SELF-MIXING PRINCIPLE BASED VIBRATION MEASUREMENT USING DIODE LASER

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Abstract: The principle and the experimental realization of a new type of laser Vibrometer based on the Self–mixing interference effect in a laser diode are presented. The self-mixing configuration allows for a practical set-up that is by far simpler than conventional laser Vibrometer schemes. This Vibrometer is based on interference Fringe Counting scheme. This allows an extended dynamic range to be achieved, whilst retaining a good sensitivity to sub-wavelength vibrations. The proposed method can find application in measurements of amplitude and frequency of vibration in industrial and scientific environments. In this project the frequency & amplitude of vibration of a loudspeaker is calculated using a simple circuit arrangement by utilizing the self mixing phenomena and a battery operated laser diode as source of light energy.

Keywords: Vibration, displacement, interferometer, diode laser, self-mixing, photodiode, non-contact measurement, non-destructive measurement, laser Doppler Velocimetry.

1. INTRODUCTION

Laser vibrometry [1] is a well established technique that allows remote and contactless measurement of the vibration of a solid target. It relies on the coherence properties of a laser beam, and on the high sensitivity of the coherent detection exploited in a Michelson interferometer, which permits us to detect the very small echo signal backscattered by a rough diffusing surface. Laser vibrometry has been demonstrated and successfully used in a variety of scientific and industrial applications, where high sensitivity and low invasiveness are of importance, e.g. modal analysis, vibration and noise testing, characterization of loudspeakers and piezoceramic transducers.

The standard approach to optical measurement of small vibrations is laser Doppler Velocimetry (LDV)[3], on which number of commercial products have been developed. The operating principle is that of conventional Michelson and Mach–Zehnder interferometers. The measuring arm projects light from a He–Ne laser onto a vibrating target, the backscattered light undergoes a Doppler frequency shift proportional to the target velocity and it is then coherently detected at the instrument side. Unlike displacement measuring interferometers, the interferometric signal is usually processed by extracting the Doppler beat frequency through a frequency demodulator, so as to obtain an output signal proportional to the instantaneous target velocity.

In this paper we present a new type of laser Vibrometer based on the self-mixing interferometric configuration.

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2. PRINCIPLE OF SELF_MIXING VIBROMETER [2]:

In self mixing a fraction of the light back reflected or backscattered by a remote target is allowed to re-enter the laser cavity, thus generating a modulation of both the amplitude and the frequency of the lasing field. In this approach, equivalently called feedback or induced-modulation interferometry, the laser source acts as a sensitive detector for the path length 2ks where $k = 2\pi/\lambda$, and s is the target distance) travelled by the light to the target and back, exploiting so-called injection– detection.

2.1 Advantages of the self-mixing sensing scheme:

(1) No optical interferometer external to the source is needed, resulting in a very simple, part-count-saving and compact set-up.

(2) No external photo detector is required, because the signal is provided by the monitor photodiode contained in the LD package.

(3) The sensitivity of the scheme is very high (limited by the wavelength of the laser used), being a sort of coherent detection that easily attains the quantum detection regime (i.e. half wavelength sensitivity in path length is possible).

(4) Successful operation on rough diffusive surfaces can be achieved.

(5) Information is carried by the laser beam and it can be picked up everywhere (also at the remote target location.

(6)This type of Vibrometer should be very effective in case of toxic and hazardous environment where non contact measurement is very essential.

3. BASIC EXPERIMENTAL SET UP:

To demonstrate of this principle we used a diode laser, a loudspeaker as a vibrating object, a photo diode as a detector and monitor the intensity variation of the laser diode which is caused by the vibration of the object. The basic set up to get the signal is shown (Fig1.) bellow.

