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Application of DDS in laser modulation

Zhang Zhang, Lu Jinhong, Xu Yunfei, Wang Zhaoying, Lin Qiang
Institute of optics, Department of Physics, Zhejiang University, Hangzhou, 310027, China

ABSTRACT

Acousto-optic modulator (AOM) and electro-optic modulator (EOM) drived by voltage controlled oscillator (VCO) are widely used to control and modulate laser, especially semiconductor lasers. We designed a frequency generator based on direct digital synthesizer (DDS) technology which can be used to replace VCO. The frequency generator with high frequency stability can reach 160 MHz bandwidth and frequency resolution up to 1 Hz. The output frequency is programmable and controlled by input TTL edge. These advantages are not available with VCO. We obtain a output radio frequency (RF) power as high as 1W with a power amplifier in order to drive an AOM. This device has been used to scan the wavelength of external cavity laser diode (ECLD) in our laser cooling experiments.
Keywords: Laser Diode, Direct Digital Synthesizer, Frequency Generator

1. INTRODUCTION

In the field of scientific research, optical communication and laser applications in industry, we usually modulate the laser frequency with AOM or EOM which is drivered by RF oscillator. The AOM or EOM devices with sophisticated design are compact, durable and efficient.

Usually, the RF oscillator works on the HF, VHF and UHF bands, from several mega hertz to several hundreds of mega hertz. There are several methords to produce analog waveforms on these bands. For example, directly frequency synthesis or phase locked loop (PLL) frequency synthesis. Traditionally, the AOM or EOM driver is on the base of vlotage controlled oscillator (VCO). If a low phase noise and high frequency stability are required, PLL would be involved in. The frequency of the RF oscillator can not be controlled conveniently in digital control system, since the analog control voltage with high resolution and stability is involved in. However, time drift and thermal drift of analog devices should be taken into account.

In this paper, we introduce Direct Digital Synthesis (DDS) as a method of producing an analog waveform as the RF oscillator of laser modulator and demonstrate an application in optical molasses experiment.

DDS technology has given us a whole new way of signal generation, modulation and control by generating a time-varying signal in digital form and then performing a digital-to-analog conversion (DAC). Because operations within a DDS device are primarily digital, it can offer any advantages you can get from digital devices: fast switching between output frequencies, fine frequency resolution, and operation over a broad spectrum of frequencies. With advances in design and process technology, modern DDS devices are very compact and draw little power.[1]

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The ability to accurately generate and control various frequencies has become the key requirement of modulation. Whether providing agile sources of low-phase-noise variable-frequencies with good spurious performance, or simply generating a frequency, convenience, compactness, and low cost are important design considerations. Therefore, DDS technology is rapidly gaining acceptance in scientific, communications and industrial applications.

2. THEORY

The main components of DDS are a phase accumulator, a phase-to-amplitude conversion, and a DAC. These blocks are represented in Figure 1.

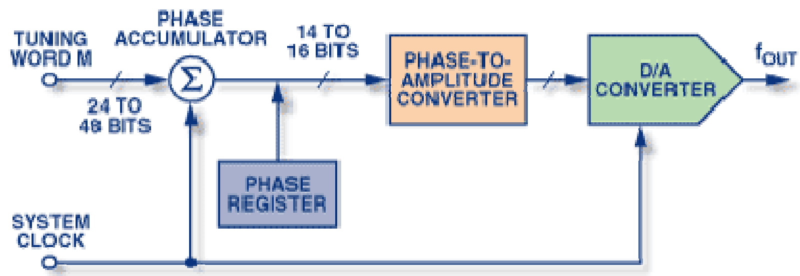

Fig. 1. The schemeof DDS (cited from reference [1])

The phase accumulator is driven by the specified frequency, which accumulates the phase increments. The phase is increasing in each driving frequency clock tick (fc). When the phase accumulator overflows, the waveform gose to the next cycle. Therefore, the ratio of the size of the phase accumulator to the phase increment determines the actual output frequency, as shown in Figure 2.

