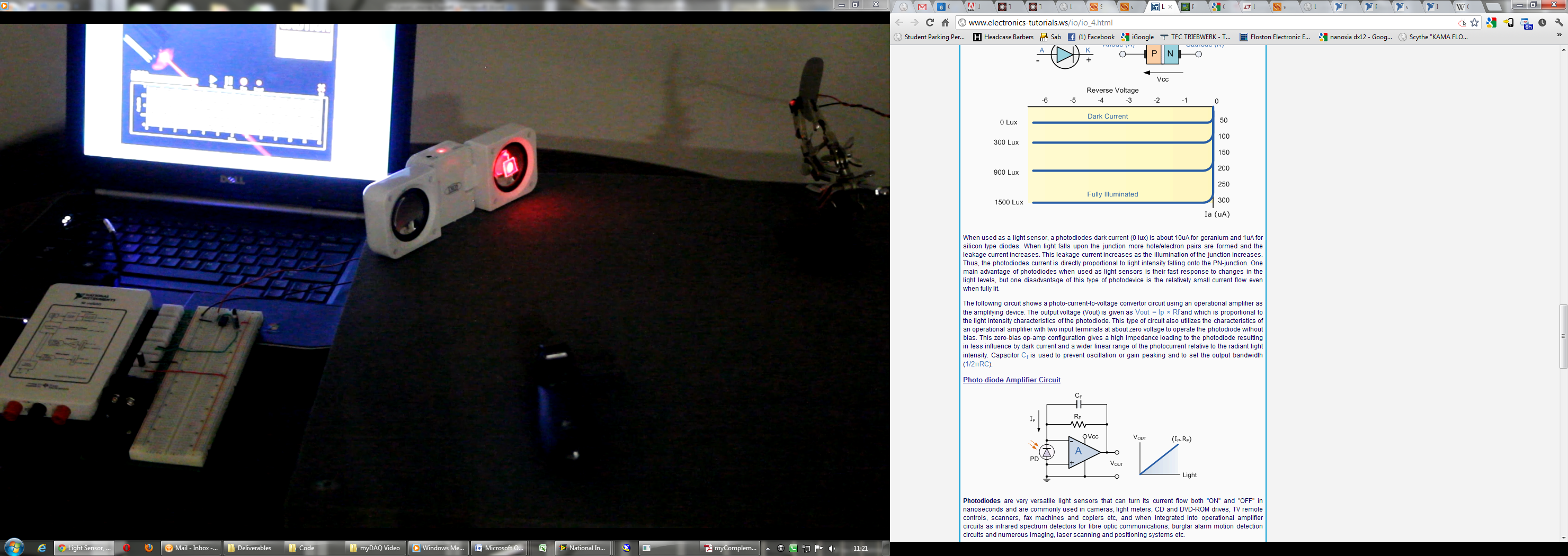
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myLaserListener

The Laser Listener is considered by many to be the ultimate spy tech device, because it gives the user the ability to listen in on conversations that take place in a distant building without having to install a bug or transmitter at the location. The Laser Listener was invented by Leon Theremin, a member of the Soviet Union, in the 1940s. Using a non-laser based infrared light source, Theremin’s original system could detect sound from a nearby reflective surface by picking up faint vibrations. It is rumoured that the KGB used this device to spy on the British, US, and French embassies in Moscow.

In building this project, you will learn about lasers, reflection, vibration transmission, electronics, filtering and NI LabVIEW.



### Required Hardware

|  |  |
| --- | --- |
| Item | Cost ($) |
| Laser Pointer | 4.00 |
| Laser Diode | 8.00 |
| Mirror | 4.00 |
| Polariser (Passive 3D glasses from cinema) | 2.00 |
| Photodiode | 0.50 |
| OpAmp (LM431) | 0.50 |
| Resistors | 0.05 ea |
| Capacitors | 0.05 ea |
| TOTAL (approx) | $17.01 |

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# Introduction

## Objective

Build a device that uses lasers to measure the vibration of a reflective surface, located outside of the device itself, which can be used to reconstruct sound.

## Laser Listener Concept

A laser listener is a surveillance device that uses a laser beam to detect sound vibrations in a distant object. A laser listener is designed to allow eavesdropping with a minimal chance of exposure. Ideally an infrared laser would be used to ensure that the chances of detection are kept as low as possible, but for safety reasons, a visible laser should be used instead.

The Laser Listener goes by several names such as Laser Microphone, Laser Spy, Laser Bug, and a few other similar names. Under ideal conditions the Laser Listener works well, but it has many strengths and weaknesses that will be discussed in this project. By building your own Laser Listener, you can experiment with this technology as you can adjust this primary design to suit your needs. This project will cost a small amount when compared to a professional Laser Listener system which can cost upwards of $100,000.

