Phase Noise Measurement in PEP II and the Linac

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August 21, 2003

Prepared in partial fulfillment of the requirements of the Office of Science, Department Of Energy's Science Undergraduate Laboratory Internship under the direction of Ron Akre in the Klystron/microwave department of the technical division at the Stanford Linear Accelerator Center.

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ABSTRACT

Phase Noise Measurement in PEP II and the Linac. MESFIN GETANEH (University of New Orleans, New Orleans, LA 70148). RON AKRE (Stanford Linear Accelerator Center, Menlo Park, CA 94025)

The Goal of this project is to provide a measurement of the phase of the radio frequency (RF) relative to electron beam traveling down the Stanford Linear Accelerator Center (SLAC). Because the Main Drive Line (MDL) supplies the RF drive and phase reference for the entire accelerator system, the phase accuracy and amount of phase noise present in the MDL are very critical to the functionality of the accelerator. Therefore, a Phase Noise Measurement System was built to measure the phase noise in the liner accelerator (Linac) and PEP II. The system was used to determine the stability of the PEP II RF reference system. In this project a low noise Phase Locked Loop system (PLL) was built to measure timing jitter about sub picoseconds level. The phase noise measured in Master Oscillator using PLL indicates that phase noise is low enough for PEP II to run.

Introduction

The Stanford Linear Accelerator Center (SLAC) is one of the world's leading research laboratories. SLAC houses a two-mile electron-positron accelerator (Softky, 2002). Approximately 240 high-powered klystron (an evacuated electron tube used as an oscillator) stations power SLAC's linear accelerator (Linac). The Linac is further divided into 31 sectors of klystrons. Each sector has a low power subbooster klystron that provides RF drive for the high power accelerator klystrons (Schwarz, 1986).

Phase stability is very critical to any high-powered RF distribution systems used for particle acceleration. Both the RF drive and phase reference for the Linac are provided by the Main Drive Line (MDL). The MDL is a rigid, gas filled, coaxial waveguide that runs the entire 2-mile of the accelerator. At each sub-booster, the internal frequency of 476 MHz is multiplied by six to reach 2856 MHz, which is needed by most RF systems at SLAC (Jobe, 1986). The 2856 MHz is then delivered to the Phase Reference Line (PRL), which provides the phase reference for all sectors and subbooster klystrons in the Linac. These klystrons are very important because they supply the RF drive for the electron beam of the Linac (Jobe, 1989). Since the RF phase stability of all accelerator components is directly affected by the phase noise (unwanted fluctuations in the signal phase) in the MDL, the presence of phase monitoring system is very important. The master oscillator (a 476MHz source generated from a quartz crystal oscillator) in sector 0 supplies the original frequency of the MDL. This frequency is passed through the master amplifier then to the MDL. Since the master oscillator and the master amplifier have phase noise, it is essential to measure the phase noise of these instruments used in

the MDL in order to determine which components are responsible for increasing phase noise levels.

In this project a phase noise tester is assembled to determine the stability of the RF reference system in PEP II and the Linac. The phase noise was measured in sector 30 and at the PEP II Master Oscillator. Then, the data collected from these places were analyzed using Labview and MathCad. A Fast Fourier Transform (FFT) was used to transform the collected data from the time domain to the frequency domain. The total phase noise of the system, measured in dBc, was then determined by calculating the integral of the transformed data over the interval on which the data was collected. This phase noise was converted into f_s and compared to requirement of PEP II.

MATERIALS AND METHODS

A Phase Lock Loop system (PLL) was designed and built to measure the phase noise in the Linac as well as in PEP II (Figure 1). Measuring the phase of a low noise oscillator locked to a system is one of the most effective ways to measure phase noise. This system uses a low phase noise 79.3MHz Oscillator multiplied by six to achieve the 476MHz frequency. A mixer is used to measure the difference in phase between the low noise oscillator and the Device Under Test (DUT). The Phase error signal is amplified and split in to the feedback to lock the oscillator to the DUT signal and the digitizing scope card in a P.C. The PLL built here has a low phase noise oscillator compared to the DUT (Akre, 2002).

When a phase noise measurements is taken, the PLL system locks in a frequency where the phase difference between the two oscillators is zero. If the phase noise is below the bandwidth of the PLL, the phase of the Voltage Controlled Oscillator (VCO) will

track the phase of the DUT and the system will not detect any noise (Akre, 2002). After collecting the data in this way, the output of the data was sent to the scope card in a computer. Then the data was analyzed using different computer programs such as Labview and MathCad.

Before taking measurement in the Linac and PEP II, the DUT needed to be calibrated in the lab. In order to calibrate the DUT, a master oscillator, similar to the one found in the Linac and PEP II, was used in the laboratory. The specific bits per radian conversion for the device were then determined to be 11314 bit/rad when the device was collecting data whose power was 1.2mW. Then the PLL was connected to the DUT using the appropriate filter. Note that the cables used in this measurement are 100% shielded from the center conductor to the outside noise.

RESULTS

The data in Table 1 was taken when the Phase Noise Measurement system was calibrated. The calibration signal that was used in the laboratory ranged between 500Hz and 0.076Hz. A number of measurements were taken to make sure the result was accurate. The result from the calibration shows that the oscillator used in the PLL system has a very low noise compared to the Master Oscillator in the MDL and PEP II. The measurement from the calibration is shown in Table 1. During the calibration two types of power source was used, one AC power and other with a battery power. Nonetheless, there was no difference in the measurement because the oscillator and amplifiers were isolated enough from the AC power supplies so as not to add noise into the signal. The reason for this is the PLL system components have internal regulators that filter the noise that comes from the AC power.