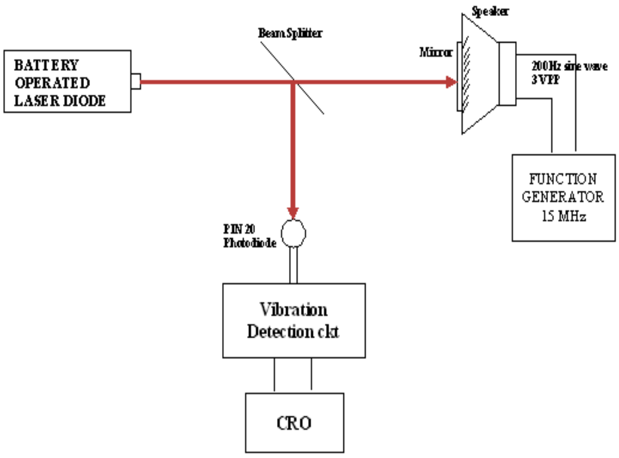


Fig. 1. Basic setup of the Vibrometer

The output beam (front output) from laser diode is sent directly onto a loudspeaker attached with a small mirror ,the reflected light goes to laser diode again and the self mixing light coming from laser diode goes to photo diode through beam splitter

4. BASIC SELF MIXING SIGNAL:

The signal collected by photo diode is like this

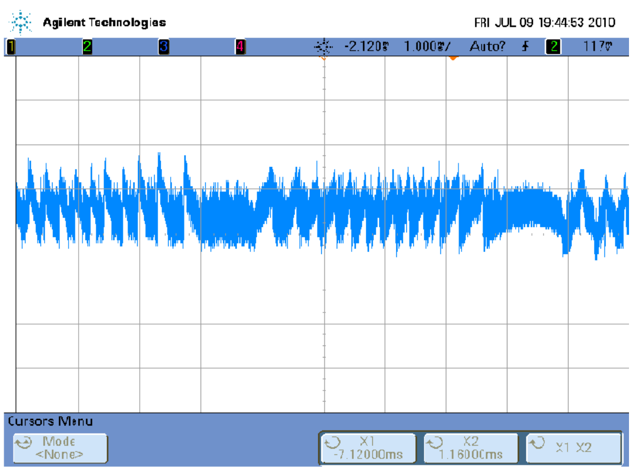


Fig. 2. Self mixing waveform

From the above signal it is clear that, the output consists of two components, one is high frequency signal and another is repetitions rate i.e. low frequency signal. The low frequency is due to variation in intensity of the laser light with vibration of the object and high frequency is due to the interference effect. Each peak in high frequency signal corresponds to vibration amplitude of $\lambda/2$(where λ is the wavelength of the used laser). With increase in vibration amplitude the overall intensity changes so we get almost sinusoidal signal. This is also shown in the result latter.

Our aim is to separate out the low frequency and high frequency signals and count the peaks, and by peak counting we can find out the amplitude of the vibration which is equal to $n\lambda/2$; where n is the no. of peak counts by the counter circuitry

5. BLOCK DIAGRM OF DETECTION CIRCUIT:

The self mixing light come to photo diode have all the information about frequency and amplitude of the vibrating object. To analysis the electrical signal comes from photo diode we use this block schematic as shown bellow

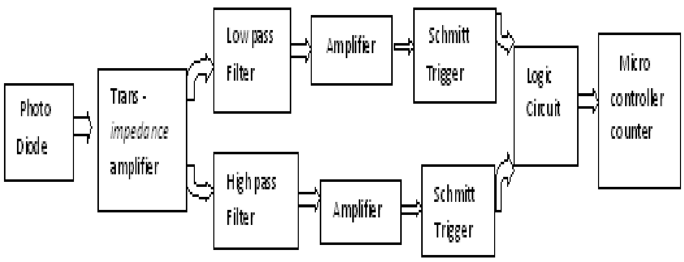
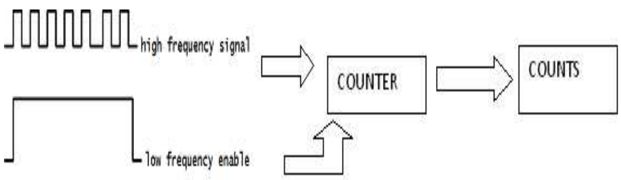


Fig. 3. Basic block diagram of the vibration detection circuit

The self mixing light signal come from laser diode fall on to the photo diode gives current signal. The Trans impedance amplifier is used to convert the current signal to corresponding voltage signal. This voltage signal consists of low frequency signal which gives frequency of vibration and a high frequency signal that gives the amplitude of vibration. The frequency difference between these signals is very large, so we use two filters (high pass & low pass) to difference them. The signals we are getting from the filters have low amplitude so we first amplify them and then send them to Schmitt trigger circuit. The Schmitt trigger gives the pulse output then we measure the no of pulses of the high frequency signal in between one period of the low pass output by counter circuit



