A novel way for wavelength locking with acousto-optic frequency modulation

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Abstract: A novel wavelength locking scheme called acousto-optic frequency modulation (AOFM) is put forward and demonstrated experimentally. The laser frequency is modulated by an acousto-optic modulator, rather than direct dithering on the laser resonator. A new optical configuration is proposed to compensate the angular deflection of the acousto-optic modulator, which is driven by a Direct Digital Synthesis generator with a frequency stability and precision on the order of Hz. This locking scheme is relatively simple and economical, and it can avoid extra frequency and intensity noise due to the direct frequency dither on the laser resonator in the conventional saturation absorption locking scheme. Our scheme provides a new way to improve the noise and stability of the tunable laser.

OCIS codes: (140.2020) Diode lasers; (140.3425) Laser stabilization; (020.2930) Hyperfine structure.

References and links

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14. Analogy Devices, Datasheet of AD9951.

1. Introduction

Due to the variation of the environmental temperature and vibration, the frequency of a free running tunable diode laser will jump or drift by up to a few GHz. That is far too much for many fields of research and application [1]. It is thus indispensable to stabilize the laser

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frequency and narrow the laser linewidth. Up to now, various techniques for frequency control have been developed. Among which the most widely used method is to apply an atomic sample for saturated absorption spectroscopy as a reference to stabilize the laser frequency. In order to get a high-sensitivity absorption or dispersion spectroscopy, one must modulate and demodulate the laser, such as the dither locking [1–3], the frequency-modulation (FM) spectroscopy [4,5] or the modulation-transfer spectroscopy (MTS) [6–9].

The dither locking is commonly used in the frequency stabilization of diode laser. The experiment configuration is quite simple [1]. However, direct laser modulation in the dither locking scheme will cause extra frequency and intensity noise. The FM spectroscopy provides a high-sensitivity absorption spectroscopy without direct laser modulation [4,5], but the electro-optic phase modulator (EOM) and other radio frequency (RF) devices are involved. Thus the experimental setup is complex and expensive, especially the electronics. In the MTS method [9], a more economical acousto-optic modulator (AOM) is used in stead of an EOM without direct modulation on the laser resonator. However, the FM driver of the AOM is a free running voltage-controlled oscillator (VCO) with the dc offset control voltage. The relative frequency stability and precision of a free running VCO is on the order of 10^{-2}. As a result, the absolute frequency stability and precision of the laser is on the order of MHz.

In order to overcome the drawbacks of the existing frequency control methods, we put forward a new wavelength locking scheme called the acousto-optic frequency modulation (AOFM) in this paper. To avoid the noise from direct modulation on the laser resonator, we use an AOM in the side loop, modulating a separate beam split from the output beam. In order to control the frequency more accurately, the direct digital synthesis (DDS) technique is applied to drive the AOM [10]. The improvement of the noise and stability of the tunable laser is demonstrated and compared with the conventional dither locking experimentally. The frequency noise of the AOFM is three times better than that of the dither locking.

2. Experimental Setup

The experimental setup is shown in Fig. 1. The laser 1 is an external cavity diode laser (Sacher, Lynx). A Faraday isolator is placed in the output beam of the laser 1 in order to avoid optical feedback. A small percentage (B1) of the output beam (about 1 mW) is split by a $\lambda/2$ plate and a polarizing beam splitter (PBS 1) for the frequency modulation by an AOM, instead of the dither on the laser resonator. The minus-first order diffracted beam (B2) is vertically polarized and reflected by the PBS 2 to the right, serving as the pump beam (0.4 mW) of Rb atoms. The retro-reflected beam (B3) serving as the probe beam (50 μW) is horizontally polarized due to the $\lambda/4$ plate. The B3 is separated from the B2 spatially by the PBS 2, and picked up by the photodiode. Both the AOM and the photodiode are in the foci of the lens, in order to compensate the angular deflection caused by the acousto-optic modulation, as shown in Fig. 2. The Rb cell is magnet-shielded.

The AOM is driven by a DDS acousto-optic driver, which is synchronized with the reference signal (TTL square wave) of the lock-in amplifier. The DDS output frequency is 121 MHz when the TTL level is high and 120 MHz when the TTL level is low. This mode of modulation is called frequency-shift keying (FSK) in electronics. The operation scheme is depicted in Fig. 3, and the actual frequency spectrum recorded with a spectrum analyzer (ADVANTEST R3267) is shown in Fig. 4.

