LASER DRIVEN RF SIGNAL GENERATION WITH AN AMPLITUDE STABILIZATION TECHNIQUE

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Abstract

Precise synchronization between rf signal and laser pulses is essential for stable operation of photo cathode rf-guns. For this purpose, we developed an amplitude-stabilized rf signal generator driven by laser pulses of the oscillator, dealing with long-term output power drift as well as pulse by pulse power fluctuations of the laser oscillator. It was realized by introducing a limiter amplifier and a comb generator in the rf generation circuit. The output rf power of the generator was almost constant within 10 dB input power range. The rf phase noise and the timing jitter between the rf signal and the laser pulse were measured. The phase noise difference between unstabilized and stabilized generators was almost the same, which correspond to RMS jitter about 250 fs in the frequency range of 10 Hz-100 MHz. Measurements using a sampling oscilloscope showed that the laser pulse and rf signal timing jitter of the stabilized generator was smaller than that of unstabilized one. Furthermore the characteristic of the synchronization was almost the same within 10 dB input power range. In this proceedings, the overview of the stabilized rf generator and results of the phase noise and jitter are presented.

INTRODUCTION

To produce stable low emittance beam from photo-cathode RF gun, it is important that the laser pulse illuminating the cathode should be synchronized with rf signal and injected to the cathode at the exactly proper rf phase of the rf cavity. There are several ways to synchronize the laser pulse and rf signal. One way is synchronizing the laser pulse with the rf signal, and the other is conversely synchronizing the rf signal with the laser pulse. The former uses phase lock technique by controlling the piezo actuator on one of the end mirrors in the laser oscillator. The latter generates rf signal from the laser pulse, for example, phase-locking of an rf oscillator to the laser pulse or extracting the high order harmonics component from the laser pulse signal itself.

We have combined the both techniques and realized high-precision synchronization between laser and rf signal. At first, the laser oscillator was synchronized with the master rf oscillator at 89.25 MHz which is the one 32nd the RF frequency 2856 MHz. The timing jitter between the laser pulse and rf signal can be 300-400 fs with this synchronization. For further high-precision synchronization, the rf signal at 2856 MHz is generated from laser pulse again. Because the laser pulse has rapid rising time, it has higher harmonics components. The 32nd component (2856MHz) can be obtained by passing through the band pass filter (BPF).

There was a problem when we pick up the rf signal with the BPF. The amplitude of the rf signal is linearly varied with that of the laser pulse. For this reason, the rf signal power changes as the power drift or fluctuation of the laser pulse.

We have developed a new rf signal generator with a limiter amplifier to stabilize the output rf amplitude. It can suppress the change of the rf power caused by the long-term drift of the laser power. We aimed to get constant rf power even if the laser power fell half. The amplitude-stabilized rf generator also designed to decrease the short-term variation of amplitude improved even the synchronization between the laser pulse and rf signal.

OUTLINE OF RF GENERATOR SYNCHRONIZING TO LASER PULSE

Synchronization Techniques

The photocathode RF-gun at SPring-8 has a short pulse laser system for illuminating the cathode. The system consists of a 89.25MHz Ti:Sapphire laser oscillator (FEMTOLASERS productions GmbH, FEMTOSOURCE SYNERGY), a 10 Hz regeneration amplifier, a multi-pass amplifier, and a third harmonics generator. The frequency of the laser oscillator is the one 32nd of the rf frequency for the S-band cavity of the gun. We have a phase locked-loop feedback system (FEMTOLASERS productions GmbH, FEMTOLOCK), which can synchronize the laser oscillator with the external master rf signal.

We used an analog signal generator (Agilent technologies, E8663B) for the external master rf source as shown in Fig. 1. In the FEMTOLOCK, the master rf signal is divided to the one eighth and the laser pulse is multiplied eight times, then both signals are input to the rf mixer, which works as a phase comparator. The output signal from the mixer is filtered and amplified. The laser oscillator with a piezo-controlled mirror works as a voltage controlled oscillator in the PLL feedback. The feedback gain and frequency range is controlled manually at the FEMTOLOCK. As the results of the feedback, an RMS jitter of the laser pulse is shown on the numerical display, which was kept 0.06-0.08 ps yearlong.

The PLL feedback shown in Fig.1 has a limit of the maximum frequency of the piezo actuator. The upper limit of the piezo is 100 kHz at most. Therefore, the synchronization over the frequency is impossible with the scheme.