6. DETECTION CIRCUIT DESCRIPTION:

6.1 Analog circuit:

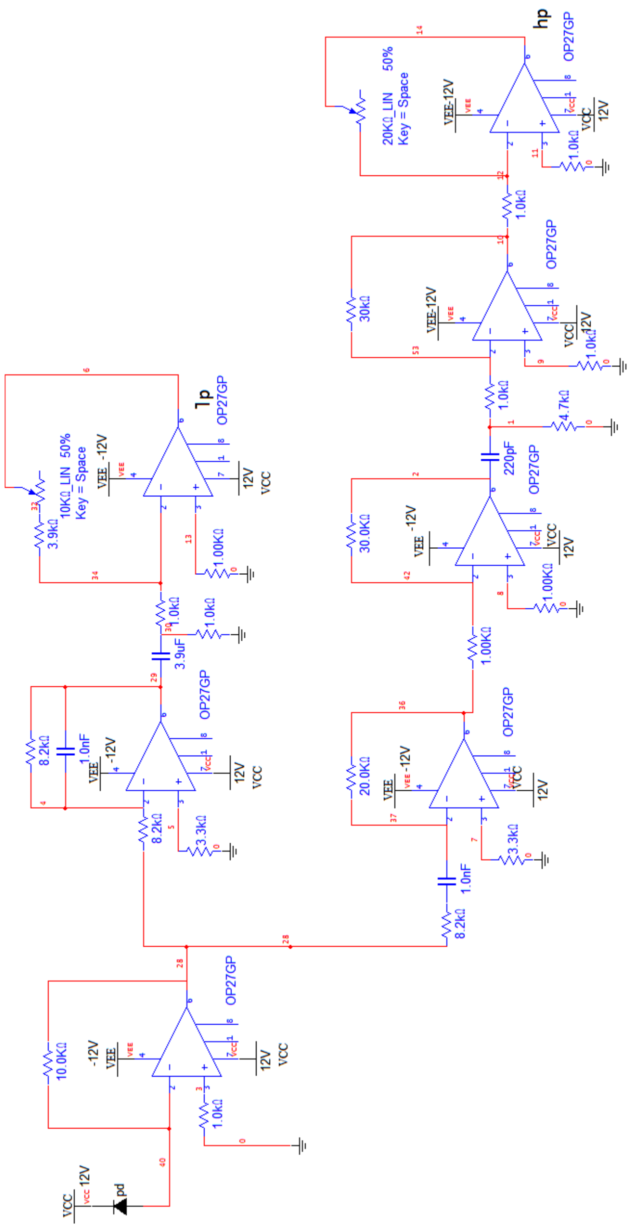


Fig: 4, Analog part of the detection circuit

The photodiode gives current output correspond to the light energy fall on it, this current is passed through a Trans impedance amplifier, so we get a voltage equal to the product of current offered by the photo diode and the feedback resistance. 1k resistance is used in the non inverting terminal so that it can adjust the dc bias offset. The output of Trans- impedance amplifier goes to low pass [appendix13.1] and high pass filter [appendix13.2]. The cut off frequency of both the filters are 20 kHz. The resistance at the non - inverting is chosen in such a way that it is equal to the resistance in the inverting side. The output of the low pass filter may contain dc value so a large value capacitor is used to lock that dc component. Then the signal is amplified & sends to Schmitt trigger. The gain- bandwidth product of the op-27GP [6] is 8 MHz, which is much higher so we can use a high gain, and it is adjusted by a variable resistor in the feedback path. In the high frequency side we can't use a large gain in a single amplifier then it may cross gain-bandwidth product of the OPAMP. So we used repeated amplifier and dc blocking in between them. With all the OPAMPs 2.2(µf)& 0.1(µf) capacitor is used within ±VCC supply and ground with proper polarity, to bypass any ripple from supply.

