Master of Science in
Devices and Technologies for Integrated Electronics and Optoelectronics

Department of
Electronic Engineering, Telecommunications and Physics

Master Thesis Report on

Saturated Absorption of Laser locking Spectroscopy and Ionization On Cesium Atom

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Abstract:

The aim of thesis is to stabilize the laser frequency by using the saturation absorption spectroscopy method on Cesium cell. The saturation spectroscopy is a high - resolution spectrum, and it also called the Doppler free spectrum technique. These stimulated emissions of photon energy absorb by a laser beam and improve its resolution. The Spectrum should measure the one wavelength of time. The Final stabilized photon beam is observed at the photodiode.

The Cesium atom is basically from the alkali metallic group atom. Alkali atoms have one free electron at the valency band. In our case cesium atom is defined in hyperfine structure have $6S_{1/2}$ and $6P_{1/2}$. The atomic number is 55(Cs) and the atomic mass is 133. In an experiment creating a feedback loop for lock the laser frequency with help of cesium vapor cell, and place at allowing the tunable laser beam through it. Final spectrum release the laser beam is stationary wave.

Using stimulated emission of the laser beam is 852nm wavelength from the Fabry-Perot interferometer laser diode. The Arduino due board is used for supplying the electric current to a laser diode. The Arduino board acts as a signal generator and as a data acquisition board.

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I would also like to acknowledge INRIM MEMBERS for helping me in the Institute. Thank you for being there and helping me in and out.

Content:

1 Introduction:

The laser is nowadays using in many industries and many applications. Mostly they need fixed or stabled frequency and wavelength of the laser. From the laser spectroscopy, we get the high resolution of laser beam but it experimentally is known that it is a short time stable of laser beam frequency. Here some external factors like temperature and pressure affect the laser beam. That's why for the long-time stabilization of laser in terms of frequency developed technique is saturation absorption spectroscopy. It is reduce the noise of the detected laser beam.

The saturation absorption spectroscopy is a Doppler-free technique. Because, if consider any one medium, the movement of an atom with velocity (V0) and the laser beam is passing in the same medium with velocity (V). In this case, both are in the same direction so collaborating both frequencies and form a frequency is upshift of high velocity (VH). Either another condition, laser and Atom are moving in the opposite direction so both velocities and resolutions are moving far each other. Then form the frequency is downshift of low velocity is (VL). This procedure is called the Doppler Effect. Here we do not obtain constant velocity of laser Beam. So developed the saturation absorption spectroscopy for avoiding the Doppler effects in terms of resolution and velocity. Using simple reference figure1.1, for understand Doppler effect.

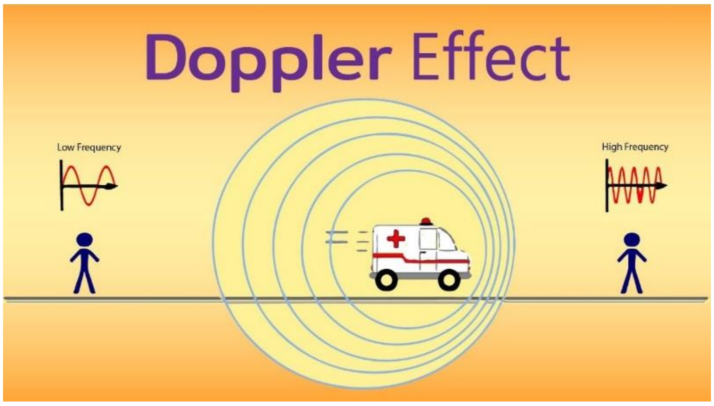

Figure 1.1: Doppler effect. Ref [16].

In Doppler-free saturation spectroscopy method setup by constant atomic vapor cell placed in two mirrors of feedback loop. The Laser beam is directly penetrated or reflected from the Beam splitter mirror and pass through the atom. An atom of electrons and neutrons excited from the lower energy level to higher energy level state. The excited electrons have specific excited lifetime T. (approx. exited lifetime is 28nsec). After that, it goes back to the original state i.e. lower state. That electrons emit energy in terms of photon and comes to a lower level state. These stimulated emissions of photon energy absorb by a laser beam and improve its resolution. The Final stabilized photon beam is observed at the photodiode.

The alkali atoms are more convenient for laser frequency stabilization. Because in alkali atoms have outer valency band one electron is free. In our experiment use Cesium (Cs). The atomic number is 55. In experiment setup using vapor cell of cesium with a small size of 100nm, interface with a laser beam. For stabilizing the laser by using Cesium in particular Cs atomic spectral line is D2 line. The coming laser beam is split into the fine and hyperfine structure of Cesium.

It requires a monochromatic and tunable laser beam for exciting atoms from a lower energy level state. The laser beam emits from Fabry-Perot interferometer laser diode, it described in laser spectroscopy.

The thesis explains into two categories, first is saturation absorption Cesium atom spectroscopy. Ionization is the process is atom or molecules get negative or positive charge. These means gaining (-ve) and loosing (+ve) the electron. Second is Arduino due microcontroller board. Arduino used for supplying the electric current to a laser diode. The Arduino board acts as a signal generator and as a data acquisition board.

The Arduino due as a function generator because the board generates the sine wave with an exact frequency of 10hz and 2Vpeak to peak by the help of sketch code in computer and potentiometer is connected to board. We observe the sine wave in the oscilloscope. Also programmed by analog sine wave converts into digital signal so we say Arduino as data acquisition board.

2 Laser:

The laser described in **light amplification by stimulated emission of radiation**.

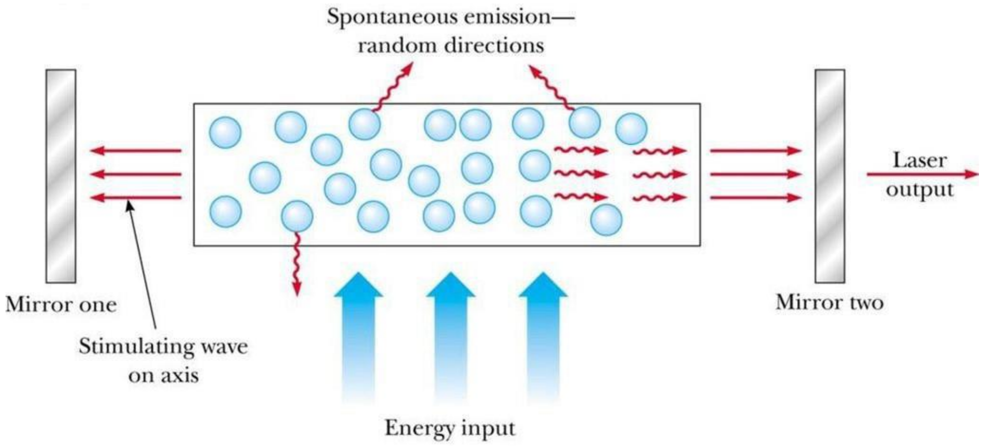

Figure 2.1: Production of laser Beam.
(from Thomson, 2003). Ref [15].