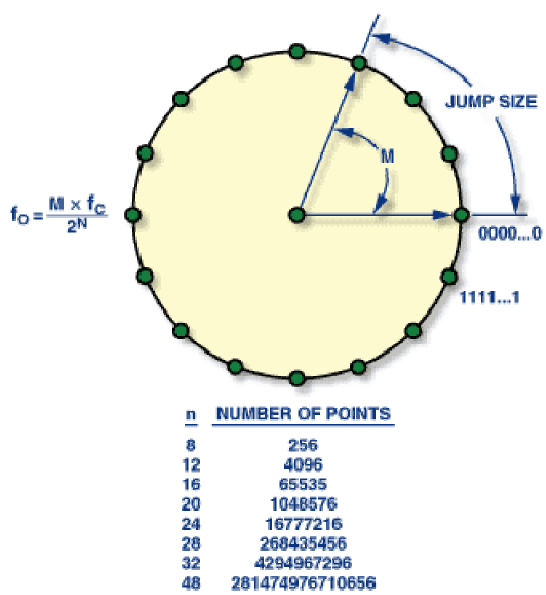

Fig. 2. The scheme of DDS (cited from reference [1])

To generate a fixed-frequency wave, a constant phase increment is added to the phase accumulator in each clock cycle. If the phase increment is large, the phase accumulator will step quickly thus generate a high frequency wave. If the phase increment is small, the phase accumulator will take many more steps, accordingly generating a slower waveform. Thus the size of the phase accumulator determines the smallest frequency achievable by the DDS. This frequency is also equal to the smallest frequency step achievable by the DDS. For example, a DDS IC, AD9951 which has a 32-bit width phase accumulator, and a 400MHz clock frequency, can achieve a frequency step of 0.09Hz.

Phase-to-amplitude conversion is usually achieved through a table of phase to amplitude. The phase accumulator computes a phase (angle) address for the table, which outputs the digital value of amplitude corresponding to the phase angle to the DAC. The table of phase to amplitude is pogrammable, so that arbitrary waveform with arbitrary amplitude can be generated by DDS. Usually, the table is a sine look-up table, and the phase-to-amplitude conversion outputs digital sine wave.

The DAC, converts the digital value of amplitude to a analog voltage. A annalog waveform is generated herein. There is always a low pass filter (LPF) following the DAC to filter the digital noise. Usually, the output of DAC is so small, that a amplifier is required.

3. EXPEIMENT

The theories and experiments of laser cooling is a popular topic in modern physics[2]. In this field, one should always modulate the wavelength of the laser, in order to compensate some atomic, molecular or optical effect, e.g. Dopple effect. When the atom is cooled by a resonant laser, it will move slower and slower. Because of Doppler effect, the laser is no longer resonant, so that the atom will not be cooled any more. In order to compensate this effect, we shall make the laser red shift with an AOM.

The traditional AOM driver based on VCO is not a convenient solution in this case. Since the frequency of the driver output is determined by the analog control voltage. It costs too much to achieve a analog voltage with high resolution and stablility, especially in a digital control system - usually a PC with digital IO card. Moreover, calibrating the coefficient of voltage to frequency is not a pleasure.

We are trying to setup an optical molasses apparatus, including some AOMs driverd by DDS drivers. An external Cavity Laser Diode (ECLD) is used as the cooling laser, locked at one of the hyperfine transition of the D_2 line of Rb^{87}. The AOM is working at 80MHz to modulate the laser slightly red detuning, in order to trap more atoms. This is the Magneto-optic Trap (MOT) step, lasting 500 ms and the atoms in the MOT will be cooled down to 100 uK. Then, the magnetic field is shut down, and the AOM driving frequency ramps down to 60 MHz. This step must be done in several micro seconds, so that the atoms will be further cooled to 1 uK. All the operations shall be controlled by a computer via TTL signals.

In this section, we will demonstrate the DDS driver for AOM designed by ourself. The components of the driver are

Micro Control Unit (MCU), DDS IC, amplifier, attenuator and power amplifier. The scheme is represented in Figure. 3.

