

# DEVELOPMENT ACTIVITIES RELATED TO RF CABLES FOR GOOD PHASE STABILITY

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## Abstract

XFEL systems require extreme RF stabilities in amplitude and phase. RF cables as parts of the systems also require very high stabilities. RF cable measurements are performed to choose good cables. A simple measurement method and test results are presented. To enhance the phase stability of RF cables a prototype jacket surrounding a RF cable is constructed and the test result is described. Finally, a modification for phase measurement of RF cables is presented.

## INTRODUCTION

XFEL(X-ray Free Electron Laser) systems can generate X-rays much brighter than those from current storage rings constructed around the world. In this strength, several XFEL construction projects are in progress. Among them are PAL-XFEL at PAL, South Korea, European XFEL at DESY, Germany[1], SwissFEL at PSI, Switzerland[2], and LCLS2 at SLAC, USA[3]. There are already two XFEL systems in operation, which are LCLS at SLAC[3] and SACLA in Japan[4]. But to achieve the X-rays planned, FEL machines must be very stable in several aspects including RF stabilities.

The required pulse-to-pulse RF stabilities for PAL-XFEL are 0.02% in rms amplitude and 0.03° in rms phase. Additionally, the drift of RF fields caused by the environmental temperature change must also be minimized to obtain stable X-rays. To consider the drift of RF illustratively, let us use Fig. 1.

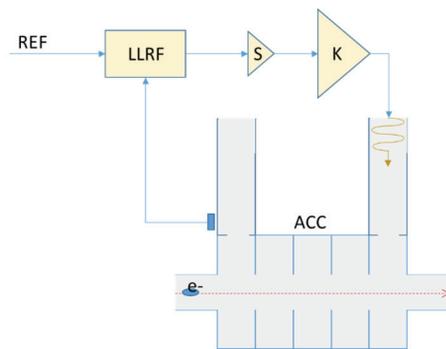


Figure 1 : RF station sketch.

Figure 1 shows a simplified RF station of a XFEL or a linac. The LLRF receives the reference CW(REF) through a coaxial cable, and it emits RF pulses into the SSA(S) through a coaxial cable. The SSA(S) amplifies the small RF pulses in mW level into kW level, which are sent through a coaxial cable to drive the klystron(K). The klystron(K) amplifies the RF pulses into about 80MW

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level and sends them to the accelerating column(ACC) through waveguides. Then the electron beams going through the column are accelerated synchronously with RF fields.

If all the components of Fig. 1 are not sensitive to the temperature variation and other causes, there will be no drift in RF fields, and there will be no needs to optimize the components and control by feedback. But in real situation, all the components are sensitive to temperature change more or less. So, each component should be optimized in temperature, or put in temperature controlled rack to minimize the drift. Though local feedback and global feedback corrects the drifts by temperature change, it should be preceded optimizing components to minimize the drifts by temperature change. The cables and waveguides applied must also be optimized with temperature change.

In this article, we present our activities to minimize the RF drifts within RF cables by temperature change for XFEL.

## CABLE SELECTION ACTIVITES

Cable manufacturers do not always provide RF drift data by temperature variation. Some papers treating this topic[5] do not consider S-band used for PAL-XFEL. So, the drift measurement for our PAL-XFEL machine was carried out to select adequate RF cables.

### Setup for RF Drift Measurement

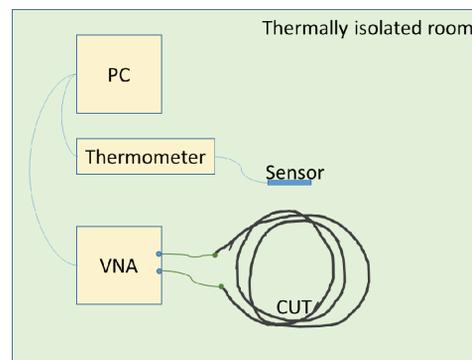


Figure 2 : RF drift measurement setup.

Figure 2 shows the simple setup invented for the drift measurement of cables. Within the thermally isolated room(usual room which is enclosed by ordinary wall), RF Vector Network Analyser(VNA) in connection with the cable under test(CUT), and the precision thermometer are used. PC for data acquisition is adopted. The above devices act as small heaters. With this setup, RF drift data along temperature are collected by the PC.