Producing the laser beam follows the three principles. Those are stimulated emission, stimulated absorption and spontaneous emission. Usually an atom, the energy levels are split into two-level states. It categories ground level state (E0) and excited level state (E1). It explained by plank's law

$$\Delta E = E1 - E0$$
$$\Delta E = hv0$$

The electric current is supplied to a laser diode. The electrons in ground - level absorb radiation of energy and jump to excited state this process is called stimulated absorption. These excited electrons are not reminding a long period of time. It has an exciting life - time is approx. 10 e-8 sec. After completion of an excited lifetime, it emits energy in terms of photons with frequency and returns to the original state i.e. ground state.

That releasing photons as consider incoherent light. This process is called stimulated emission. Already at high energy level electron are also loose energy in terms of photon and comes to lower energy state. This procedure is called spontaneous emission. Both emissions of photons are in a random direction.

The stimulated absorption and emission repeat continuously until the electric current source is off. So the same phase of all photons is collaborating with each other, then made one coherent beam of radiation. The only one direction of a photon of the same frequency and phase can match with other photons. But photons are the random direction in a medium. Using the two optical mirrors for photons to multiply their same number of photons and amplification of radiation. In that one mirror is completely reflecting and another is partially reflecting and partially transmitting mirror because it transmits the coherent laser beam is called an optical wave.

The two mirrors place near a1mm length of distance for forming an optical cavity. In an optical cavity, the photons randomly move and interface with the mirror get to reflect's back and finally tuned with same direction of the radiation beam. Here cavity length is (L) and refractive index is (n). a phase shift depends on the external electric supply and refractive index of a medium also the mirror bandgap. When those functions are change then phase shift also varies. Figure 2.1 is explained clearly.

The laser was first recognized by Albert Einstein. and then Gordon Gould. Proved on a ruby laser which is an optical laser. In the ruby laser are used xenon and helium and semiconductors. Described in the quantization of light.

lasers are monochromatic wavelength and single frequency. Produce any single color, those are Green, Red, blue, Yellow. Green is very famous nowadays. Laser flows 700 km in space without any loss, other normal electromagnetic lights do not flow 1km. The velocity of the laser is 300,000 km/s and sharp focus.

Fluorescence card is used for laser beam view also we can observe the infrared rays producing in a beam.

2.1 Laser safety precautions:

The infrared lasers are invisible to our human eyes. So it's very problematic and damages to human eyes. In laboratory room laser operate in a dark situation. This is the reason to wear safety goggles when the laser beam is on.

In a laboratory, when operating the laser beam required to close all the doors and windows because it cannot affect to outside peoples.

The laser diode is very delicate, if the supply electric source varies (high or low current supply) then the diode is damage so maintain constant power supply.

Also care of optical mirrors, when clean the lenses use tissue rub slowly. But don't scrub.

2.2 Laser applications:

The lasers have many applications in different sector's usage nowadays. Those are clearly in

Communication – laser help to transmit the information of long-distance in optical fiber. Send many signals because of narrow bandwidth.

Navigation - In national defense for guide the rockets and missiles also selected planes.

Surgery- Use for the eye surgery and tumor operation. The medical sector also preferring bloodless operation with a laser.

Measuring long distance: the beam is coherent so it no losses of long-distance.

Nuclear power – helps to power production

Industry – it does drill holes for metal and many usages in cutting purposes.

3 Saturation absorption spectroscopy:

The saturation absorption technique is the Doppler free technique. And its high-resolution spectrum with the measure by the natural linewidth of Cesium atom transition. This is usually to improve the tuneable of the laser frequency. Absorption lines correspond to atomic transitions and crossover resonances.

The theoretical block diagram is shown in 3.1 figure. The block diagram explains how the saturation absorption spectroscopy setup in a laboratory.

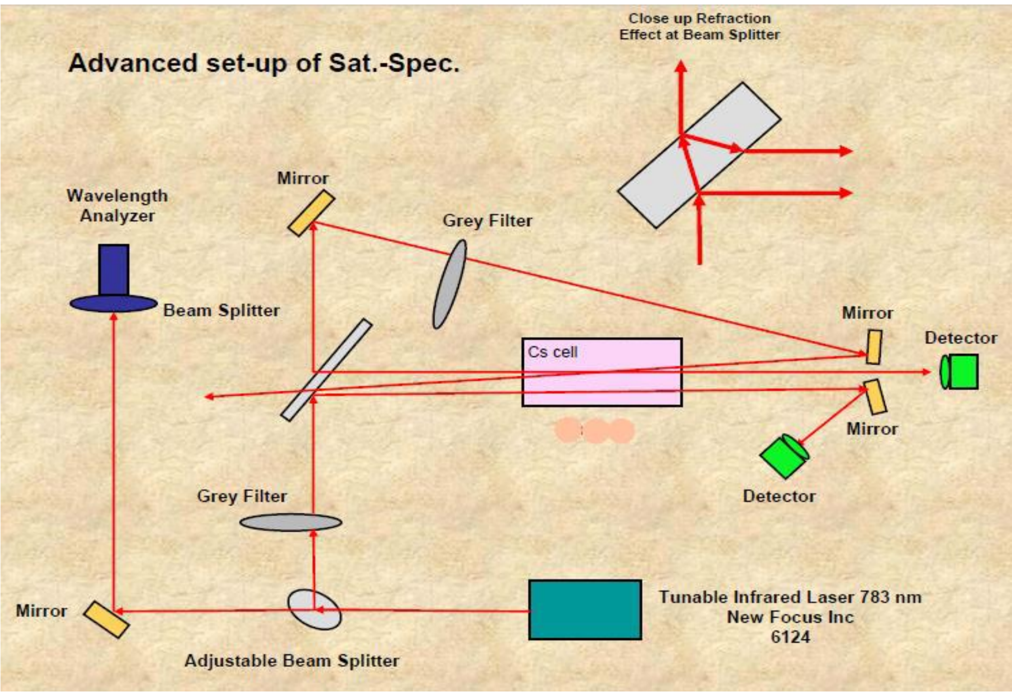

Figure 3.1: saturation absorption of Cesium atom spectroscopy.(from Theodor Haensch : pp 10). Ref [5].

To reduce the Doppler effects developed this saturated absorption technique. In this technique, three beams are playing the main role. They are probe beam, reference beam, and pump beam. These beams are generated by a laser. Laser produced by a laser diode. The stimulated laser beam coming from diode focussing on a mirror. This optical mirror partially reflects and partially transmits the incident beam so it acts as a beam splitter. The beam splitter mirror has the antireflection coating so it transmits a maximum of coming laser wave beam. But not completely some resonance of frequency beam can reflect.

Here transmitted high energy of the beam is pump beam and reflected waves are probe and reference beam. Deep look at beam splitter mirror in fig 3.1, it reflects in two low resonance laser beams. Here first reflected wave is a reference beam and second is probe beam of a laser. Clearly, the coming incident laser is touch to the first interface then it partially reflects beam is a reference and refract in mirror medium only with an angle, then at the end of same layer surface of a mirror is reflect again partially is probe beam. The mirror reflects partially because it has an anti-reflection coating.

In saturation absorption spectroscopy is used Fabry-Perot interferometer. It explained that two mirrors are used for a feedback loop. Here one mirror completely reflects and another one reflects and transmits a narrow beam for output. In the Fabry-Perot interferometer, the atom vapor cell is placed between two mirrors. Atoms are like Helium, Rubidium, Cesium and Sodium atoms of alkali group atoms are very useful to tune or stabilize the laser lock in terms of narrow beams. In our experimental study about the Cesium atom. So placed Cesium vapor cell in between two mirrors. Set up of two reflected waves are passed through the Cs cell. Also, optical mirrors are set up for the transmitted high intensity of the pump beam also pass through the same Cs vapor cell. We clearly observe in 3.1 figure. Finally, coming out laser beam is detect the photodiode. This above saturation absorption setup is to remove the Doppler broadening effects.

