Title: Phase Noise Measurements in SLAC Linac

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ABSTRACT

Phase Noise Measurements in SLAC Linac. KATIE SCHAFFOLD (Temple University, Philadelphia, PA 19122) RON AKRE (Stanford Linear Accelerator Center, Menlo Park, CA, 94025).

The Linac Coherent Light Source that is under development at SLAC will become the world's first x-ray free electron laser. This laser will enable revolutionary studies in many different areas of science. Before the laser goes into operation at SLAC, phase noise measurements need to be taken to determine whether the existing linac structure will be able to run the LCLS. The phase noise of a system is translated into timing jitter, and the LCLS can only tolerate a certain amount of jitter. The measurements taken on the linac were higher than expected and we hypothesized that our measuring devices might have been the source of high noise readings. After designing new low noise amplifiers to amplify the signal, the phase noise and timing jitter levels went down. We were able to target the PEP phase shifter as the component of the linac system that was adding a lot of noise. More work needs to be done to further reduce the phase noise and timing jitter levels.

INTRODUCTION

The Linac Coherent Light Source (LCLS) that is in development at SLAC will produce x-rays in short intense bunches. These pulses of x-rays will be brighter and shorter than the x-rays from any other sources and will be used to study many different areas of science in a way that has never been possible [1]. Phase noise measurements need to be taken along the SLAC linear accelerator (linac) to determine whether the existing linac apparatus will be able to run the LCLS.

Noise occurs in a system, such as an oscillator on the SLAC linac, when a sinusoidal wave is excited from its normal state to produce a slightly different wave. Amplitude noise occurs when the amplitude of the sine wave changes, and phase noise occurs when the timing or the phase of the sine wave changes. We are concerned only with the phase noise in the RF system, because this type of noise leads to timing jitter on the system that could hinder the LCLS.

The LCLS committee members stated that the timing jitter of the system should be around 70 – 100 femtoseconds. In order to be sure that the LCLS can achieve this goal, professionals at SLAC have said that they need to be able to measure phase noise that relates to timing jitter of fewer than 30 femtoseconds.

MATERIALS AND METHODS

The phase noise that we measured on the linac was very small; therefore we could not use typical tools, such as a spectrum analyzer, to measure it. The apparatus that I used to measure the phase noise consisted of two oscillators that were phase locked to each other. One oscillator was the one I was taking the measurements on, and the other was a reference oscillator. The two

oscillators were fed into the LO and RF ports of a mixer, and the IF output of the mixer was sent through amplifiers and to an analog to digital converter scope card in the computer.

Measurements on the linac were taken in a couple of different spots in order to determine which parts of the linac contributed noise to the whole system. The diagram in Figure 1 shows the different components of the linac. For my project, I took phase noise measurements at the master oscillator (MO), PEP phase shifter (PEP), master amplifier (MA), main drive line (MDL), and sector 30 of the linac. One would expect the phase noise and timing jitter at the MDL or sector 30 to be higher than at the MO because between those two points, the signal has to run through a lot of equipment that can add noise to it.

I collected data both in the lab and on the linac. Once the data was in the scope card of the computer, I used an existing computer program written in LabVIEW to analyze the data. This program read the initial signal from the scope card and automatically converted the data from the time domain to the frequency domain using a fast Fourier transform. In another existing program in MathCAD, I further analyzed the data. I entered the data from the scope card into the program and it produced graphs of the noise and the timing jitter, all in the frequency domain.

Another part of my project involved improving the phase noise-measuring device. My mentor and I decided that we needed to design new low noise amplifiers. We looked at many different company's low noise amplifiers and decided to use the Analog AD797 and the National LMH6624 (specifications in Table 1). We decided that the noise voltage of the amplifiers should be under $4 \text{ nV}/\sqrt{\text{Hz}}$, and both amplifiers were well under this limit. In order to produce the desired gain of 200 with the amplifiers, I designed a circuit where the first amplifier, the AD797, produced a gain of 10 and the second amplifier, the LMH6624, produced a gain of 20.

RESULTS

After I learned how to use the phase noise measuring device, I took some data in the lab to compare it to the data I would later take on the linac. Figure 2 shows the FFT of one of the standard signals generated in the lab on June 30, 2004. Figure 3 then shows the graph of the same signal's timing jitter. This data was collected with a 40 kilohertz sample rate.

On July 13, 2004 I moved all of the phase noise measuring apparatus to the linac and collected data. Figure 4 shows the timing jitter of the master oscillator of the linac, collected at a 20 Megahertz sample rate. Figure 5 shows the timing jitter of the main drive line of the linac, also collected at a 20 Megahertz rate.

After the new amplifier circuit was designed, data was once again collected. Figure 6 shows the timing jitter data from a single oscillator taken in the lab on August 9, 2004 using the new amplifiers and sampled at a 20 Megahertz rate. Figures 7 through 11 show the timing jitter data of the master oscillator, PEP phase shifter, master amplifier, main drive line, and sector 30, respectively. All of this linac data was collected using the new amplifiers and sampled at a 20 Megahertz rate.