After calibration was done in the Phase Noise Measurement System, measurements were taken in sector 30 and the data is shown figures 2, 3, 4, and 5. The power in the end of the Linac was about 0.86mW. The Master Oscillator has a low phase noise in between 100Hz and 5MHz. The total timing jitter between these frequencies is around 0.5ps rms (Figure 3). The timing jitter is small enough for the PEP II to run. The biggest contribution for the noise lower than 100Hz is comes from around 48Hz (Figure 2 and 3).

The last two measurements were taken in PEP II reference and the Master Oscillator (Figure 6, 7, 8, 9, 10, 11, 12, and, 13). The measurements taken from PEP II reference and Master Oscillator are very similar to the measurement taken from Master Oscillator in sector 30. In the PEP II reference there is a high phase noise approximately at 48Hz. By taking further measurements in the end of the Linac and in sector 0, the phase noise at 48 Hz was traced back to the Master Oscillator in sector 0 of the Linac. The noise between 10 KHz and 10 MHz has a timing jitter under 0.2ps. As shown in figure 6 and 7, the Master Oscillator in PEP II has a similar phase noise level as PEP II reference and the Linac.

DISCUSSION AND CONCLUSIONS

The result in the figures shows that both the frequency domain and the timing jitter showed similar result. As it is shown in the graphs the most contribution for the noise came from 48Hz. This is very unusual to see a timing rms jitter of 1.2ps (Figure 3 and 7). Since this is critical for the running of PEP II, it is necessary to find what caused this high noise around 48Hz and has to be fixed. The phase noise measurement at this point other than the 48Hz is acceptable for the running of the MDL and PEP II. Even

though the result found is encouraging, the measurement that was taken when the beam was not running. This has to be taken into consideration and it will be necessary to take other measurements if there will be a change when the beams are running. As it is the Master Oscillators in both the Linac and PEP II are working with the required low phase noise.

ACKNOWLEDGMENTS

I thank the U.S. Department of Energy for giving me the opportunity to participate in SULI program and the chance to have an incredible learning experience. Special thanks go to my mentor Ron Akre for his full cooperation throughout the project. I also thank Clive O'Connor, George Barillas, and Greg Dalit for helping me to get started as well as carry on my project. Further, I would like to thank Helen Quinn, Roberto Vega, and Erin Smith who facilitate and organize the SULI program in SLAC.

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Figures

Figure 1: Phase Noise Measurement system

The Phase Noise Measurement System in figure 1 was used to measure the phase noise in Sector 30 and PEP II. The system uses a low phase noise 79.33MHz oscillator multiplied to 476MHz. A mixer is used to measure the difference in phase between the low noise oscillator and the Test Input. The Phase error signal is then amplified and split. One side is used for feed back to lock the oscillator to the Test Input signal. The other side is amplified and input into a digitizing scope card in a P.C.

Figure 2: Low Frequency Phase Noise at Sector 30 and Test Unit.

This measurement was taken in sector 30 master oscillator. The phase signal was digitized at 40kHz. The measurement seen above shows phase noise from 0.076Hz to 20kHz.

Figure 3: Timing Jitter of the master oscillator in sector 30.

This is the integration of the phase noise from figure 2.

Figure 4: High Frequency Phase Noise Sector 30 and Test Unit.

The phase signal in this measurement was digitized to measure the phase noise at high frequencies.

Figure 5: Timing Jitter of Sector 30 digitized at 20 MHz.

PEP II REFERENCE 08/08/03 REF 40kHzbatF

Figure 6: Phase Noise Measurement at PEP II Reference. This is a low frequency Phase Noise. The phase signal was digitized at 40kHz.

PEP II REF. 08/08/03 PEP II Ref. 40kHz.

Figure 7: Timing Jitter of PEP II Reference at 40KHz.

Figure 8: PEP II phase noise measurement at high frequencies.

Figure 9: Timing Jitter for PEP II Ref. digitized at 20MHz.

PEP II MO 08/08/03 PEP II MO 40kHzbatF

Figure 10: Phase Noise measurement in PEP II master oscillator.
This is a low frequency measurement digitized at 40kHz,

Figure 11: Timing Jitter of PEP II master oscillator at low frequency

Figure 12: Phase Noise Measurement in PEP II master oscillator at 20MHz.

PEP II MO 08/08/03 PEPII MO 20MHzF

Figure 13: Timing Jitter in PEP II master oscillator at a digitized frequency up to 20MHz.

Frequency signal (Hz)	Phase Noise (dBc)
500	-40.67
400	-38.48
300	-38.60
200	-41.20
100	-39.36
90	-40.09
80	-40.99
70	-42.20
60	-40.70
50	-40.18
40	-39.43
30	-38.89
20	-38.57
10	-38.60
8	-43.66
6	-40.92
4	-42.67
2	-43.87
1.52	-44.70
1	-48.86
0.912	-47.99
0.763	-50.59
0.61	-53.18
0.305	-56.60
0.076	-58.48

Table 1: Measurements taken during Calibration in the Lab.

Figure 14: Plot of the frequency signal versus the Phase Noise of the PLL system.