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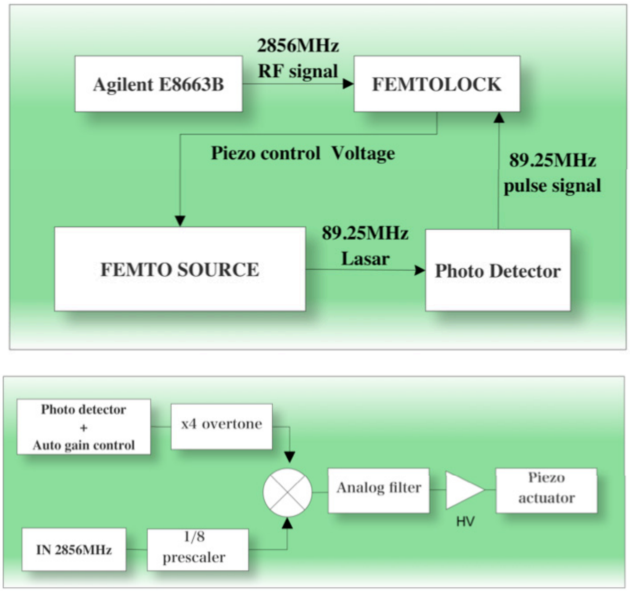

Figure 1: Block diagram of synchronization feedback with FEMTOLOCK (upper) and circuit diagram in the FEMTOLOCK (lower).

In SPring-8, we have used an additional circuit for generating an rf signal to the cavity in order to overcome the limit of the PLL feedback and frequency characteristics of the piezo. The rf signal was generated from the 89.25 MHz laser pulse with a laser-driven rf generator as shown in Fig. 2. In the circuit, we pick out the 32nd harmonics (2856MHz) from the laser pulse signal with a BPF. A cavity type BPF was used for the BPF, as it has high Q value and therefore narrow band width (~10MHz@3dB).

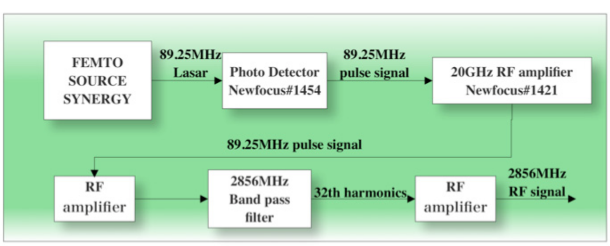

Figure 2: Block diagram of the laser driven rf generator. The output rf signal is automatically and passively synchronized to the 89.25MHz laser pulse.

Amplitude Stabilized RF Generation

When the laser pulse has some time jitter, the output rf also fluctuates as the laser pulse fluctuates. For this mechanism, the laser pulse and rf signal can be synchronized precisely. Comparing the passive circuit in Fig.2 with the PLL circuit in Fig.1, the circuit in Fig.2 is not affected by the limit of the piezo characteristics and can ideally decrease the time jitter.

The main issue of the laser-driven rf generator is that the rf amplitude is linearly varied with the amplitude of the laser pulse. Because the long-term variation of the laser amplitude is not evitable, the stabilization of the rf signal was necessary. The pulse by pulse fluctuations of the laser pulse also caused a short-term power jitter of the rf signal. To resolve this problem, we developed a new laser-driven rf generator as shown in Fig.3.

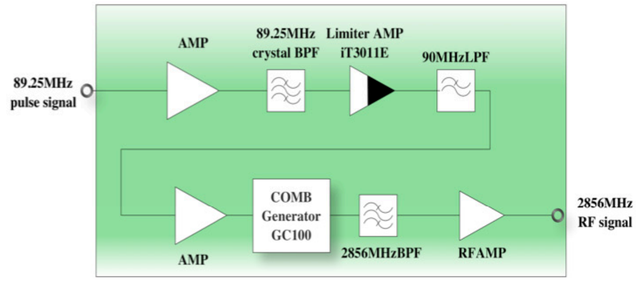

Figure 3: Block diagram of the amplitude-stabilized laser-driven rf generator.

The main improvements in the new generator are as follows. Firstly, the output rf amplitude was stabilized with a limiter amplifier (GigOptix, iT3011E). Secondary, an 89.25 MHz sinusoidal wave was generated with a crystal band pass filter and a comb generator (Herotec,Inc, GC100) was used to get higher harmonics. The comb generator produces a narrow pulse with a fast rise-time and only the 32nd harmonics can passes after the cavity type BPF.

As well as the laser-driven rf generation, 89.25 MHz pulse signal (NIM signal) is generated for the synchronization of the laser amplifier system or other measurement system. The photograph of the laser-driven rf generator with amplitude stabilization is shown in Fig.4.