The drift data gathered include VNA drift also. The VNA drift must be removed from the data. To do the

removal, VNA drift data are gathered as shown in Fig. 3. The only difference is that two ports of VNA are connected directly.

The RF drift of the cable along temperature is finally obtained from the drift result of Fig. 2 eliminated by the drift result of Fig. 3. This method can be applied to measure amplitude and phase drift along temperature simultaneously for several RF cables.

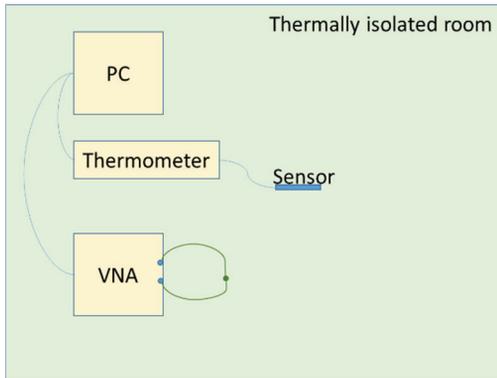


Figure 3 : The setup for VNA drift measurement.

**Measurement Results**

Several cables are measured to choose best one. Because the main frequency of PAL-XFEL is 2.856GHz, cables are measured mainly at this frequency. Though measurements are done for both amplitude and phase, phase change along temperature is mainly investigated because it is more critical for XFEL.

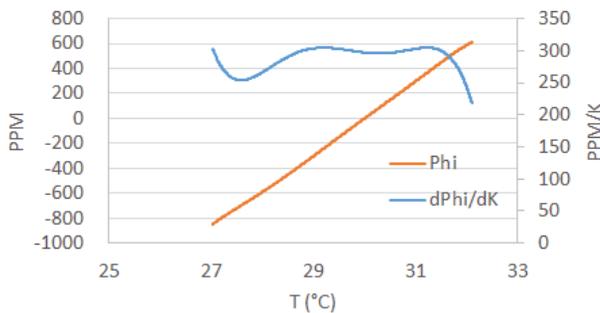


Figure 4 : Result of phase stability(drift) of RG-214. “Phi” means phase, and dPhi/dK means the rate of change of phase.

RG-214 is widely used because this cable is very flexible and can support high power. The measurement of RG-214 cable showed poor phase stability(drift) along temperature(Fig. 4). The slope of phase change along temperature is around 300PPM/K.

LMR cables are measured because this cable is often used instead of RG-214. LMR cables showed good phase stability. Among LMR cables tested, LMR400 showed best phase stability of 4~5PPM/K, LMR500 5~6PPM/K, and LMR600 about 9PPM/K.

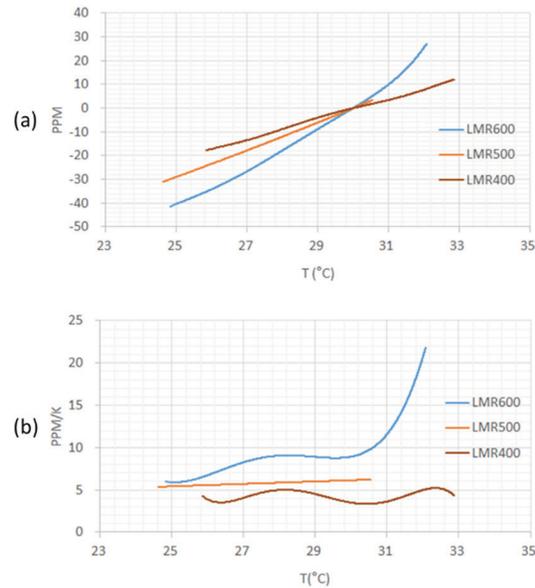


Figure 5 : Results of phase drifts of LMR400, 500, and 600. (a) means phase vs. temperature, and (b) means the slope of phase change.