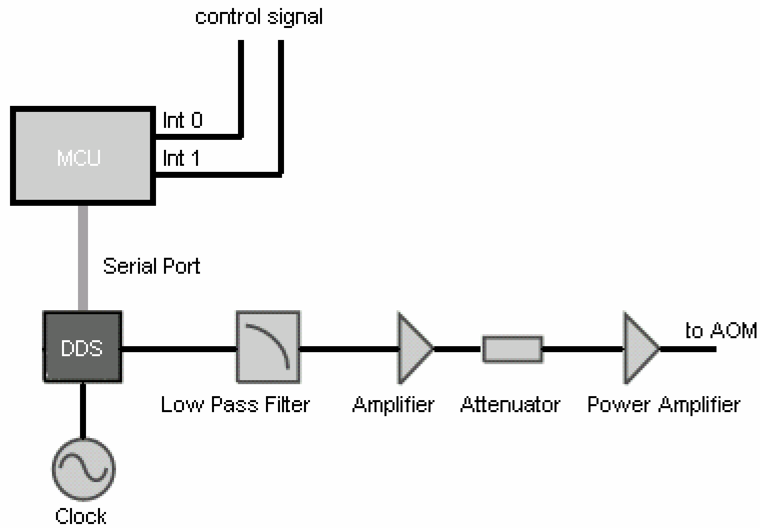

Fig. 3. The scheme of AOM driver.

We chose the DDS IC AD9951 produced by Analogy Devices as the core of the driver. The AD9951 uses 1.8 V CMOS process, coupled with a 14-bit internal high performance DAC operating up to 400 MSPS. It is a digital programmable, complete high frequency synthesizer capable of generating a frequency-agile analog output sinusoidal waveform at up to 160 MHz. The AD9951 with 32-bit frequency tuning word is designed to provide fast frequency hopping and fine tuning resolution. The frequency tuning and control words are loaded into the AD9951 via a serial I/O port.[4]

Since the amplitidue of DAC output is quite small, we amplified the signal with a amplifier MSA-0886, which is produced by Aglient. The MSA-0886 is a silican bipolar Monolithic Microwave Integrated Cicuit (MMIC), which can be used as a high gain block up to 1 GHz. It has a gain of 32 dB typically at 100 MHz. In order to drive the AOM, we used a power amplifier CA2832 produced by Motorola Semiconductor. It amplifies the sine wave to 1 watt, which is the optimal driver power of the AOM.

We chose the MCU AT89S52 as the microcontroller of the driver. The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8k bytes of in-system programmable Flash memory. The device manufactured by Atmel is compatible with the industry-standard 80C51 instruction set and pinout. The AT89S52 provides the following standard features: 8k bytes of Flash, 256 bytes of RAM, 32 I/O lines, Watchdog timer, two data pointers, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full duplex serial port, on-chip oscillator, and clock circuitry. The Atmel AT89S52 is a powerful microcontroller which provides a highly-flexible and cost-effective solution to many embedded control applications.[5]

The initial frequency is set to 80 MHz, and the frequency shift of the driver is controlled by TTL signals via interrupt architecture. When the first interrupt of AT89S52 (INT 0) is triggered, the frequency will ramp down to 60 MHz by 30 steps. So that every step is smaller than 1 MHz, howerve, the laser bandwidth is wider than 1 MHz, the atoms will feel that the wavelength of the cooling laser is extending continously. When the second interrupt (INT 1) is triggered, the frequency will recover to 80 MHz. All these paraments can be re-programmed if necessary. The process is demonstrated in Figue. 4.