DISCUSSION AND CONCLUSION

I collected the data in the lab to compare with the data from the linac. The data in the lab was taken on a very low noise oscillator, so the phase noise and timing jitter that I observed was most likely going to be lower than phase noise and timing jitter I would measure on the linac. As expected, the timing jitter from the MO and MDL of the linac on July 13, 2004 (Figures 4 and 5) was higher than the timing jitter from the lab (Figure 3), but what was unexpected was how high the timing jitter on the linac actually was. The maximum timing jitter on the MO is around 100 femtoseconds, but the jitter from the MDL goes above 150 femtoseconds, which is above the

LCLS specification.

The phase noise and timing jitter levels were reduced with the usage of the new amplifiers. The lab data taken with the new amplifiers from August 9, 2004 (Figure 6) looked very good. Since the data was collected on only one oscillator, the timing jitter that showed up was only from the amplifier and the mixer. The timing jitter was about two orders of magnitude better than any of the data previously taken on the linac or in the lab, so we hypothesized that the new amplifiers would not add a significant amount of noise to the system.

The low timing jitter data from the lab on August 9, 2004 led us to hypothesize that we would be able to measure lower phase noise and timing jitter levels on the whole linac. Our hypothesis was proven correct when we collected the data from the linac on August 17, 2004. All of the timing jitter levels from the data on August 17 were lower than the timing jitter levels from July 13. The timing jitter from the MO (Figure 7) was very low—the highest it reached was 12 femtoseconds. The data taken at the PEP phase shifter (Figure 8) then shows that the maximum timing jitter jumps up to just above 60 femtoseconds. This data shows us that the PEP phase shifter is somehow adding a lot of noise and jitter to the system. The maximum timing jitter at the master amp (Figure 9) then increases slightly to a maximum around 80 femtoseconds, so the master amp might also be adding some noise to the system. The data at the MDL (Figure 10) and sector 30 (Figure 11) shows that the timing jitter of these two components stays around the 80 femtoseconds maximum jitter of the master amp. This data from the MDL and sector 30 shows that both of those components probably are not adding a lot of phase noise to the whole linac system because the timing jitter recorded *before* those components is around the same as the timing jitter recorded *after* those components.

My results show that work needs to be done to the linac system before it goes into use with the LCLS. Specifically, the PEP phase shifter needs to be more closely studied to determine why it appears to be adding phase noise and timing jitter to the linac system. The measurement system should be improved so that the noise of the measurement system will not add to the noise that we are trying to measure and so that the measurement system will be easier to transport between the lab and the linac. The timing jitter data that I collected is under the 100 femtoseconds LCLS specification, but more work needs to be done to measure even lower phase noise and timing jitter and get below our 30 femtoseconds timing jitter specification.

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REFERENCES

- [1] "Linac Coherent Light Source," [Online document], [2004 June 28], Available at HTTP: <http://www-ssrl.slac.stanford.edu/lcls/>

Tables

Company Name	Model Number	Noise Voltage (nV/ $\sqrt{\text{Hz}}$)	Gain Range	Integrated Noise (nV _{p-p})	Gain Bandwidth (MHz)
Analog	AD797	0.9	up to 1000	50	110
National	LMH6624	0.92	up to 100	not specified	1500

Table 1. Specifications of amplifiers we chose.

Figures

Figure 1. Block diagram of the different components of the linac system.

6/30/2004 Lab Data 97-99 40kF.dat

Figure 2. FFT of signal from lab on June 30, 2004 taken at a 40 kilohertz sample rate.

6/30/2004 Lab Data 97-99 40kF.dat

Figure 3. Timing jitter data taken in the lab on June 30, 2004 with a 40 kilohertz sample rate.

7/13/2004 MO Data mo1-20mF.dat

Figure 4. Timing jitter data taken on the master oscillator on July 13, 2004 with a 20 Megahertz sample rate.

7/13/2004 MDL Data mdl-20mF.dat

Figure 5. Timing jitter data taken on the main drive line on July 13, 2004 with a 20 Megahertz sample rate.

8/9/2004 Lab Data 8-9_new_amp2F.dat

Figure 6. Timing jitter data from a single oscillator taken in the lab on August 9, 2004 with a 20 Megahertz sample rate.

8/17/2004 MO Data MO1 20MF.dat

Figure 7. Timing jitter data taken on the master oscillator on August 17, 2004 with a 20 Megahertz sample rate.

8/17/2004 PEP Data PEP 20MF.dat

Figure 8. Timing jitter data taken on the PEP phase shifter on August 17, 2004 with a 20 Megahertz sample rate.

8/17/2004 MA Data master amp 2 20MF.dat

Figure 9. Timing jitter data taken on the master amplifier on August 17, 2004 with a 20 Megahertz sample rate.

8/17/2004 MDL Data MDL 20M 2F.dat

Figure 10. Timing jitter data taken on the main drive line on August 17, 2004 with a 20 Megahertz sample rate.

8/17/2004 Sector 30 Data sec30 20MF.dat

Figure 11. Timing jitter data taken at sector 30 on August 17, 2004 with a 20 Megahertz sample rate.