Andrew cables are tested because these are widely used for current accelerators including PLS(Pohang Light Source) and LCLS. The measurement results showed that LDF2-50A(LDF2) has very good phase stability of <3PPM/K, but LDF4-50A(LDF4) did not have quite good phase stability compared with LDF2 and LMR 400 (Fig. 6). Figure 6 also shows an interesting point that the phase stabilities are different for two frequencies 1.3GHz and 2.856 GHz. That justifies our measurement for PAL-XFEL application.

RFS cables are widely used at DESY[5]. The measurement results showed very good phase stabilities of 2PPM for LCF38-50J(LCF38), and <3PPM for LCF12-50J(LCF12) for >25.5°C. Interestingly, LCF78-50J (LCF78) cable which is widely used for main drive line, showed good phase stability, but not excellency as the usage of main drive line for S-band.

From the test results, LMR400, RFS LCF38 and LCF12, and Andrew LDF2 cables are selected for PAL-XFEL application. Each of them is applied for different purposes; monitoring, feedback, and driving application.

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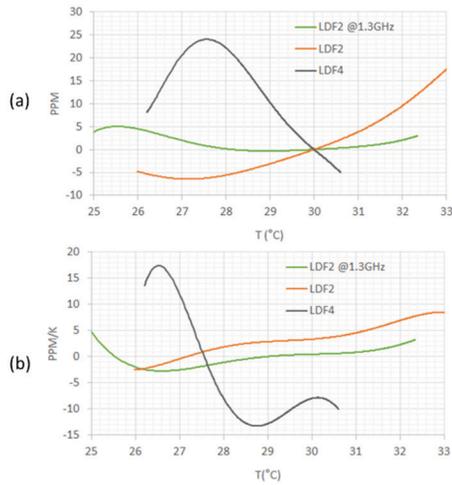


Figure 6 : Results of phase drifts of Andrew cables. (a) means phase vs. temperature, and (b) means the slope of phase change.

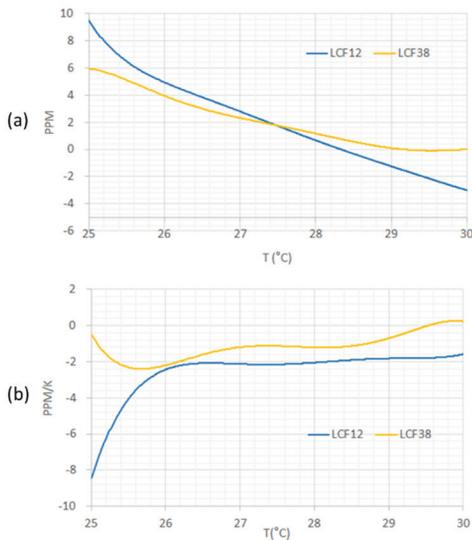


Figure 7: Results of phase drifts of Andrew cables. (a) means phase vs. temperature, and (b) means the slope of phase change.

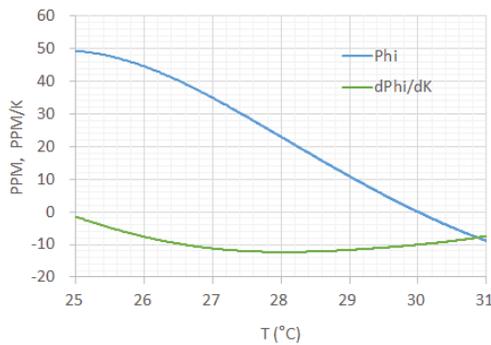


Figure 8 : Result of phase stability(drift) of LCF78-50J. "Phi" means phase, and dPhi/dK means the rate of change of phase.

### JACKET FOR DRIFT REDUCTION

It is impossible to choose RF cable with no temperature drift. To reduce the RF drift of cable along temperature, a prototype jacket enclosing a RF cable is tested. The cross-section view(Fig. 4) is similar to the cable duct applied to SACLA[6].

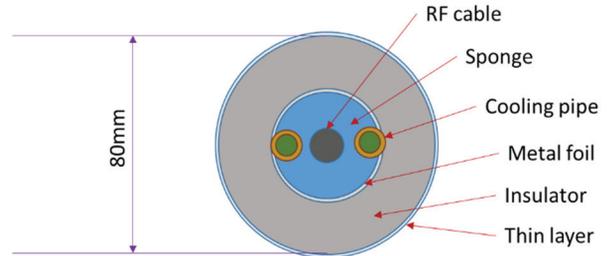


Figure 9 : The cross section of the jacket.

