Design and development of a low-noise redundant piezo driver *cum* scan generator

Sankar Majhi[1,2], Sankalpa Banerjee[1], Bhagyashree Joshi[2] and Subhadeep De[1]*

[1] Inter-University Centre for Astronomy and Astrophysics (IUCAA), Post Bag 4, Ganeshkhind, Pune 411007, Maharashtra, India.
[2] Savitribai Phule Pune University (SPPU), Ganeshkhind, Pune 411007, Maharashtra, India

Abstract

We are developing an Interference Filter based Extended Cavity Diode Laser (IF-ECDL) system, operating at 1550 nm wavelength, comprise of the opto-mechanics, driving electronics and computer-controlled user interface. This wavelength is of interest for the future gravitational-wave detectors, standard optical as well as for the quantum communications, optical fiber based distributed sensing and many more. Here we report design of a low noise stable micro-controller-based accurate voltage source along with its scanning possibility, namely the piezo controller, which will be used for controlling the piezo used in the IF-ECDL. The piezo controller is capable either for scanning or to set the piezo length in order to change IF-ECDL's cavity length for tuning or fixing the lasing wavelength. The piezo driver features an open loop bandwidth of 500 kHz with a noise floor of 4×10^{-7} V/√Hz with a 2 uF piezo as the load. The stability of the 100 DC bias, as an example set value, is ~2 mV measured over a period of 3 days. Range of the DC bias is 0 to 150 V with a maximum scan signal amplitude of 90 V peak-to-peak. The driver can generate triangular, sawtooth, sinusoidal and square waveforms with a frequency range from 0.01 Hz to 30 kHz.

1. Introduction

Since operation of the Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors several possible upgradations have been identified for further enhancement of its sensitivity and widening the gravitational wave (GW) detection bandwidth. One suggested upgradation is changing of the operating wavelength, which at present is at 1064 nm, to 1550 nm or >2000 nm for the third-generation detectors. The proposed underground Einstein telescope having 10 km arm length is also planned to operate at the 1550 nm wavelength. This particular wavelength is of interest primarily because of less coating absorption therefore resulting to a lower coating thermal noise which is also a decisive factor in order to achieve the designed arm cavity power in the detector. Scattering loss is also reduced at this wavelength which in turn increase the power recycling gain in the arm cavities, reduced backscattering noise and also lower the losses in the squeezing filter cavity. Quantum efficiency of InGaAs photodiodes is > 99% at 1550 nm and it is very crucial for highly efficient squeezing detection. Therefore, high stability narrow linewidth 1550 nm laser system are of high demand for the future GW research. A 1550 nm laser also have ample of applications in normal fiber optic communication, quantum key distribution, quantum sensing, quantum imaging and many more. Keeping these wide range of applications in mind, we are indigenizing a novel design of the interference filter based extended cavity diode laser (IF-ECDL) system operating at 1550 nm which comprise of the opto-mechanics, driving electronics compatible to a touch screen based graphical user interface (GUI). Here we are reporting a low noise stable piezo controller which we shall use to tune the IF-ECDL's cavity length. Otherwise this also finds wide range of applications, for example, in arm length tuning of interferometers, laser beam pointing, optics alignment etc., where accurate and controlled piezo actuations are necessity.

2. Circuit description

A piezo driver accurately controls mechanical displacement of the piezoelectric actuators by accurate tuning of the applied voltage on it. In an ECDL, the piezo is used to set its cavity length therefore fine tuning and fixing of the output wavelength is controlled using the voltage applied to the piezo [1]. Hence, low noise, fine resolution in tuning steps, different waveforms for the generated scan voltage and stable output are inevitable requirement for the piezo controller. Our developed hardware has six major subsections: (i) high voltage amplifier, (ii) bias control, (iii) waveform generator, (iv) monitoring, (v) modulation input and (vi) power supply. The output from bias control, waveform generator and modulation section are summed up using a 1st stage amplifier before feeding it to the input of the high voltage amplifier. The output of the high voltage amplifier is directly connected to the piezo and a small fraction of this output is picked up for monitoring. The electronic circuitry has been designed after simulation of each subsections using Analog Devices's opensource electronic circuit simulation tool LTSpice. A simplified circuit diagram of the piezo controller is shown in Fig. 1. All the ICs other than high voltage amplifier is given ± 15 V, +170 V and -

15 V are given to the high voltage amplifier. Power supply section is not shown in the circuit diagram. The circuit is assembled on a 12 mm×10 mm printed circuit board (PCB) and most of the components except the high voltage amplifier, DC-DC converter and few resistors with 250 mW power rating, used are surface mount to reduce the unwanted noise pickups and interferences between other circuit elements. The measured performance of the controller in terms of bandwidth, system noise floor, bias stability etc. are excellent and better than similar commercial products.

