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EXTENSION OF REFERENCE TRACKING METHOD TO REDUCE RF AMPLITUDE DRIFT IN PARTICLE ACCELERATORS

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Abstract

RF long-term stability (drift) is as important as RF short-term stability for the stable operation of particle accelerators including PAL-XFEL. Increasing the performance of LLRF itself becomes an important factor in maintaining the long and short-term stability of the RF field. The reference tracking method applied to LLRF is effectively used as a method of reducing the drift of the RF phase. However, this drift improvement method was not applied to the RF amplitude. This time, the method of reference tracking was newly expanded to improve the RF amplitude drift. As a result of applying this new function to PAL-XFEL LLRF, it is showing some effect in improving the RF amplitude drift. We would like to share the progress so far.

INTRODUCTION

In the operation of an accelerator, not only short-term stability but also long-term stability is important. In particular, in the case of sensitive accelerators such as XFELs (X-ray Free Electron Lasers), the influence of short-term and long-term stability is critical. An illustrative Fig. 1 shows a typical XFEL intensity. The left side of the dotted line is a case where long-term stability is well maintained, and the right side is a case where long-term stability is poor and normal user service cannot be provided. Through this, it can be seen that long-term stability must also be well maintained. In order to do so, it is very important to improve the long-term stability of the LLRF (Low Level RF controller) itself. We will present the improvement of the long-term stability of the LLRF by applying reference tracking to the amplitude as well.

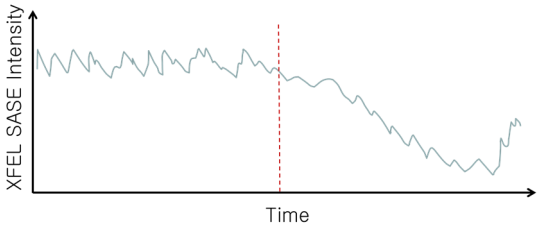

Figure 1: An illustrative sketch of typical XFEL intensity graph.

REFERENCE TRACKING METHOD

The reference tracking method is occasionally used to improve the long-term stability of LLRF systems. There is also the method of reference injection applied to European XFEL [1]. Although the method is considered more accurate, it is needed to add hardware configurations, while reference tracking has the advantage of simple implementation with little additional hardware. Reference tracking is mainly used to improve the stability of the phase.

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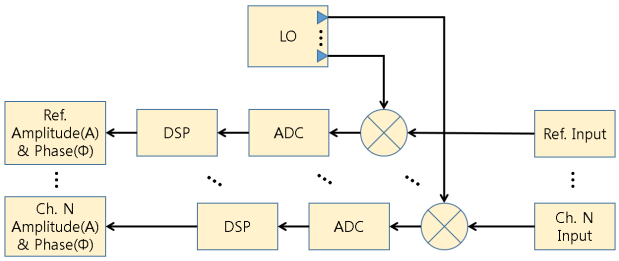

Figure 2: A typical structure of a LLRF receiver.

Figure 2 is a diagram of a typical LLRF receiver. The input RF signals are downconverted to IF signals, then the analogue signals are converted to digital signals, and the phases and amplitudes of the RF are calculated. The reference tracking method of the phase is a method of compensating for the phase drift of other channels by using the phase variation of the reference, and can be implemented as shown in Eq. 1.

$$Ch.N\,\Phi\,(Ref.track) = Ch.N\,\Phi - \Delta\,(Ref.\Phi) \quad (1)$$

where $Ch.N\,\Phi\,(Ref.track)$ is the compenstated phase of nth channel, $Ch.N\,\Phi$ is a phase before compensation, and $\Delta\,(Ref.\Phi)$ is the change in the reference phase.