The temperature change at the surface of the RF cable within the jacket is measured at the setup of Fig. 5. By the chiller, the temperature of cooling water is controlled within  $\pm 0.05^\circ\text{C}$ . The room temperature and the inner temperature of the jacket(DUT) are measured with the air conditioner turned on and off. The following result shows for the case of air conditioner turned on.

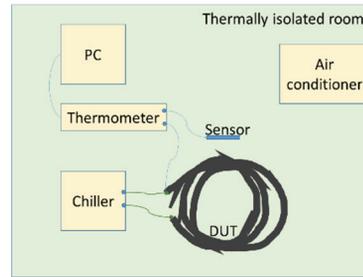


Figure 10 : The setup for Jacket measurement.

Figure 11 shows the result of measurement of the prototype jacket. The test range of environmental temperature is  $27 \pm 2.5^\circ\text{C}$ , which is very close to the temperature condition of PAL-XFEL gallery  $26 \pm 2^\circ\text{C}$ . For this environmental change, the inner temperature of the jacket is varied within  $\pm 0.25^\circ\text{C}$ , which corresponds to about  $\pm 0.2^\circ\text{C}$  for the condition of PAL-XFEL gallery.

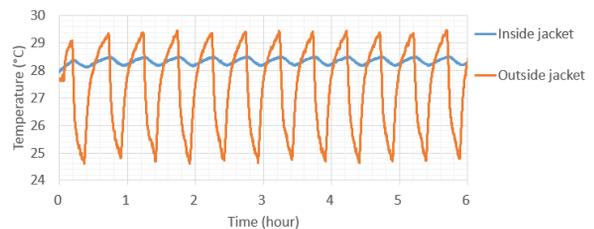


Figure 11 : The measured data for the prototype jacket.

To raise the performance of jacket, the thickness of the surrounding insulator will be increased from 80mm to

100mm in outer diameter. The upgraded jacket will be installed for PAL-XFEL this year.

### **MODIFICATION OF THE METHOD OF MEASUREMENT OF PHASE STABILITY**

The measurement method of phase stability described in the previous section, have the weakness that the result of measurement includes the phase variation of the cable and the connectors assembled at both ends of the cable. To see the phase variation of the cable only, we propose a modified method slightly changed from the method. In the following the modified method is described.

We prepare two test cables of the same kind, but having different lengths. Next, we measure the phase variations of the two cables according to the method shown in Fig. 2. From the two results, we get the phase variation of the cable only, by eliminating the measured variation of the shorter cable from that of the longer cable.

### **CONCLUSION**

XFEL machines require extremely stable RF fields. To achieve the requirements, the pulse-to-pulse stability and the drift stability of RF fields along temperature, must be optimized.

To optimize the drift stability of cables, a drift measurement method is invented. By the usage of the method, the cables having good phase stabilities are selected for PAL-XFEL.

To enhance the drift stabilities of cables, a prototype jacket is made and tested. The jacket showed the optimistic result. The improved jackets will be installed for PAL-XFEL this year.

The modified method of the RF drift measurement of cables along temperature is described to increase the measurement accuracy.

### **ACKNOWLEDGMENT**

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### **REFERENCES**

- [1] <http://www.xfel.eu>
- [2] <http://www.psi.ch/swissfel>
- [3] [https://portal.slac.stanford.edu/sites/lcls\\_public/lcls\\_ii](https://portal.slac.stanford.edu/sites/lcls_public/lcls_ii)
- [4] <http://xfel.riken.jp/eng>
- [5] K. Czuba, D. Sikora "Temperature Stability of Coaxial Cables", ACTA PHYSICA POLONICA A, Vol. 119 No. 4(2001).
- [6] N. Hosoda et al., "Construction of a Timing and Low-Level RF System for XFEL/SPRING-8", TUPE024, Proceedings of IPAC'10, Kyoto, Japan(2010).