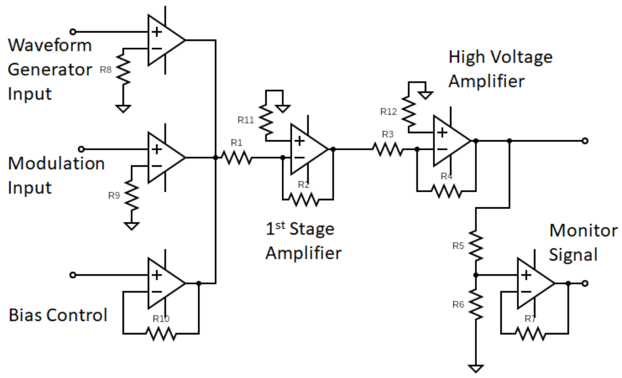

Figure 1. Circuit diagram of the developed piezo driver.

The heart of the driver is the high voltage amplifier section which also defines the bandwidth of the controller. Apex Microtechnology based PA15FL high voltage power OPAMP is used for the amplifier section. This amplifier features a high voltage range of maximum ±225 V with high driving output current up to 200 mA. The external compensation capacitor and resistor offers flexibility in selecting the bandwidth and slew rate for different applications. A small fraction of about 0.1% of the high voltage output is picked up through AD8671 precision amplifier to provide the signal monitoring option. The designed driver has provision for the modulation input, which can be used to give reference feedback signal generated by an external servo for the laser frequency locking. The IC AD8671 is used for the modulation input.

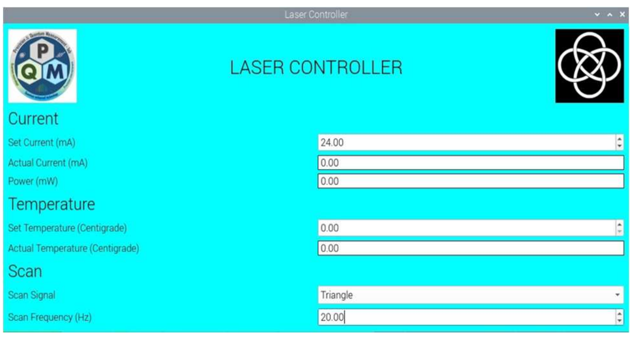

Figure 2. The graphical user interface (GUI) to control the current, temperature and scan parameters of the IF-ECDL.

The precision shunt reference LM399H is used in the bias control section. It provides a very stable voltage reference and an excellent temperature stability over a wide range of voltage, temperature and operating current conditions. It is used along with AD8671 to generate the bias voltage in the range of 0-150V. The IC AD8671 is also used in various other parts of the circuit like input buffer section, output monitor section due to its low noise, wide bandwidth, low input bias current and low offset voltage.

Scan generator provides an excellent feature of the driver. We have developed a STM32 micro-controller base scan generator which can generate different type of scan signal like: triangular, sawtooth, sinusoidal and square in the frequency range from 0.01 Hz to 30 kHz. The scanning waveform type and scan frequency can be controlled through a Python based user friendly graphical user interface (GUI), as shown in Fig. 2. The controller is designed for fully controllable from a touch screen display which is extendable to a remote PC.

All the ICs required ± 15 V DC supply other than the high voltage amplifier PA15FL which requires around 170 V DC for its operation. ± 15 V DC supply has been generated using L7815 which is positive voltage regulator and L7915 which is a negative voltage regulator. Traco Power based THV 12-300P DC-DC up converter is used to generate the 170V DC. THV 12-300P features excellent output stability, low temperature coefficient, ultra-low ripple etc. which is at most important for bias stability of the high voltage output signal. An additional +12 V DC is required at the input of the DC-DC converter and it is generated by using L7812 voltage regulator. Polar and non-polar capacitor filter combination is used to reduce the noise level in different parts of the driver circuit. The described hardware is packaged in a standard 3U size 19-inch metallic box inclusive of all the required control knobs, input/ output ports and a 7-inch TFT display for monitoring and the touch screen control, as shown in Fig. 3.

Figure 3. An in-house developed complete laser controller unit for current, temperature and piezo control of ECDL laser.