Similarly, the reference tracking of the amplitude can be written as in Eq. 2. This method has been applied to the LLRF of PAL-XFEL.

$$Ch.N\,A\,(Ref.track) = Ch.N\,A - \Delta\,(Ref.A) \quad (2)$$

APPLICATION TO PAL-XFEL

The implemented amplitude reference tracking was applied to PAL-XFEL during the winter maintenance in 2023. The layout of PAL-XFEL is shown in Fig. 3. PAL-XFEL is based on a copper linac which accelerates electron bunches to 10 GeV at a repetition rate of 60 Hz. It generates ultra-strong and short X-ray pulses in each of hard X-ray and soft X-ray beamline for experiments. The linear accelerator (linac) of PAL-XFEL consists of a total of 51 RF stations, which are divided into five sections, named INJ, L1, L2, L3, and L4. The amplitude reference tracking (ART) has been applied to all 51 LLRFs and has been used to date. Some RF stations are selected and the data comparing before and after the application of the amplitude reference tracking are shown in Figs. 4-8.

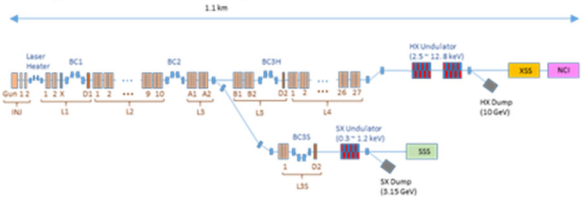

Figure 3: PAL-XFEL layout.

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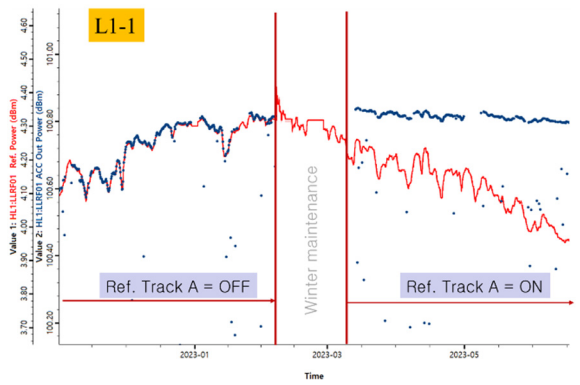

Figure 4: The amplitude (or power) data of the reference and 'ACC out' of a PAL-XFEL RF station L1-1 showing the drift improvement after the application of the amplitude reference tracking method.

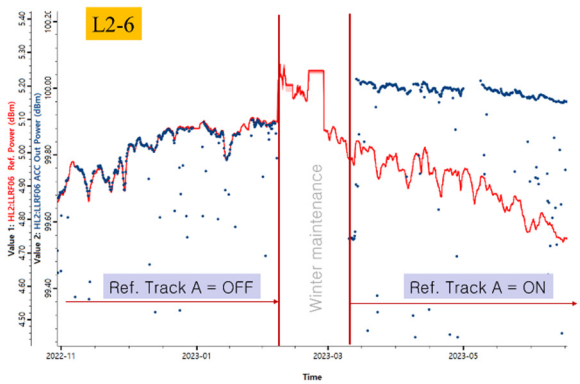

Figure 5: The amplitude (or power) data of the reference and 'ACC out' of a PAL-XFEL RF station L2-6 showing the drift improvement after the application of the amplitude reference tracking method.

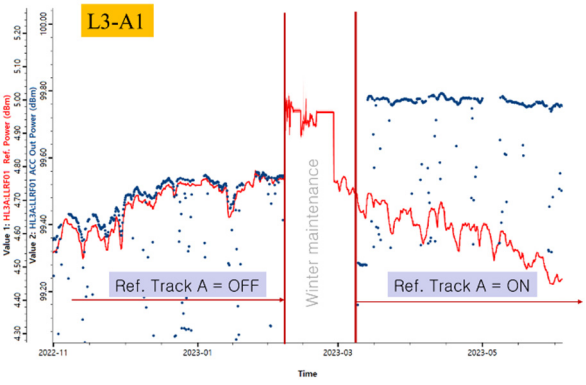

Figure 6: The amplitude (or power) data of the reference and 'ACC out' of a PAL-XFEL RF station L3-A1 showing the drift improvement after the application of the amplitude reference tracking method.

