Abstract

The SwissFEL is driven by more than 30 RF stations at different frequencies (S-, C-, X-band). To control the RF, a new, in-house developed digital Low Level RF (LLRF) system measures up to 24 RF signals per station and performs a pulse-to-pulse feedback at a repetition rate of 100 Hz. The RF signals are down-converted to a common intermediate frequency. The state-of-the-art digital processing units are integrated into the PSI’s EPICS controls environment. Emphasis has been put on modularity of the system to provide a well-defined path for upgrades. Thus the RF front-ends are separated from the digital processing units with their FMC standard interfaces for ADCs and DACs. A first prototype of the LLRF system consisting of the digital back-end together with a C-band RF front-end was installed in the SwissFEL C-band test facility.

SwissFEL Design Parameters

- Charge per bunch: 200 pC
- Beam energy for 1 Å: 5.8 GeV
- Peak current at undulator: 2.7 kA
- Electron bunch length: 25 fs (rms)
- Bunch compression factor: 125
- Number of bunches: 2
- Bunch spacing: 28 ns

Requirements for C-band Station

- C-band frequency: 5.712 GHz
- Repetition rate: 100 Hz
- RF pulse length: 0.02 to 5 µs
- Amplitude stability of C-band in LINAC: 0.036 deg (rms)
- Phase stability of C-band in LINAC: 0.0017 deg (rms)
- Number of channels per RF station: 16
- Channel-to-channel drift: 0.1 deg/day
- Phase stability of vector modulator: 0.020 deg (rms)
- Phase resolution of receiver: 0.0017 deg (rms)
- Signal distortion of receiver: 1 %
- Amplitude resolution of receiver: 0.0017 deg (rms)
- Amplitude readback error: < 0.1 %

Analog Front-End

Vector Modulator

- VM and LO in 1 unit 19” box
- Baseband modulator with DC-coupled, differential I/Q inputs
- Common mode spurs from the DACs are suppressed by 40 dB
- Added jitter of the vector modulator driven by the DACs is around 1 fs

Channel-to-channel Isolation

- Depends on RF-to-LO isolation of the mixers and design of power splitter in LO distribution
- Channel-to-channel isolation of 80 dB achieved, corresponds to measured amplitude stability.

Drifts

- Only important on the receiver side because slow changes on the transmitting path are corrected by pulse-to-pulse feedback
- Temperature drift of analog front-end is 4.4e-3 rel/
- Temperature controlled rack at 24 °C ±0.05°C
- Temperature generated channel-to-channel phase drift can be improved by reference tracking to ~0.1 deg/day.
- Performance of reference signal distribution: phase drift of 0.04 deg/day

Amplitude and Phase Resolution

- Amplitude and Phase resolution of the LLRF system is limited by the noise floor of the output of the down-converter, the noise floor of the ADC and the phase jitter of ADC clock and LO signal.
- The noise floor of the down-converter measured at the IF port is -137 dBm/Hz. This is 6 dB above the ADC noise floor. For a sampled sine wave the clock jitter introduced by the onboard clock distributor increases the noise floor of the ADC by 2 dB. In contrast, the jitter of the external ADC clock from the LO unit is low enough to have no significant contribution.
- The pulse-to-pulse resolution of the whole system is 0.01 deg in phase and 1.5e-4 rel. in amplitude. It is calculated over 100 pulses with an averaging window of 300 ns per pulse. This averaging limits the bandwidth from 0.5 Hz to 1.5 MHz, which corresponds to the filling time of the C-band structures.
- The noise floor of the down-converter can be improved by increasing the input signal on cost of the intermodulation distortion of the system. Figure on the right shows the relation between distortion and noise floor as function of the required IF gain. With a chosen IF gain of 27 dB the OP3 measurement of the prototype down-converter results in a distortion of 0.75 %.

Conclusion and Outlook

The prototype LLRF system performs well and is an important step towards the SwissFEL LLRF system. Further attempts are being made to reduce the noise floor of the down-converter to the noise floor level of the ADC on cost on a slightly relaxed distortion requirement of 1%. With this approach and additional filtering of power supplies the measurement resolution of the LLRF will be well below the required RF stability tolerances. The implementation of reference tracking and additional drift calibration will help to improve the channel-to-channel phase and amplitude drift. For the common digital back-end emphasis was put on setting up the firm- and software environment and its integration into the control system. Now, the focus moves on the development of specific LLRF applications.

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