3. Results and discussion

The performance of the designed controller in terms of its operation bandwidth, system noise floor, bias stability etc. are better than some of the commercially available controllers such as Thorlabs MDT694B, KPZ101. As per the present configuration, the maximum peak to peak scan voltage is 90 V which can also be modified depending on the end user's need by changing the gain resistor of the 1st stage amplifier. The scan frequency can range from 0.01

Hz to 30 kHz. Considering the peak to peak scan amplitude and slew rate of the high-power amplifier (PA15FL), the maximum power bandwidth of the controller is approximately 35 kHz. If we increase the scan amplitude the power bandwidth will decrease as gain bandwidth product is constant for any amplifier. The small signal bandwidth with 1 V peak to peak sinusoidal input signal is nearly about 500 kHz at no load condition (Fig. 4) and it goes down to 3 kHz with a load of 2 uF capacitive load of a typical piezo (Thorlabs, PK44LA2P2).

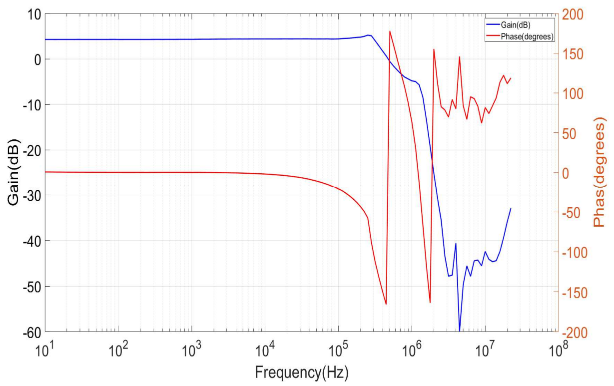

Figure 4. Small signal bandwidth of the driver at open load condition. Blue and red curve represent the gain and phase responses of the driver.

The bandwidth measurement has been done using Rohde & Schwarz RTA4004 digital oscilloscope. The system's noise floor has been measured using Tektronix RSA512B real-time signal analyzer. The voltage noise power spectral density (Fig. 5) at 1 kHz is 6×10^{-7} V/√Hz (without load) and 4×10^{-7} V/√Hz (with 2 uF piezo as load). The voltage PSD with the piezo is slightly lower than the voltage PSD without piezo, as the piezo capacitance is acting as a filter in this case. The bandwidth stability is <0.01% over a period of 24 hours.

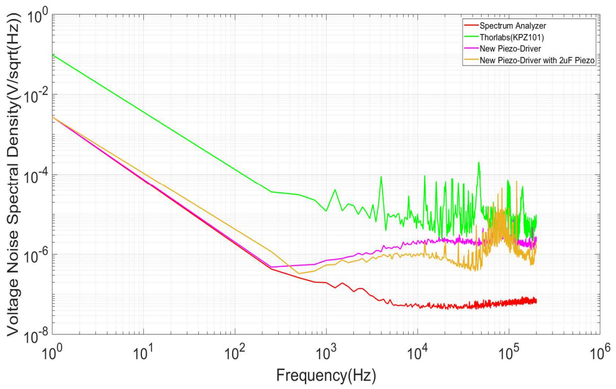

Figure 5. Voltage noise spectral density of the piezo driver. Red curve presents the noise floor of the measurement instrument (Tektronix, RSA5126B real-time signal analyzer). Thorlabs KPZ101's noise floor is presented by the green curve. Magenta (at no load condition) and yellow (with 2 uF piezo as load) color represents the noise floor of our in-house developed piezo driver.

We are using a piezo ring with maximum length change of 6 micrometer for 150 V DC applied on it. Considering an external cavity length of 40-45 mm in our case, then the corresponding frequency change coefficient with respect to bias voltage fluctuations will be approximately 170 kHz/mV. So, stability of the bias voltage is very crucial for wavelength stability of the laser. The bias voltage fluctuation is measured using Keysight 34461A 6.5 digital multimeter and the value is around 2 mV over a period of 3 days when the bias voltage is set at 100V. The equivalent frequency deviation of the laser corresponding to the bias fluctuations is around 340 kHz which is within the acceptable range.

4. Conclusion

Our custom piezo driver is designed specially for achieving accurate low noise actuations of the piezo, which are used in wide variety of applications. The performance of the driver is tested and benchmarked at both unloaded and loaded conditions. It features accurate control, low noise, stable performance over a wide range of bandwidth. The measured bias stability (~1-2 mV) meets the acceptable criteria as well. The added micro-controller-based scan generator provides precise voltage scanning with high stability. The overall system noise floor is well below (6×10^{-7} V/√Hz) and it improves (4×10^{-7} V/√Hz) slightly at the loaded conditions due to the filtering effect of the piezo.

5. Acknowledgements

We thank IUCAA for supporting this work.

6. References

1. S. Charles. Doret, "Simple, low-noise piezo driver with feed-forward for broad tuning of external cavity diode lasers," *Rev. Sci. Instruments.* 89, 023102 (2018), doi: 10.1063/1.5009643.