Figure 4: Photo of the amplitude-stabilized laser-driven rf generator.

PERFORMANCE OF AMPLITUDE STABILIZED RF GENERATOR

Output Power Stability

To examine the input and output characteristics of the amplitude-stabilized rf generator, the output power was measured as varying the input laser-pulse amplitude with an attenuator at the input connector. The output stability is shown in Fig. 5.

The output power was almost constant within 10 dB input power range. In the range, the variation of the output power was kept within 1.5 %. Because the long-term drift of the laser power is normally less than 20 %, this results shows that the stabilized range is wide enough to get a constant output rf power.

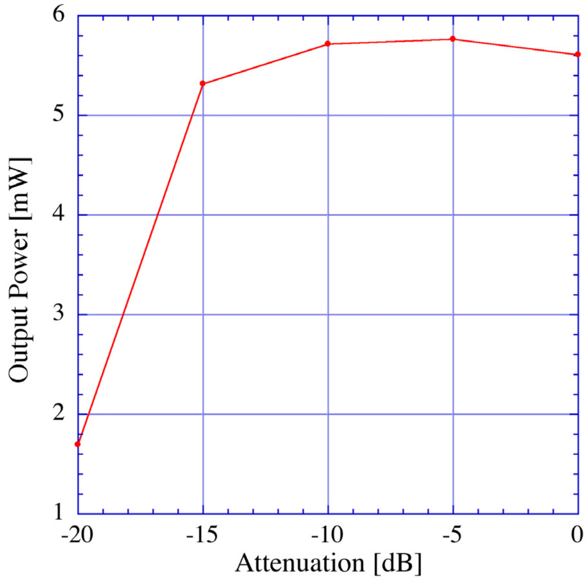

Figure 5: Output power characteristic as the input pulse power is changed.

Next, the short-term (less than one minute) rf power fluctuations were measured with no attenuator at the input connector. The amplitude stability for the amplitude-stabilized rf generator was decreased to 0.20 % (RMS), while that for the unstabilized rf generator was 0.27 % (RMS).

From these results, we have confirmed that the amplitude stabilization was effective not only to the long-term drift but to the short-term power fluctuation of the laser oscillator.

Phase Noise Measurements

Because the amplitude-stabilized rf generator was more complex than the unstabilized one, the increase of the phase noise was expected. We were especially afraid that the phase noise increased in the sinusoidal wave converter or in a comb generator.

The phase noise of the amplitude-stabilized and non-stabilized rf generators was measured with a signal source analyzer (Agilent technologies, E5052B). The measurement results are shown in Fig. 6.

The phase noise for the amplitude-stabilized rf generator was larger in the frequency range less than 10 kHz. This shows that some problems still remain in the circuit. The effect of the crystal BPF of 89.25 MHz for the stabilized rf generator decreased the phase noise in the frequency range more than 10 kHz. The phase noise reduction could be seen also in the region more than about 10 MHz for both generators due to the effect of cavity BPF at 2856 MHz. The time jitter of the both rf signal was calculated from the phase noise measurements data (estimated in the frequency range from 10 Hz to 100 MHz).

The time jitter of the unstabilized rf generator was estimated as 255 fs, while the jitter for the stabilized one was 249 fs. They had almost same time jitter. The resolution of the jitter measurements using E5052B is the order of 10 fs.

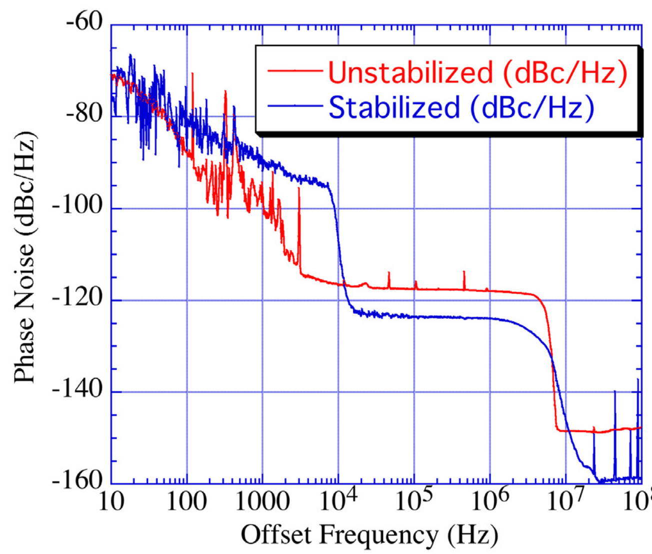

Figure 6: Comparison of the phase noise of the two generators. The red line is for unstabilized rf generator and the blue one is for amplitude-stabilized rf generator.