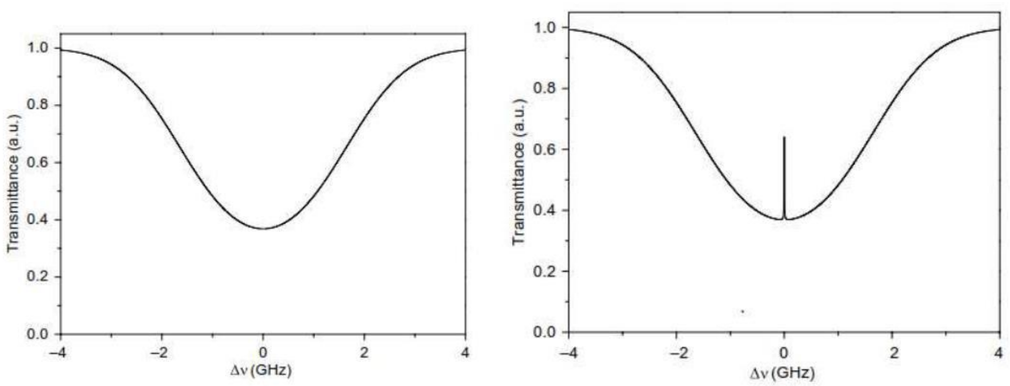

Figure 3.2: a) Doppler Broadening spectra at the absence of pump beam
b) Saturation absorption at the presence of pump beam collecting at the photodiode. Ref [13].

Suppose we consider the pump beam is absent (set-up optical mirror design is pump beam is not passing through the Cs vapor cell). In this situation, the photodiode is absorbing extremely strong Doppler broadening. But absorption spectra is a little blurred because of the Doppler effect. Clearly, when no have any resonance (pump) in an atom. The energy of photons in an atom is moving randomly so it's easily combine with the same direction of probe beam so in photodiode received simple line evaluate the strong Doppler broadening. Shown in fig3.2 (a), it happens of the horizontal velocity of Cs atom energy is parallel to the laser propagation direction.

The temperature and atomic density play an important role in the absorption spectrum. In-room temperature, the Doppler broadening is natural linewidth. Because of the Doppler effect, the probe beam is shifting to resonance. When using the lower density of Cs cell and of-course probe beam will combine and form shorter Gaussian shape either use high density and probe beams are combined and give the Gaussian shape is wider and deeper. Increase the atomic density is also proportional to absorption spectra is increase profile.

Another condition is the high intensity of the pump beam is present. (set-up design is optical mirror reflects the pump beam direction into Cs cell and interacts the probe beam). The pump and probe both beams are in the same Cs cell. This case pump beam present means on resonance, in on resonance Atoms are not moving horizontally. Atoms are move perpendicular because the high intensity of the energy pump beam helps to excite the electrons in the ground state to an excited state. The low-level atoms are gain the energy then transverse to higher energy level so atoms are lost their velocity movement.

Doppler shift is reducing by a combination of a pump (strong) and probe (weak) beams with different populations of an atom. Same time the probe beam is combining with low-level atoms but atoms are already in an excited state so no have a collaboration with a photon. We can observe at the photodetector, their sudden decrease of plot like a dip. This scenario is called hole burning.

The coming pump beam intersects to probe beam in the opposite direction. By opposite phases and frequency, they do not interact and not produce the resonance beam. The detector gives us a plot of a sharp dip line.

This explained by the lamb in huge potential of saturation spectroscopy so named as lamb dip. Shown in fig3.2 (b).

The natural linewidth of the atomic transition is much narrower then Doppler width. But faraday isolators are placed at laser output to avoid any errors in lasers. The absorption spectra depend on the intensity of a laser pump beam, atomic cell density and temperature. Suppose increasing the pump beam intensity with fixed Cs vapor density then get lamb dip is broader and high. Width of the lamb dip is finite. So the saturation absorption spectroscopy is basically adjustment parameters of pump beam intersect on the resonance of optical depth.

In each atom have a different velocity along the horizontal propagation direction. Obtain different results of velocity affects the optical depth for laser frequency and atomic velocity. The emitting photon with frequency does not produce with an external field. Comparing the two different plots in one figure (3.3) is absorbed photodiode detector at with and without of high-intensity pump beam and subtract from 1st to 2nd case. The result is a show at 3rd plot.

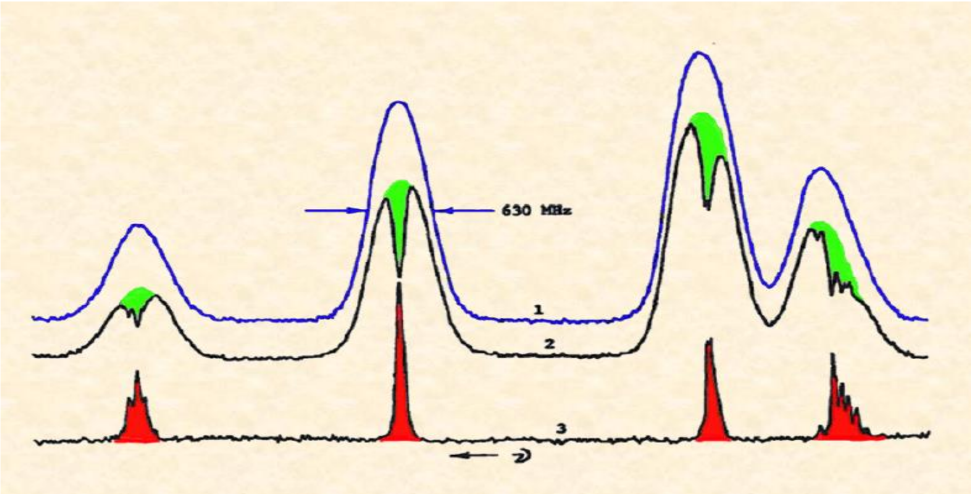

Figure 3.3: comparing plots of Doppler broadening (1) at the absence of a pump beam. And saturating absorption spectra at the presence of a pump beam (2). Finally, subtraction from beam 1 to 2 is plotting in (3) wave. Spectra lines are followed by the hyperfine structure of the Cesium atom cell.(from Theodor Haensch: pp 6). Ref [5].

3.1 Fabry – Perot interferometer:

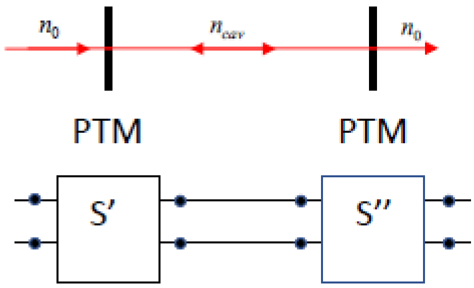

Figure 3.1.1: Interferometer of Fabry -Perot of two mirrors block diagram. (from Renato Orta, Nov. 2012 : pp-141). Ref [11].