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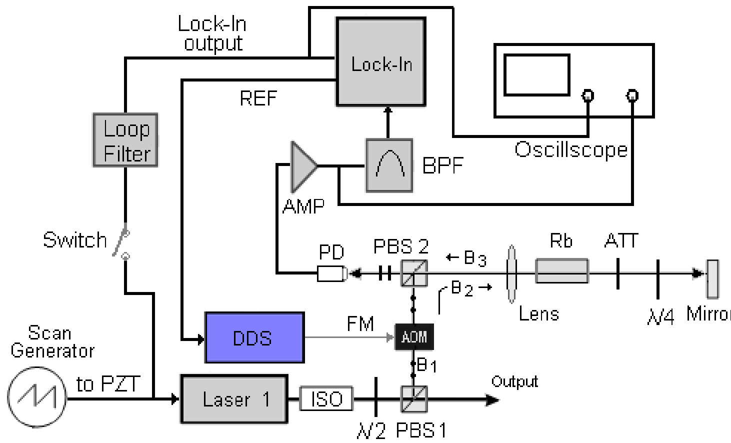

Fig. 1. The experimental setup. ISO, isolator; ATT, attenuator; DDS, DDS acousto-optic driver; PD, photodiode; AMP, amplifier; BPF, band-pass filter; REF, reference signal.

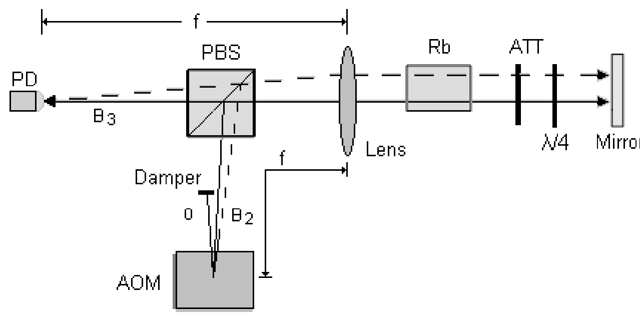

Fig. 2. The optical layout to compensate the angular deflection due to the frequency modulation. 0 represents the zero order diffraction beam. B_2 represents the minus-first order diffraction beam. Solid line represents the minus-first order diffraction beam at one frequency, and the dash line at another frequency.

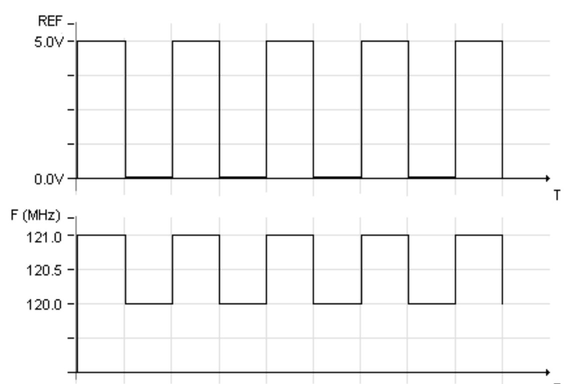

Fig. 3. The scheme of the reference signal (REF) and the output frequency (F) of the DDS.

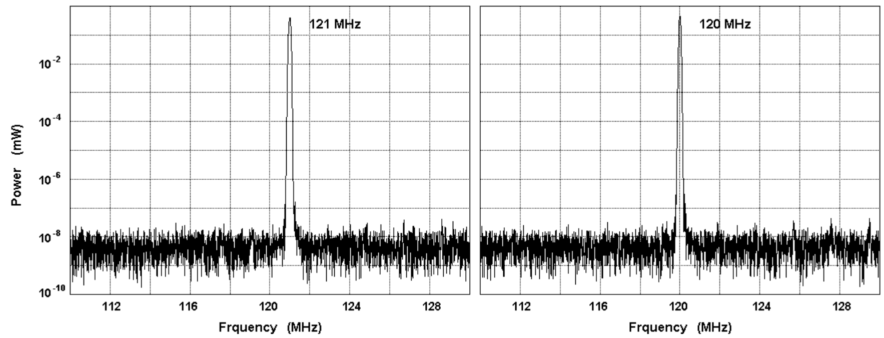

Fig. 4. These are the output spectra of the DDS driver. In the left figure the input TTL level is high and the output frequency is 121 MHz. In the right figure the input is low and the output frequency is 120 MHz.

