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# Relative and Absolute Timing Jitter in Actively Mode-Locked Semiconductor Lasers

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This paper discusses the magnitude and origin of the pulse-to-pulse timing jitter that is added to that of the modulating source by actively mode-locked lasers.

Short pulse generation from mode-locked semiconductor lasers is an important research area for applications such as electro-optic sampling, optical analog to digital conversion, optical communication systems, and sources for physics measurements. Optical pulses as short as 0.58 ps with 30 mW peak powers have been produced using active mode-locking [1]. Relative timing jitter measurements show the jitter contribution from the laser alone, which is the relevant parameter for multiple laser experiments such as time division multiplexing. Absolute timing jitter measurements are dominated by the noise from the driving source. Measurement of the timing jitter relative to the driving source have not been made previously and show the contributions from spontaneous emission in the laser.

The actively mode-locked laser of Figure 1 consists of a high speed 1.3 μm semi-insulating planar buried heterostructure laser that is antireflection coated on one facet and high-reflection coated on the other. The laser is coupled into an external 200 ps round trip time linear cavity with a graded index lens. The external cavity laser has a threshold current of 14 mA, average power of 260 μW, and differential quantum efficiency of 10%. The laser was biased at 17.1 mA and the cavity length adjusted for a minimum pulsewidth of 15 ps. An optical isolator was included to reduce external reflections and their effect on noise measurements.

Figure 2 shows the experimental configuration used to measure absolute timing jitter. The laser is modulated by a 24 dBm, 5 GHz signal from a low phase noise HP8340B microwave synthesizer and power amplifier. The absolute timing jitter is measured in the frequency domain with a high-speed photodetector, preamplifier and microwave spectrum analyzer. Figure 3 shows the carrier to noise level at offset frequencies from the first 3 harmonics of the 5 GHz mode-locking frequency. The absolute rms timing jitter was calculated [1] from Figure 3 as 200 fs over the 150 Hz to 50 MHz offset frequency range. The mode-locked laser makes significant contributions to the total jitter beyond 100 kHz offsets from the carrier.

Relative timing jitter was measured using the heterodyne technique shown in Figure 4. A portion of the driving source signal is mixed with the detected output of the mode-locked laser to produce the offset noise spectrum centered at 0 Hz. The phase of the LO signal to the double balanced mixer is adjusted for a 20 dB cancellation of either the AM or PM component of the laser noise. Figure 5 shows the results of the heterodyne experiment. The relative timing jitter was measured from this data as 80 fs. The data shows a clear 1/f noise contribution from the laser with a corner frequency of 5 kHz. There is also a baseline phase noise contribution which is explained by amplitude to phase noise conversion in the laser as a result of carrier density fluctuations causing delay fluctuations through the laser.

This work shows that multiple mode-locked semiconductor lasers driven from the same modulation source will have extremely small relative timing jitter between the sets of pulse streams. It also shows some of the limiting mechanisms for timing jitter when lower phase noise sources are used to drive the mode-locking. The timing jitter has also been measured for other laser biases, modulation frequencies, and cavity configurations showing that the jitter contribution from the laser can be significantly increased for large DC biases and cavity length detunings.

[1] Bowers, J. E. et. al.,IEEE J. Quatum Electron., **25**, pp. 1426-1439, (1989)

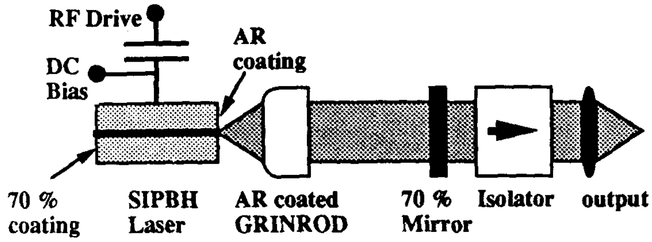


Figure 1. The actively mode-locked laser configuration used for the timing jitter experiments. The fundamental cavity resonance frequency is 5 GHz.

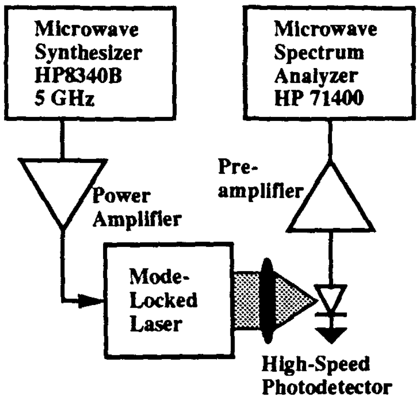


Figure 2. Experimental configuration for measuring absolute timing jitter in the frequency domain.

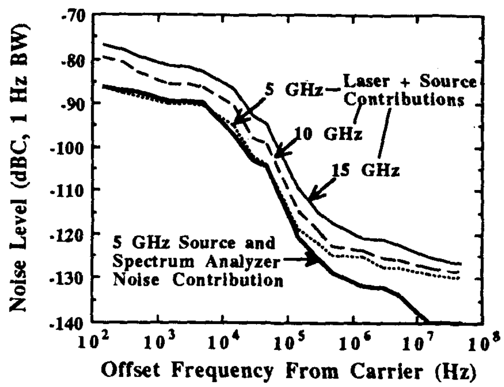


Figure 3. Carrier to noise level normalized to a 1 Hz bandwidth for the first three harmonics of 5 GHz as measured by the system of Figure 2.

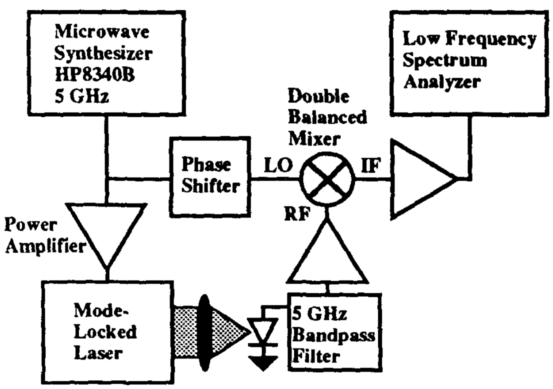


Figure 4. Heterodyne technique for measuring relative timing jitter in the frequency domain. The AM or PM noise can be cancelled by adjusting the phase shifter.

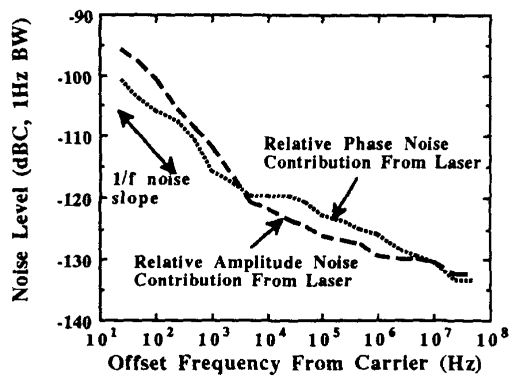


Figure 5. Additional noise added to the driving source by the mode-locked laser relative to carrier level normalized to 1 Hz bandwidth as measured by the system of Figure 4.