All the circuits are electrically tested by applying signal from function generator before applying photo diode signal

6.2 Digital Circuit

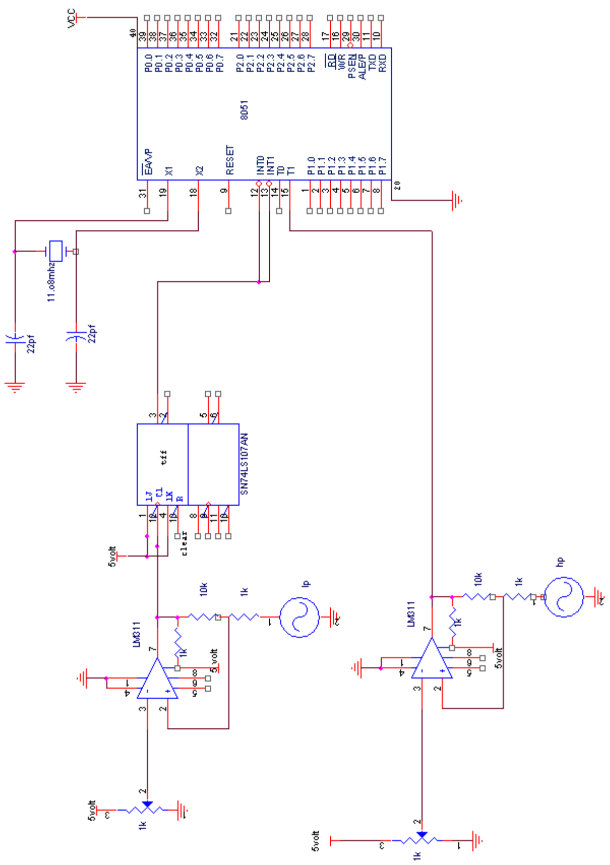


Fig: 5, Digital part of the detection circuit.

The filtered signal with sufficient amplitude sends to Schmitt trigger. Then depending on the reference threshold value it gives the pulse output. The 1k pot. is used to adjust the threshold value, and R1, R2 combination is chosen for proper hysteresis. IC LM311 [6] is used as Schmitt trigger, which is open collector, so additional 1k is used to pull-up the output. The threshold value in low frequency signal Schmitt trigger is so adjusted that it allows passing only the fundamental vibration frequency. For this reason the threshold value is adjusted slightly higher. As a result we do not get 50% duty cycle at the output pulse. So we used a TFF to get the 50%duty cycle, but it reduces the frequency to half value, this is adjusted in the final calculation.

7. EXPERIMENTAL RESULT OF VIBROMETER:

The Vibrometer is tested by using a battery operated laser diode (wavelength is 630nm), a loudspeaker as a vibrating source, a function generator to drive the speaker and a PIN 20photodiode as a sensor. All the signals are analyzed by a20MHZ oscilloscope. The speaker is operated for 200HZ vibrating frequency and different voltages. The result is shown bellow in tabular form

Function generator frequency (Hz)	Function Generator Voltage (Volt)	Low pass filter output frequency (Hz)	counts	Amplitude of vibration (µm)
200	2 2 2	200 200 200	158 124 154	47.4 37.2 46.2
200	3 3 3	200 200 200	200 216 200	60 64.8 60
200	4 4 4	200 200 200	267 250 252	80.1 75 75.6

8. DISCUSSIONS:

The amplitude of vibration of a loud speaker is calculated in our basic Vibrometer set up, and the result is verified again by optical method. In both the cases the results are almost same.

We are working with laser, so alignment plays a great role in our experiment. The whole set up should be well clamped so that it maintains the alignment for a long time.

The entire optical component should be on the same plane for good alignment. The reflected light from the vibrating object must goes to the laser diode so care should be taken.

In our experiment we are using a beam splitter so set up is little bit complex, but a compact laser diode package with photo diode is available in the market. This will reduce the alignment headache.

In the PCB all the components should be well solders otherwise dry soldering will create loose contact problems.

In Analog domain noise create lots of problems, so all the decoupling capacitance must be used with proper type and value.

In our experiment we design the microcontroller part but not use it, the peaks are counted by using an oscilloscope after ANDed output of TFF & high frequency pulses

In our set up we use a battery operated laser and the self mixing light goes to the photodiode via a beam splitter and the detection circuit is made on a general purpose PCB. It can be made as an instrument for no contact measurement of the amplitude and frequency of vibration of a vibrating object by using the compact laser diode package and a permanent PCB.

9. REFERENCES:

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