The B_1 has a frequency of $f(0)$ and the DDS output frequency is $f(t)$, then the B_2 has a frequency of $f(0) - f(t)$. Thus the B_2 is frequency modulated and synchronized with the reference signal of the lock-in amplifier. The error signal is obtained via the lock-in amplifier in the same way as earlier experiments [2,6,9]. In our experiment, the central frequency of $f(t)$ is 120.5 MHz, the FM amplitude is 500 KHz and the FM frequency (the frequency of the TTL square wave) is 10 KHz. All the parameters above are programmable.

3. DDS AO driver

The DDS acousto-optic driver [10] is the core of the experiment, thus we introduce it briefly in this section. The DDS technique provides a whole new way of signal generation, modulation and control by generating a time-varying signal in digital form and performing a digital-to-analog conversion (DAC) [13,14]. Because the DDS is a digital device which can offer many advantages, such as fast tuning, fine frequency resolution, and operation over a broad spectrum of frequencies [11]. A DDS device can provide an output frequency stability and precision on the same order of the reference oscillator for the DDS [12]. Since a temperature compensated crystal oscillator (TCXO) is used as the reference oscillator, the DDS acousto-optic driver has a relative frequency stability and precision on the order of 10^{-7}. Our experiment benefits largely from this feature, the laser frequency in this experiment is therefore stable and precise.

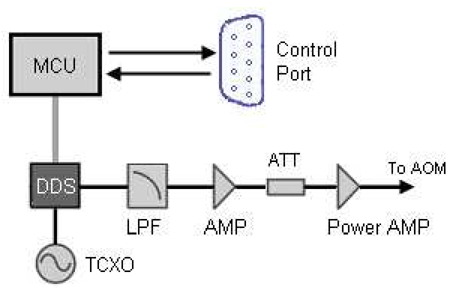

Fig. 5. The scheme of the DDS driver for the AOM. MCU, micro control unit; AMP, amplifier; ATT, attenuator; LPF, Low Pass Filter, with a cut-off frequency of 160 MHz.

A custom DDS driver for the AOM was designed and built for this application. The scheme is depicted in Fig. 5. We use the DDS IC AD9951 for the AOM driver. It is a digital programmable, complete high frequency synthesizer capable of generating a frequency-agile analog output sinusoidal waveform at up to 160 MHz [14]. Since the amplitude of DAC output is small, we amplified the signal with a Monolithic Microwave Integrated Circuit

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(MMIC) amplifier SGA-6489. In order to drive the AOM, we used a power amplifier CA2830. It amplifies the sine wave to 1 watt, which is the optimal drive power of the AOM. We chose the STC89C54 as the micro control unit of the driver. The clock of the micro control unit is 33 MHz; as a result, a FM frequency of 10 KHz is obtained.

4. Experimental Result

We tune the wavelength by scanning the voltage on the piezoelectric transducer (PZT) of the laser 1 to get the saturated absorption spectra of the hyperfine structure of ^{87}Rb $5s_{1/2}$- $5p_{3/2}$ as shown in Fig. 6(a) (lower curve). The lock-in output is shown in the same figure (upper curve). The frequency span of the spectra is about 650 MHz. The linewidth of the peak (indicated in Fig. 6(a) by an arrow) we propose to lock is 6 MHz. The saturated absorption signal after locking is shown in Fig. 6(b), from which we can see that the wavelength is stabilized.

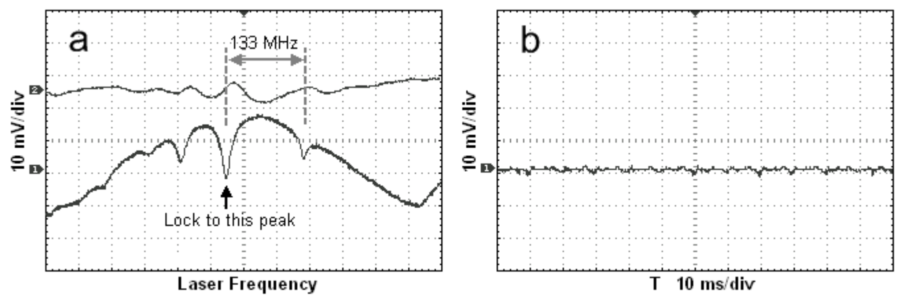

Fig. 6. (a) the saturated absorption spectra (lower curve) and the lock-in output (upper curve). (b) The saturated absorption signal after locking.