The Fabry – Perot is an optical cavity. Our case using a laser optical cavity. The electromagnetic force store in the electric field ('c') and magnetic field('L') in the cavity. If the dielectric cavity follows the gain and refractive index, its lossy optical cavity so the refractive index is

Refractive index (n) = n' – jn'' of cavity

But in our case, we use a lossless dielectric medium. Consider the total internal reflection at the cavity ends. The two optics have a reflection coefficient is high. With the help of transmission line theory express the propagation constant in the cavity of incident wave with help angle is (theta). The two optical mirrors are made a cascade of the block box. So measure on scattering matrix of reflection and transmission coefficient in the optical interferometer.

$$k_z = k_0\sqrt{n_{cav}^2 - n_0^2 \sin^2 \vartheta^i} = \beta - j\alpha$$

$$S_{11} = \frac{S'_{11} - S''_{11} \det \boldsymbol{S}' e^{-j2k_z L_{cav}}}{1 - S''_{11} S'_{22} e^{-j2k_z L_{cav}}}$$

$$S_{21} = \frac{S''_{21} S'_{21} e^{-jk_z L_{cav}}}{1 - S''_{11} S'_{22} e^{-j2k_z L_{cav}}}$$

But in two mirrors cavity, there are multiple reflections inside. It explores the mirror reflection of power. ‘ as rule of considering, if the size of mirrors is smaller then cavity length, then scattering matrix is considered frequency-independent’. The reflection coefficient of mirrors are R1 and R2 is

$$R_1 = |S'_{11}|^2 = |S'_{22}|^2 \qquad\qquad R_2 = |S''_{11}|^2 = |S''_{22}|^2$$

In the mirror cavity also consider the RTPS (round trip phase shift) and loop gain (LG). The reflection coefficient is frequency independent and the transmission coefficient is frequency dependent. The relation shows the frequency of transmission term (S12). And reflection term (S11).

$$|S_{11}|^2 = \frac{(\sqrt{R_1} - G_0\sqrt{R_2})^2 + 4G_0\sqrt{R_1R_2}\sin^2\varphi}{(1 - G_0\sqrt{R_1R_2})^2 + 4G_0\sqrt{R_1R_2}\sin^2\varphi}$$

$$|S_{21}|^2 = \frac{(1 - R_1)(1 - R_2)G_0}{(1 - G_0\sqrt{R_1R_2})^2 + 4G_0\sqrt{R_1R_2}\sin^2\varphi}$$

Figure 3.1.2 shown clearly explain the reflection and transmission coefficient. Observing mostly mirrors is reflecting completely so magnitude is 1. And certain points transmission magnitude is high.

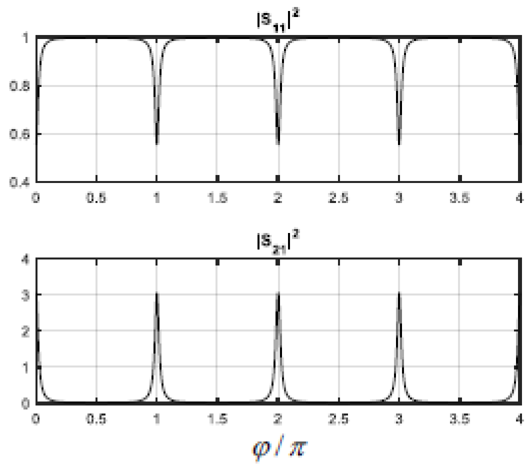

Fig 3.1.2: explain the Fabry- Perot S matrix in cavity with R1 = R2 = 0.8.(from Renato Orta, Nov. 2012 : pp-143). Ref [11].

Here deeply observe that mirrors are not dispersive. In the cavity forward wave and backward wave with an electric field and magnetic field. Both are longitudinal each other so when the electric field is high automatically magnetic field is low. The VSWR (voltage standing wave ratio) is very large. The active power is transmitted towards out from the second mirror. The two successive frequency interval maximum is the free spectral range (FSR). The transmission peaks are very narrow because estimation of phase and frequency is produced small. Here group velocity develops as a sum of group reflection delays relative to the two mirrors.

3.2 Beam splitter design:

It made from two triangular glass of prism which are joined together by glue of adhesive of polyester and urethane based. the two glasses are fixed for coming rays are partially reflected and pass through the mirror.

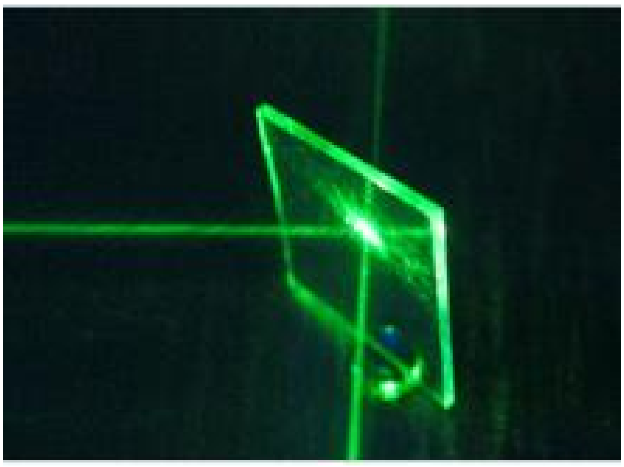

Figure 3.2: Beam splitter with two glasses joined of Aluminium coated. (from zareth, 23-March-2011). Ref [10].

3.3 Group velocity:

Group velocity is important in saturation spectrum. Structure is contain with energy velocity. The group velocity is almost similar to phase velocity and it small at band edges. Group velocity is always less then light velocity c/n. Group velocity is depend on dispersion in dielectric.

If dispersion value is small then group velocity is equal to phase velocity. Resonance frequency is evaluated the group velocity (v).

4 The Cesium atom:

The Cesium atom is from the alkali group element. In alkali group elements have only one electron is free at the outer valency band. Those are Helium, Cesium, Rubidium, Sodium all these atoms have alkalic metal properties. This is S-block in the periodic table. Alkali metals are easily ionized and low melting point. Our experiment study about Cesium atom. Cs electron configuration is **$1s^2$ $2s^2$ $2p^6$ $3s^2$ $3p^6$ $3d^{10}$ $4s^2$ $4p^6$ $4d^{10}$ $5s^2$ $5p^6$ $6s^1$**. The one-electron is empty in 6s orbital. Its atomic number is 55 and chooses the atomic mass 133 because its neutron is stable. If Cs atomic mass is 152(Cs) high neutrons and 122 (Cs) low neutrons. So Cs-133 is stable Is gives more reliable results.

Atoms are used to cool and trap of laser beam. In the experiment setup, uses the Cesium atomic vapor cell of the D2 atomic transition line. In laser chapter discussed only two levels that are High and Ground-level but in Atom is following multilevel transition level of lines. The multilevel atom is made the structure fine and hyperfine structures. In an experiment, optical pumping and crossover resonance principles are must be considered.

The coming pump is a laser beam that interacts with two different levels of atom. In the ground-state electron absorbs the energy and get spontaneous saturation to an excited level. Saturation from the ground to high-level state, so electrons are decaying at a lower state. So no combination of photons with probe beam of laser and observed the lamb dip in output photodetector. Additionally, absorption dips are also due to opposite overlapping of pump and probe at cesium cell. Clearly describing the fine and hyperfine structure below.