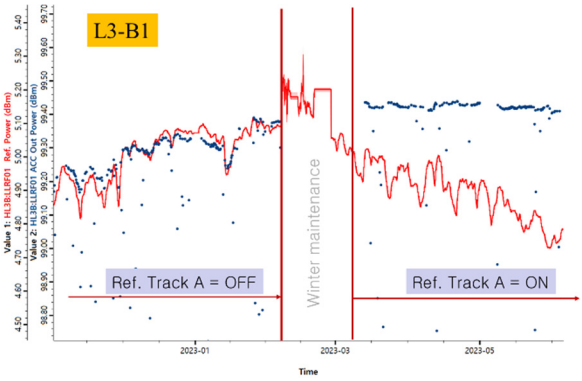

Figure 7: The amplitude (or power) data of the reference and 'ACC out' of a PAL-XFEL RF station L3-B1 showing the drift improvement after the application of the amplitude reference tracking method.

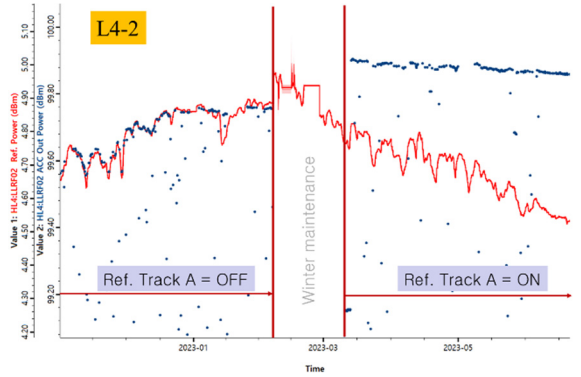

Figure 8: The amplitude (or power) data of the reference and 'ACC out' of a PAL-XFEL RF station L4-2 showing the drift improvement after the application of the amplitude reference tracking method.

Figures 4-8 shows the result of the application of the amplitude reference tracking method for several months. The red trace in each figure means the reference power (amplitude) measured by the LLRF and the blue line means the 'ACC (Accelerating Column) out' power. As shown in each figure, the amplitude change of the 'ACC out' is similar to the reference power before the application of the amplitude reference tracking, while the amplitude change of the 'ACC out' was reduced significantly after the application of the method.

To see quantitatively, the amplitude change of the 'ACC out' relative to the reference change was roughly estimated for each of the sampled stations and was shown in Table 1. The second column means the ratio of the 'ACC out' power change before the amplitude reference tracking (ART) method to the change of the reference power, the third column means the ratio of the 'ACC out' power change after applying the method to the change of the reference power, and the last or fourth column means the average ratio of the third column to the second column. As can be seen from the table, average change (drift) of the 'ACC out' power after applying ART is reduced to about 1/5, which means that the amplitude drift performance of each LLRF is improved by about 5 times through the method.

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Table 1: Rough estimation of the drifts of some selected RF stations of PAL-XFEL shown in Figs. 4-8. Second column means the ratio of amplitude drift between the ACC and the reference before the application of the amplitude reference tracking(ART), and third column means the same ratio after the application of ART. The fourth column means average ratio of second column and third column.

RF station	Before ART	After ART	Drift
L1-1	1.00	0.13	
L2-6	1.04	0.23	
L3-A1	0.80	0.22	
L3-B1	0.82	0.14	
L4-2	0.83	0.21	
Average	0.90	0.18	0.21

CONCLUSION

The reference tracking method used for improving RF phase drift was developed in a similar way to improve RF amplitude drift. The method was applied to PAL-XFEL during the winter maintenance in 2023, and the results showed improved RF amplitude measurements compared to the previous case (drift reduction to ~1/5). To our knowledge, there seems to be no other case where this amplitude reference tracking has been applied. The method can be applied to various accelerators.

REFERENCES

[1] F. Ludwig *et al.*, "Drift Calibration Techniques for Future FELs", in *Proc. IPAC'10*, Kyoto, Japan, May 2010, paper TUPEA041, pp. 1419-1421.