In order to evaluate the laser frequency noise and the linewidth, another tunable diode laser (Toptica, DL pro, noted as laser 2 in the following) is used as the reference laser. The laser 2 is dither locked to the same peak as the laser 1 locked to, therefore, there should be a frequency difference of 120.5 MHz between the laser 1 and the laser 2 caused by the AOM. The beat note between the laser 1 and the laser 2 is detected by a fast PIN photodiode and recorded by a spectrum analyzer, as shown in Fig. 7(a). The central frequency of the beat note is 120.5 MHz, and the average FWHM bandwidth of the beat note in 5 second is 1.61 MHz, those are measured with the spectrum analyzer.

For comparison, we do the same experiment, but the laser 1 is dither locked. The dither locking is done by apply a modulating voltage on the PZT and the modulation amplitude is 5 mVp-p. The experimental configuration is shown in Fig. 8. This is a normal setup of the dither locking. The laser 1 and the laser 2 are locked to the same peak as in the AOFM locking. The electronics except the DDS driver are the same as in the AOFM, too. An AOM working at a fixed frequency of 120.5 MHz is used to tune the frequency of the laser 1. So that the frequency of the first order diffracted beam should be 120.5 MHz higher than the frequency of the laser 2 output. The beat note between them is shown in Fig. 7(b). The average bandwidth of the beat note in 5 second is 4.85 MHz.

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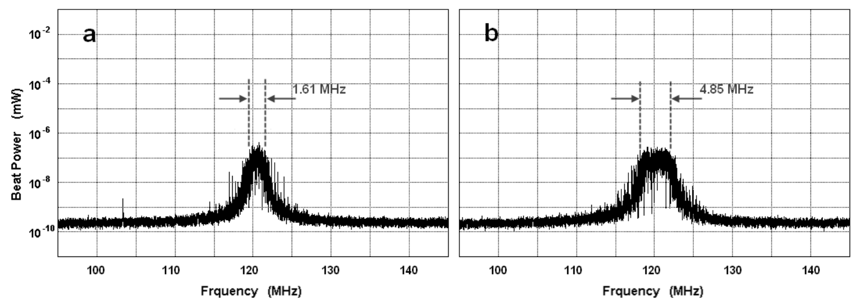

Fig. 7. The beat note between the laser 1 and the laser 2. The laser 1 is AOFM locked in the figure (a) and dither locked in the figure (b).

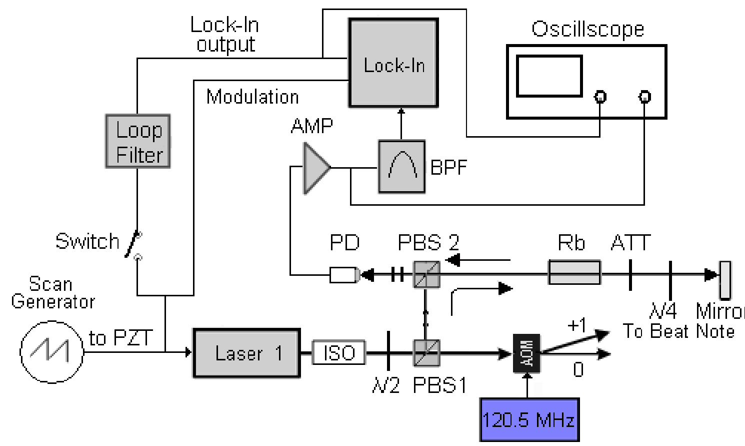

Fig. 8. The configuration of the comparison experiment.

It is obvious that the bandwidth of the beat note shown in Fig. 7(a) is much narrower than that in Fig. 7(b). It indicates that the frequency noise and the linewidth of the laser 1 using the AOFM locking are three times better than that using the dither locking.

5. Conclusion

In conclusion, we have put forward a novel way called AOFM for wavelength locking, which can be applied to lock a tunable laser to the sub-Doppler spectra of a atomic vapour cell with lower frequency noise and higher frequency stability and precision. We demonstrated experimentally to lock an external cavity diode laser to the hyperfine structure of ^{87}Rb D2 line. The laser frequency is modulated by an AOM driven by a frequency-shift keying DDS acousto-optic driver. The AOFM locking is relatively simple and economical, and it can avoid extra frequency and intensity noise due to the direct frequency dither on the laser resonator in the conventional saturation absorption locking technique. Our scheme provides a new way to reduce the frequency noise and increase the stability of the tunable laser, which is applicable in many experiments, such as in cold atom physics.

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