4.1 Fine structure of the Cesium atom:

In Cesium atom lower 5 electron shells are completely fill with electrons. The only outer 6s shell has one electron. Due to relative motion in electron are moving in the atomic spectrum because interact with another atom for a stable. Anyhow, electron spinning means it carries some magnetic field.

The electron spin movement in spectra is denoted by ‘S’. Also electron movement around in orbit is called angular movement and denoted by ‘L’.

The combination of angular and spin movement with the magnetic field is called the spin-orbit interaction in the spectrum is denoted as ‘J’. The sum of angular movement and spin is J’ = L+S also J’’ = L-S. It clearly explains by using figure 4.1 shown in below. So spin-orbit interaction split the spectral line into a small separation structure.

4.2 Hyperfine structure of Cesium atom:

In the spectra line, there is not only a fine structure of the spin-orbit movement. Also, the nucleus movement makes the split the few more spectral lines. This interaction made with a fine structure of the spin-orbital electron with a magnetic field. The nucleus has extra charge and mass. The movement of the nucleus is ‘I’. and spin-orbit movement is ‘J’. Both interactions are split into multiple lines. That is called the hyperfine structure defined by ‘F’. F = I +J the lines are made F = 1,2,3,4 observe in the diagram given below.

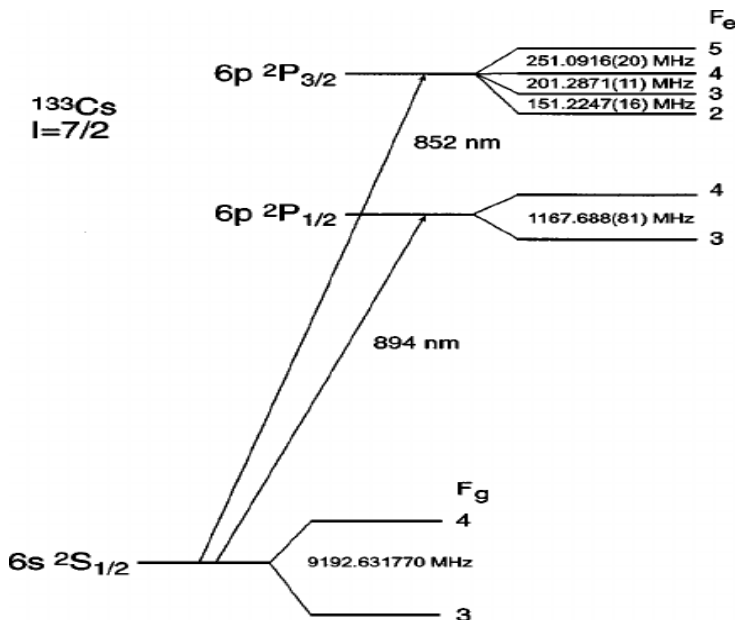

Figure 4.1: Energy band diagram of fine and hyperfine structure of Cesium cell. Ref [14].

5 Arduino due:

The board 2.1 and 4 inches of microcontroller board is ready to use and effortless function because unit conversion system. Board can carry anywhere with update the programme sketch in board. It can use in industrial companies, security, automation purpose. In Arduino due to used ATMEL SAM3X it' s using power consumption and protects external memory information.

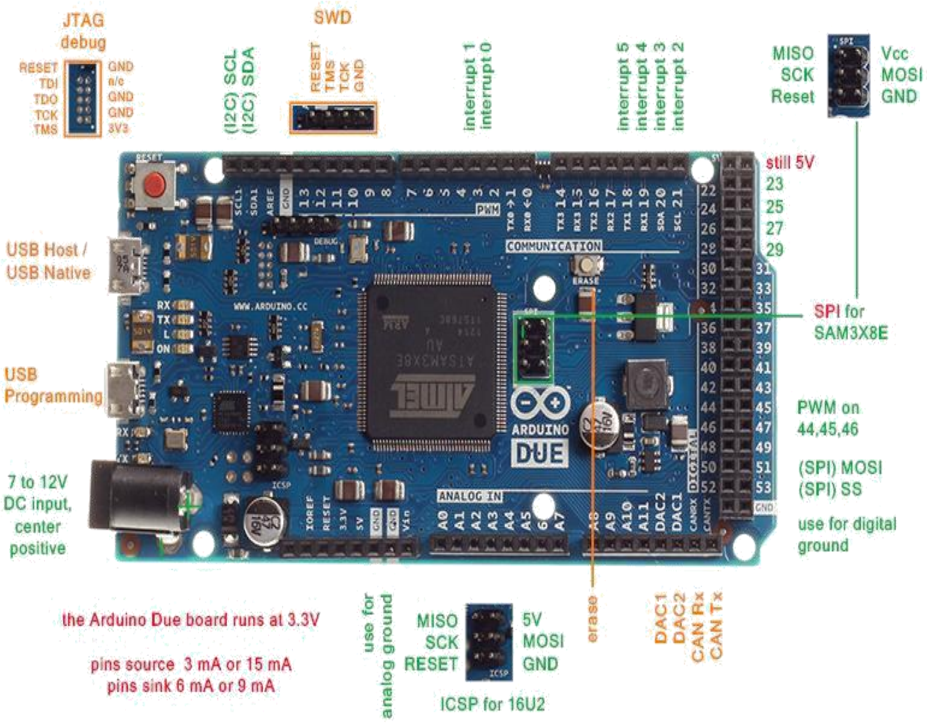

Figure 5.1: Arduino due microcontroller pinboard. Ref [12].

The Arduino boards are microcontroller and quick and fast implement board. Arduinos are many types. They are Arduino UNO, DUE, Nano and Mega. Our experiment used Arduino due board. The above figure 5.1 is explained clearly pin mode. This developed by Atmel SAM3X8E arm. The Arduino due board has 54 PWM are digital input/output pins, 2 Digital to Analog output (DAC), and 12 analog pins (A0 to A11). Also, there are two USB connecting ports are programming and native ports. Arduino due works at 3.3V. The board will damage at a higher voltage.

The 512KB flash memory and 2 banks (64 and 32KB) of SRAM 96KB are available in board. This memory is for store the code from the computer. We can delete or erase from flash memory, when press the erase or reset buttons is in Arduino due board Data will erase.

Power supply:

For Arduino board is used to USB power supply from connected computer and it operates 3.3V. it's safe for the board. Either if connected to an external battery connected directly to a board then the board will damage at much higher power supply. Have to use the regulator is to avoid the heat and damage for high voltages. The coming input power must be AC to DC converted battery or adapter.

Arduino due pins:

Arduino due Board has digital or pulse width modulation (PWM) input and output pins are 54. These pins operate at 3.3V and it gives current 3mA. Board has the pullup resistors internally inbuilt.

Pins 0 and 1 are connecting to serial chip from USB. Pins from 2 to 13 are PWM input or output with resolution of 12 - bit. These resolution can modified by using function is analogWriteResolution. Pins are like (1,14,16,18) are serial transmitting data(TX) and pins (0,15,17,19) are serial receive data(RX) at 3.3V power supply. These designed by using pinMode(), digitalWrite() and digitalRead() library functions.

1) Analog pins:

Inboard analog pins are 12 those are from A0 to A11. It has a 12-bit resolution. The 12 but is maximum but we can change 10 or 8 by using library function analogReadResolution(). Analog pins are works at 3.3V of power supply.