Synchronization jitter between laser pulse and rf signal

The synchronization jitter between the laser pulse and rf signal was measured. We measured the jitter with a sampling oscilloscope (Lecloy, SDA-100G). The clock jitter of the sampling oscilloscope is 250 fs. Thus the jitter measurement does not have enough accuracy less than 250 fs. However, the measured short-time jitter of the amplitude-stabilized rf generator was actually less than 250 fs as described later. It means that the measured jitter of the amplitude-stabilized rf generator may have a large measurement error. But the relative comparison between the amplitude-stabilized one and unstabilized one should be possible even though the measured jitter is less than 250fs.

The short-time jitter (less than one second) was measured over 1000 repetitions for about 10 minutes. The rf signal output from the rf generators was input to the clock signal of the sampling oscilloscope and the laser pulse was input to the signal input. As the clock signal of 2856 MHz is divided to the one 32nd, the laser pulse can be seen stationary in the oscilloscope as shown in Fig.7. The synchronization time jitter was estimated as the ratio between the rms amplitude fluctuation and the through rate of the falling edge of the laser pulse.

The measured timing jitter was 161 fs for the amplitude-stabilized rf generator, while that of the unstabilized generator was about 270 fs. These results show that the stabilized generator has advantages in the timing synchronization compared to the unstabilized one.

We also measured the timing jitter between the laser pulse and the rf signal when the input laser pulse power was attenuated. The measurement results are shown in Fig. 8. The time jitter for both generators was almost the same within 10 dB input power range.

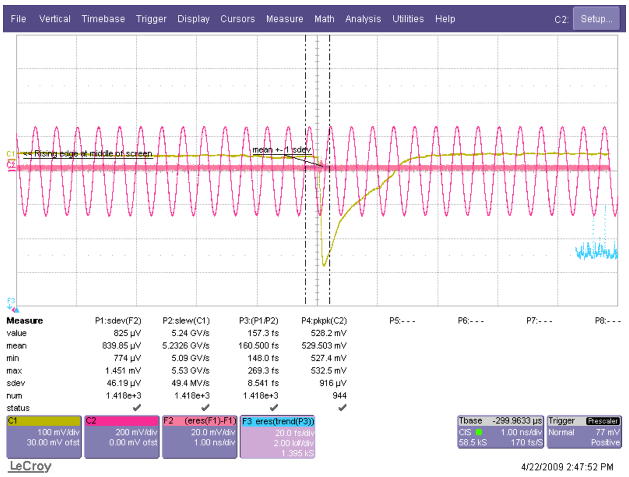

Figure 7: Time jitter measurement of the amplitude-stabilized rf generator with a sampling oscilloscope. The jitter is shown as “mean” of P3 (P1/P2).

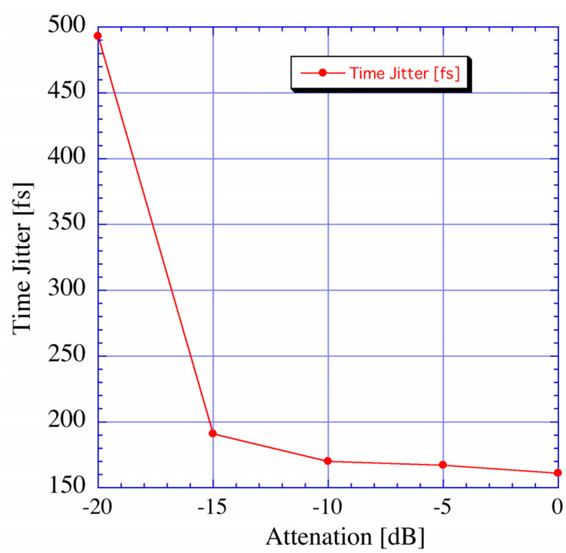

Figure 8: Time jitter measurement as the input power of the laser pulse was changed by using attenuators at the input connector of the rf generator.

Summary and Conclusion

We developed an amplitude-stabilized rf generator synchronized to the laser pulse and succeeded enough

We are going to improve the remaining phase noise enhancement in the frequency region less than 10 kHz. The beam experiment with the amplitude-stabilized rf generator is planed to examine the stability and the synchronization jitter of the beam.

We would like to thank to Mr. Eiji Nonoshita, Mr. Toyoyuki Ishikawa, Mr. Shun Akiyama of Candox Systems, Inc. for their circuit designing and producing the rf generator.

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