were caused by extremely heavy simultaneous GPAC, IOC, and control network loads. To prevent such situations, BAM data collecting BSDAQ software was modified. After each successful data collection cycle, the ID of the following bunch is immediately saved in a local buffer, and the data collecting software waits until the data processing performed by GPAC and IOC is finished. As soon as this processing is done, the software collects all required data, tags them with the saved bunch ID, and gets ready for the next bunch. The overall SwissFEL beam synchronous data consistency is much more important for the facility than the existence of rare gaps in BAM beam synchronous data produced by the modified data collecting BSDAQ software.

CONCLUSION

The BAM control setup was designed by diagnostics and control system experts. As a result, all its components are highly optimized to do their jobs as efficient as possible. A very good performance of the setup was demonstrated during SwissFEL Injector Test Facility operations and commissioning of first SwissFEL BAM stations.