2) AREF: Reference voltage of analog inputs. Library is analogReference().

3) DAC0 and DAC1:

These pins present real analog outputs of 12-bits decision (4096 ranges) with the analogWrite() library. These pins are helpful to collect the analog signal.

4) Reset & erase: buttons are used to corrupt the data or erase data from stored in ROM memory.

5) Serial peripheral interferometer header.

These pins are used interface between peripheral communication by using function SPI library. In Arduino due to advanced function used as Extended SPI methods for Due.

6) TWI 1: 20 (SDA) and 21 (SCL) & TWI 2: SDA1 and SCL1.

Support TWI conversation with the usage of the Wire library. SDA1 and SCL1 are supporting to Wire1, which is in the Wire library. SDA and SCL maintain the inbuilt pull - up resistors but SDA1 and SCL1 are not internally so Add 2 more resistors at SDA1 and SCL1 strains are the usage of Wire1.

Connections:

Signal to transmit from Arduino microcontroller to many electronic devices like computers, cameras, and phones. Arduino due board has two USB connecting pins those are programming port and native port. Both works at 3.3V and works at 1200bps trigger. Two buttons (reset and erase) are help to delete the data from memory in the microcontroller unit.

The programming port: in Arduino due these UART port is connected to a computer to use collect the code from the computer. It's used for received and transmit the data. The ATMega16u2 set the COM port. The computer recognizes or sets the COM port.

The Native USB port: is permits for serial (CDC) communication through USB. It affords a serial connection to the Serial Monitor or different programs on the computer. It also communicates with a mouse or keyboard from the computer.

- ❖ The USB wire carries the maximum 500mA. If higher then this value received from the source. It will automatically remove or short. In computers also have an internal safe fuse to protect the external power supply.

5.1 Arduino due as function generator:

The Arduino due generates the wave signals by using computer code. The software used to compute the different wave signal. Those are sine, triangular, sawtooth, square waves. Arduino board connects the USB wire from the program port to a computer. When we upload the code into Arduino due. It will generate the signals and observed at oscilloscope. By using a potentiometer will change the frequency range.

In our experiment used 10hz of frequency and 2Vp-p sine signal. The potentiometer's first pin is connected to power supply 3.3V pin, central pin is connected to 'A0' of an analogue pin, and third one is connected to ground in Arduino due board. This generated a continuous sine wave signal is connected to a laser diode in a laboratory setup. The output data collected from DAC0 (digital to analog) pin from Arduino due board. Before applying to a laser diode, check the signal in an oscilloscope. Here the program is written below it described for generating the sine wave.

A high analog is needed for pulse width modulation is increase. This Arduino board is used test equipment. The Arduino is charging and discharging by using the capacitor. By using power supply and instruction following by code, the capacitor store the value in charging and discharging so we observe at oscilloscope positive and negative waves like a sine wave. The Arduino based function generator is multi-purpose usage because quick and simple programmable kit and sudden changes of chance availability are complimentary.

5.2 Arduino due as data acquisition board:

Nowadays Industries are much more likely to use DAQ to accumulate the data that measure because it's easy and speedy. It will result in the manner of data acquisition a lot extra precise, bendy and dependable of digital devices. The Data acquisition method by way of using computerized will permit the data to gather in lesser time. Analog signals alerts that produce by way of different forms go through of transducer are gain with the aid of maximum of data acquisition system and most of the implementation

In Arduino due board acts as a data acquisition kit. The data acquisition means that the available analog signal wave data is convert to digital wave. The conversion is in Arduino due microcontroller board has inbuilt. Collecting the data from analog data from DAC to A1 pin from Arduino due board. Here already generated analog signal and observed on an oscilloscope.

With the help of an oscilloscope, we set the analog signal in fixed frequency 10hz and voltage 2peak to peak. That wave is connected to an analog input (A1) and observes the output digital data at 12^{th} pin is act digital input or output pin. The PWM pins are basically analog filter can use conversion wave is the digital wave. High pulse width modulation is needed high analog wave.

5.3 Program:

The complete sketch is written on the computer and verify at computer software of Arduino. Then upload the sketch into Arduino board by using USB wire connecting to the programming port. The sketch store in flash memory, if reset button press complete will erased. When uploading the new sketch onto it before data will completely deleted.

This sketch is had created by one function library is called Waveforms.h and the main sketch is programmed by generating the sine wave and modified to converts in a digital signal. Using one motherboard connecting the power supply at 3.3V and ground from Arduino to motherboard. The potentiometer is connected to A0 pin. Analog output measuring at DAC0 and Digital output at 12pin.

```
#include "Waveforms.h"

#define oneHzSample 1000000/maxSamplesNum  // sample for the 1Hz signal
expressed in microseconds

const int button0 = 2;
volatile int wave0 = 0;

int i = 0;
int sample;
int val = 0;  // variable to store the value read
int val1 = 0;
pinMode(12, OUTPUT);



void setup()
 {

  analogWriteResolution(12);  // set the analog output resolution to 12 bit
  analogReadResolution(12);   // set the analog input resolution to 12 bit

  attachInterrupt(button0, wave0Select, RISING);
                          // Interrupt attached to the button connected to pin 2


   Serial.begin(112500);        //  setup serial

}
```

```
void loop()
{
  // Read the potentiometer and map the value between the maximum and   //the
minimum sample available
  // 1 Hz is the minimum frequency for the complete wave
  // 170 Hz is the maximum frequency for the complete wave. Measured
considering //the loop and the analogRead() time

sample = map(analogRead(A0), 0, 4095, 0, oneHzSample);
  sample = constrain(sample, 0, oneHzSample);

  analogWrite(DAC0, waveformsTable[wave0][i]);
                              // write the selected waveform on DAC0
  digitalWrite(22, waveformsTable[wave0][i]);
                               // write the selected waveform AT 22

  i++;
  if(i == maxSamplesNum)   // Reset the counter to repeat the wave
    i = 0;
 val = analogRead(A0);      // read the input pin
  val1 = analogRead(A1);
  Serial.println(val); // debug value
 ;
  delayMicroseconds(sample);  // Hold the sample value for the sample time
}

// function hooked to the interrupt on digital pin 2
void wave0Select() {
  wave0++;
  if(wave0 == 1)
    wave0 = 0;

// change the PWM resolution to 12 bits & DAQ
  // the full 12 bit resolution is only supported on the Due
  analogWriteResolution(12);
  analogReadResolution(12);
  analogWrite(12, map(sensorVal, 0, 1023, 0, 4095));
```

```
  Serial.print(" , 12-bit PWM value : ");
  Serial.print(map(sensorVal, 0, 1023, 0, 4095));
  analogWrite(DAC0, analogRead(A1));

// analog to digital output is collect at pin12 data from A1
}
```