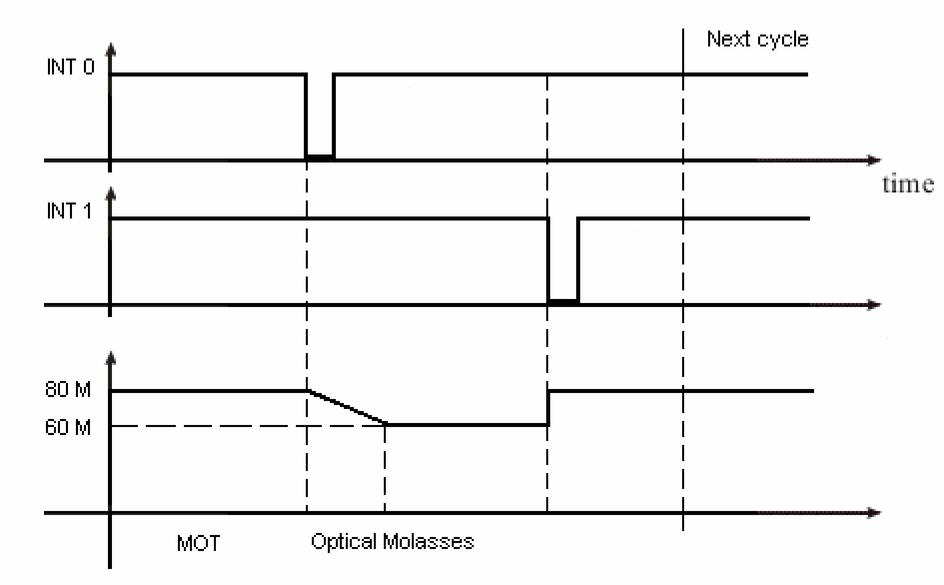

Fig. 4. The process of MOT and opticsl molasses controlled via TTL signals

The driver is housed is a aluminum box in order to shield against EMI. We analyse the output with the oscilloscope TDS1012 produced by Tektronics and the spectrum analyser AT-5005 produced by ATTEN.The result is demonstrated in Figures. 5.

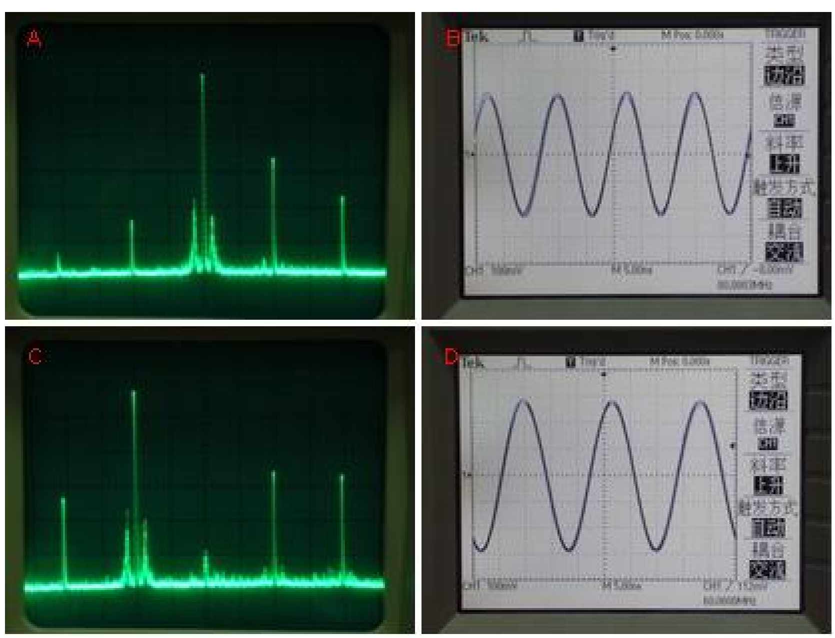

Fig. 5. The output of the driver. (a) output signal measured by spectrum analyser at 80 MHz, the second highest peak presents the 100 MHz clock frequency; (b) output measured by oscilloscope to demonstrate the distortion of the sine; (c) the same as (a), but at 60 MHz; (d) the same as (b), but at 60 MHz.

4. CONCLUSION

We have designed a frequency generator with high agility based on DDS technology which can be used to replace VCO. The frequency generator with high frequency stability can reach 160 MHz bandwidth and frequency resolution up to 1 Hz. The output frequency is programmable and controlled by TTL edge. These advantages are not available with VCO. The Harmonic rejection ratio is higher than 25dB. We obtain a output RF power as high as 30 dBm with a power amplifier in order to drive an AOM.

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