Waveform.h

```
#ifndef _Waveforms_h_
#define _Waveforms_h_

#define maxWaveform 1
#define maxSamplesNum 120

static int waveformsTable[maxWaveform][maxSamplesNum] = {
  // Sin wave
  {
    0x7ff, 0x86a, 0x8d5, 0x93f, 0x9a9, 0xa11, 0xa78, 0xadd, 0xb40, 0xba1,
    0xbff, 0xc5a, 0xcb2, 0xd08, 0xd59, 0xda7, 0xdf1, 0xe36, 0xe77, 0xeb4,
    0xeec, 0xf1f, 0xf4d, 0xf77, 0xf9a, 0xfb9, 0xfd2, 0xfe5, 0xff3, 0xffc,
    0xfff, 0xffc, 0xff3, 0xfe5, 0xfd2, 0xfb9, 0xf9a, 0xf77, 0xf4d, 0xf1f,
    0xeec, 0xeb4, 0xe77, 0xe36, 0xdf1, 0xda7, 0xd59, 0xd08, 0xcb2, 0xc5a,
    0xbff, 0xba1, 0xb40, 0xadd, 0xa78, 0xa11, 0x9a9, 0x93f, 0x8d5, 0x86a,
    0x7ff, 0x794, 0x729, 0x6bf, 0x655, 0x5ed, 0x586, 0x521, 0x4be, 0x45d,
    0x3ff, 0x3a4, 0x34c, 0x2f6, 0x2a5, 0x257, 0x20d, 0x1c8, 0x187, 0x14a,
    0x112, 0xdf, 0xb1, 0x87, 0x64, 0x45, 0x2c, 0x19, 0xb, 0x2,
    0x0, 0x2, 0xb, 0x19, 0x2c, 0x45, 0x64, 0x87, 0xb1, 0xdf,
    0x112, 0x14a, 0x187, 0x1c8, 0x20d, 0x257, 0x2a5, 0x2f6, 0x34c, 0x3a4,
    0x3ff, 0x45d, 0x4be, 0x521, 0x586, 0x5ed, 0x655, 0x6bf, 0x729, 0x794
  };
#endif
```

6 Saturation Absorption of Cesium spectrum setup:

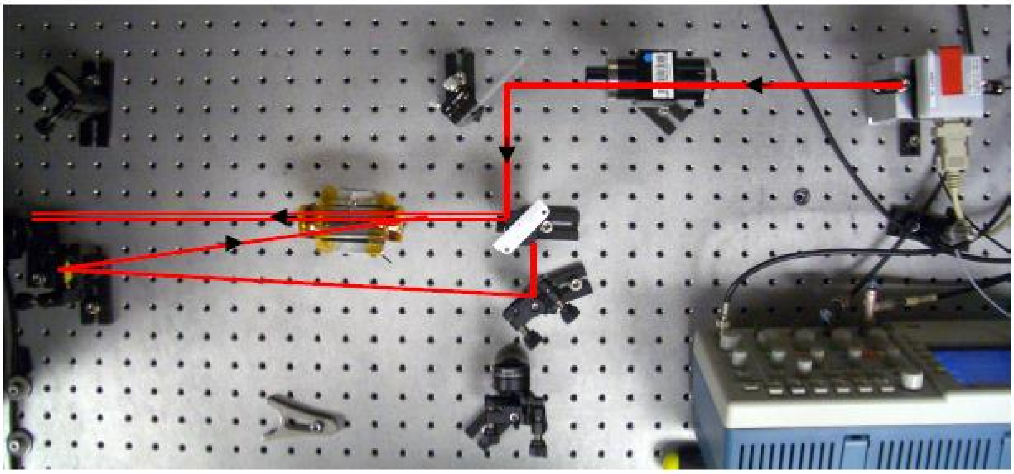

Figure 5.1: experimental setup in a laboratory room of a saturated absorption spectrum by using optical mirrors and Cs vapor cell. (from Paul L. Stubbs and W&M Quantum Optics Group, 12-May-2010 : p 6). Ref [7].

As the above figure explained as the laser diode is producing the laser beam with 852nm of wavelength. And it hit to mirror (M1) is used to protect the PBSC mirror, If coming laser has high temperature then optical lens will damage but PBSC is safe. The reflected beam from M1 is going to PBSC (partial beam splitter cube) is split into three beams are reflected weak beams are probe, reference beams, and high power pump beam is transmitting through Beam splitter mirror.

Saturation spectroscopy is used Fabry – Perot interferometer. Making the two optical laser cavity so placed other mirror opposed to the weak probe beam direction. In between two mirror Cs vapor cell is keep the position at weak beams can penetrate into it. And the few more mirrors are helped to pump beam is passing into same Cs cell. These complete optical feedback loop schematic made Opto-electric (Piezo-electric) transmitting in the optical laser cavity.

7. Summary:

The saturation absorption spectrum of Cesium atom with a laser beam has locked. The frequency of laser is at the hyperfine structure of Cesium described by cross over lines split by using nucleus energy split. It saturated a very narrow frequency range, in our case absorbed approx. in nm of the wavelength of a laser beam. When the laser beam is penetrate into the Beam splitter mirror, it divides into one strong and two weak beams. Atoms are excited in the Cesium vapor cell with help of strong laser beam (PUMP).

That excited atoms don't have velocity movement and can't interact with others because of the different phase & Doppler shift. This mechanism is called Doppler free saturation absorption spectroscopy. The beam splitter mirror reflects the two weak beams are reference and probe beam. The reference beam is don't proceed with the saturation absorption. It considers for test beam and compares the result with probe beam absorption. Observe output at photodetector. Use two photodiodes because of one for probe and other for reference beam. For probe beam observe that sharp line that closely natural spectra line width Also we find lamb dip beam. Another thing reference beam is absorbed Doppler broadening spectra. Complete setup in between two mirrors is known as Fabry – Perot interferometer.

The output photodiodes are used to convert into a current (electrons) from photons. These electrons can measure electric current as voltage peak to peak. The photodiode absorption is shown in below figures. Reference and Probe beams are observing the two different photodiodes of detectors. In figure 7.1 absorption is displaying in Wavelength and Voltage labels. Observing in graph that coming beam energy of photons where convert into a voltage of electrical current. Voltage is slightly increasing. The wavelength also slightly changes as observed this information from diagram. In the absorption lines, there is no sudden lamb dip. Because the high pump beam is absent. Do not consider the high-intensity beam into Cs vapor cell. So we get the Doppler broadening wave from two photodiode detectors.

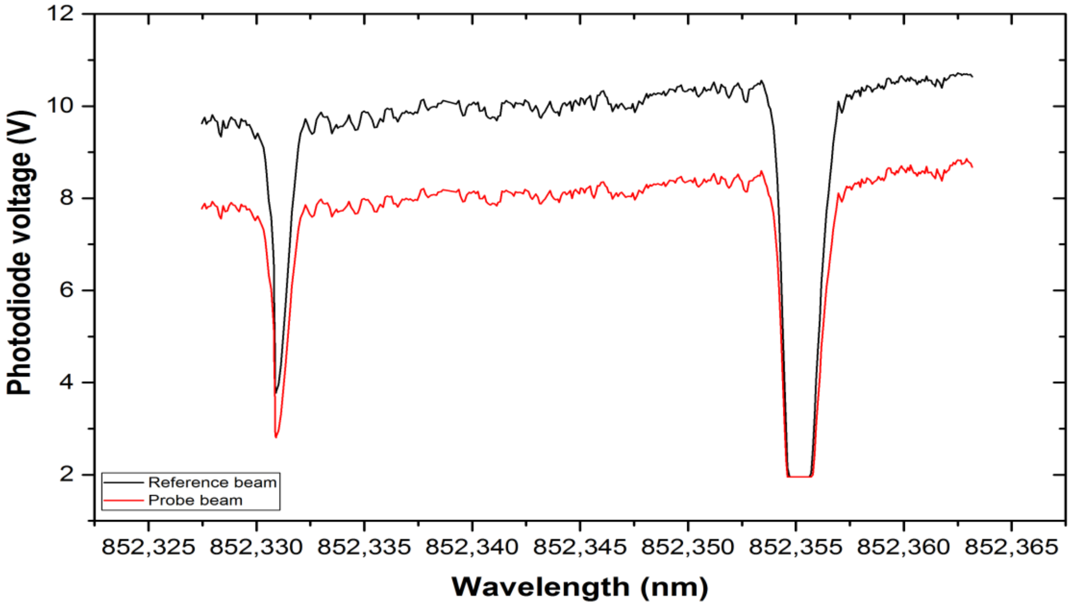

Figure 7.1: Doppler Broadening spectrum of reference and probe beams absorb at absence of pump beam in an interferometer. (from Amr Mohamed Ibrahim, april-2016 : p 28). Ref [6].

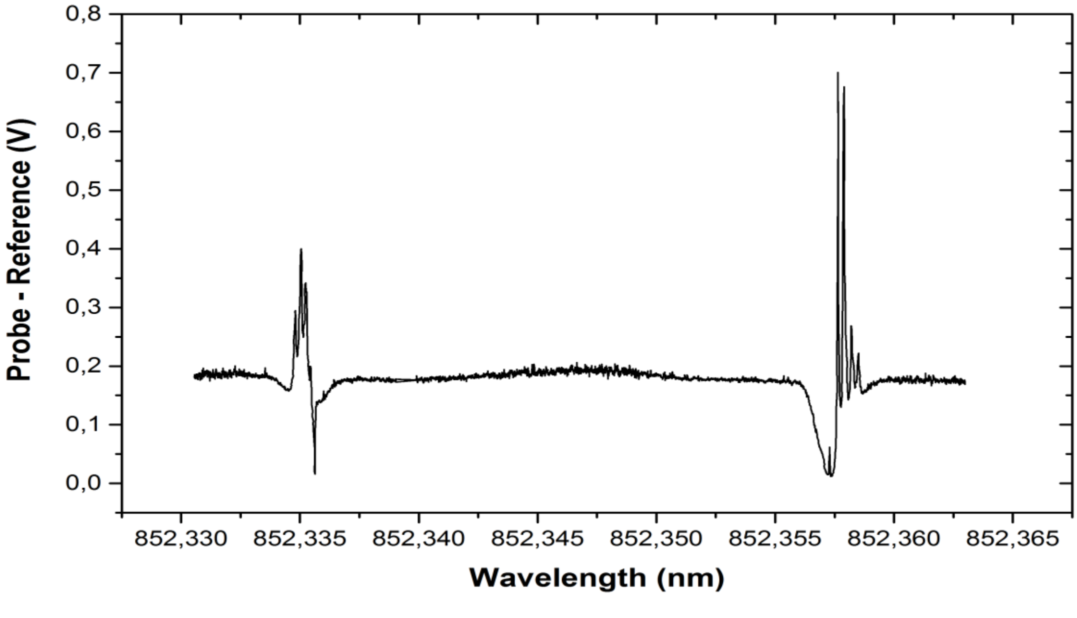

Figure 7.2: Doppler-free saturation absorption spectra in the presence of a pump and probe beam and absence of reference beam at interferometer (from Amr Mohamed Ibrahim, april-2016 : p 34). Ref [6].

The saturation absorption spectrum method presence of pump beam and two beams are (pump and probe) must participate in Cs cell. Then atom horizontal movement will stop and we get Doppler free saturation absorption. By use of a pump beam, it makes electron excite from ground to excited level. Clearly in figure 7.2, in that didn't consider the reference beam so single line in the diagram.

Also studied about different spectral lines, those are Two-level atoms and Multi-level atoms. In two-level atoms have two states are ground state (low energy level) and excited state (High energy level). Another one is Multi-level atom, which structure has explained spin-orbit movement (J) made fine structure in D1 lines and nucleus energy combine with spin-orbit angular movement and split some energy spectral line are called cross–over (D2) lines. Which made in Cesium vapor cell in presence of Electric and magnetic fields.

For producing the laser beam from laser diode need continuous analog wave from outside. So used Arduino due as a function generator and giving continuous sine signal to a diode. Also Arduino due as the data acquisition board, it internally has an analog to digital conversion setup. We observed the output saturation spectrum at an oscilloscope. Understood that temperature and resolution are from applied or by external environment it affects the output frequency of a saturation spectral beam.

8 References:

[1] January - 30-2020 : Saturated Absorption Spectroscopy Experiment SAS University of Florida - Department of Physics PHY4803L - Advanced Physics Laboratory.

[2] Camden Kasik, 2018 : Constructing a Saturated Absorption Spectroscopy System for laser locking, University of Washington.

[3] Stefka Cartaleva1, Anna Krasteva1, Dimitar Slavov1, Petko Todorov1, Kapka Vaseva1, Armen Sargsyan2, David Sarkisyan2, and Sofia 2, : High-Resolution Laser Spectroscopy of Cesium Vapor Layers with Nanometric Thickness.(1)- Institute of Electronics, Bulgarian Academy of Sciences, (2)- Institute for Physical Research Ashtarak 1Bulgaria, National Academy of Sciences of Armenia, Ashtarak 2Armenia.

[4] Abirkel, 29-11-2012 : Doppler-Free Spectroscopy - MIT Department of Physics.

[5] Theodor Haensch : Saturation spectroscopy, Nobel price 2005, pp 6 & 10.

[6] Amr Mohamed Ibrahim, april-2016 : SATURATION ABSORPTION SPECTROSCOPY ON Cs ATOMS, pp 28 & 34.

[7] Paul L. Stubbs and W&M Quantum Optics Group, 12-May-2010: Laser Locking with Doppler-free Saturated Absorption Spectroscopy, pp 6.

[8] Stephen Dennis Wilson, 05-07-2002 : Resonance Ionization and Saturated Absorption Spectroscopy of Cesium at *University of Tennessee – Knoxville.*

[9] Thomas Rieger and Thomas Volz : Doppler-Free Saturation Spectroscopy at Max-Planck atInstitut fÄur Quantenoptik, Garching.

[10] Zaereth, 23-March-2011 : category optics. "Beam Splitters". RP Photonics - Encyclopedia of Laser Physics and Technology.

[11] Renato Orta, Nov. 2012 : Lecture notes on Passive Optical Components PRELIMINARY VERSION, department of electronics and telecommunications, Politecnico di Torino, pp (141 -143).

[12] Arunabho Mukherjee, Anirudh Singh, Praveen Bagriya and Aman Aggarwal, may-2016 : FUNCTION GENERATOR USING ARDUINO DUE, pp 18.

[13] F. J. Duarte, Tunable Laser Applications (CRC Press, 2008).

[14] V. gerginov, C.E.Tanner, S Diddams, L Hollberg and A. Bartels, 20-oct-2004 : Optical frequency measurement of 6s^2s1/2 – 6p^2p3/2 transition in a Cs(133) atomic beam using a femtosecond laser frequency comb

[15] Thomson, 2003 : atomic physics, slide number 28.

[16] Ankit Gupta : https://www.learnindialearn.com