This design is a basic proof of concept test system that will show you how the Laser Listener converts vibration into sound and how careful alignment of the laser and receiver are required for optimal performance. This guide explains how to build a laser listener using the NI myDAQ platform and NI LabVIEW. The hardware and software are explained in detail, and a step by step guide to build your own Laser Listener is included.

# Using myLaserListener

### Required Software and Hardware

* LabVIEW for Education
* NI myDAQ
* NI myDAQ Protoboard or other breadboard accessory
* Laser Pointer
* Photodiode
* Circuit components

### Hardware

#### NI myDAQ



Figure NI myDAQ

NI myDAQ (shown in Figure 1) is a low-cost portable data acquisition (DAQ) device that uses NI LabVIEW-based software instruments, allowing students to measure and analyze real-world signals. NI myDAQ is ideal for exploring electronics and taking sensor measurements. Combined with NI LabVIEW on the PC, students can analyze and process acquired signals and control simple processes anytime, anywhere.

NI myDAQ provides analogue input (AI), analogue output (AO), digital input and output (DIO), audio, power supplies, and digital multimeter (DMM) functions in a compact USB device

#### Required Hardware & Electronic Components

The obvious first component of the Laser Listener is the laser pointer. A laser pointer is a small portable device with an onboard power source and a laser diode emitting a very narrow coherent low-powered laser beam of visible light. Jurisdiction dictates output power must not exceed 5mW in the UK. The laser pointer will be targeted at the object you are trying to capture sound from, which will reflect the beam back to the receiver. The principle of a basic Laser Listener system uses movement of the beam to convert vibration into sound. As the laser reflects from the target window or surface, the slight vibrations from conversations or noise that vibrate the window case a very slight change in position of the returned laser beam. This change in position is converted into voltage, as the sensor in the receiver catches the returning beam. This is why alignment is crucial and why the beam must be slightly offset from the centre of the receiver.

For this project, any common laser pointer will be sufficient. These can be found on the internet for a few Pounds. There will be no difference in sound quality whatsoever between a £1 laser and a state-of-the-art gas lab laser. The only disadvantage to using a cheap laser pointer is that you will probably want to modify it for an external power supply. Although this is not crucial, you can jam the switch on when the Laser Listener is operating if you wish. An infrared laser would suit this design best because it would be undetectable at the target location, but for safety reasons a visible laser would be best. Lasers can be dangerous if the beam enters your eye, so a visible laser is safer as your blink reflex will protect your eye from permanent damage. Visible lasers are also much easier to aim than infrared ones.

To test the system, I will be using a mirrored speaker to simulate a window. The output from the speaker should only be audible from a few centimetres away to best simulate the amplitude of vibrations that you will be measuring from a window. Any piece of highly reflective surface, such as a mirror or piece of CD/DVD, can be used to reflect the test beam from the speaker. A mirror will work best, and a piece can be snapped from an old mirror using pliers, gloves, and eye protection or a small dental mirror can be taken apart instead. The size of the mirror is not important since the laser beam is only a few mm across.

**NOTE:** *If you intend to break up an old mirror, use a cloth or towel to wrap the corner, so glass shards do not fly from the mirror as you break it.*

The speaker needs to be driven by an audio source, but the level should be low so you can only hear it when your ear is next to the speaker. Set your audio player to loop the output indefinitely and then adjust the volume as low as it will go but still allow you to just barely hear it.

The alignment of the laser from the source to the target is not a trivial task. As the distance to the target is increased, the error level is also increased. Initially, set up the speaker and pointer about 1 meter apart, and then increase the distance as you become more familiar with aiming your test system. With a powerful enough laser, the Laser Listener could potentially work many hundreds of meters away, but alignment would be very time consuming and the receiver would need a very sturdy base to ensure it does not move.

To make your life easier when experimenting with the test setup, create adjustable stands for the speaker, laser pointer, and photodiode.

#### Circuit Design

The basic test system makes use of an operational amplifier, capacitor, resistor and a photodiode as shown in Figure 2.

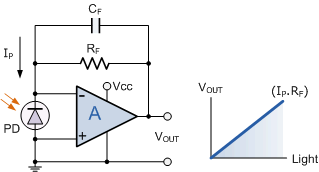


Figure Photodiode Amplifier

Photodiodes are basically PN-Junction light sensors made from silicon semiconductor PN-junctions which are sensitive to light. These are similar in form to a normal LED but with a clear lens to focus the received light on the PN chip. Photodiodes are very versatile light sensors that can turn its current flow on and off in nanoseconds and are often used in cameras, light meters, CD, and DVD-ROM drives. This basic circuit uses the photodiode to change the current, Ip, based on the amount of light falling on the photodiode. Any op amp will do (an LM741 for example), as this circuit is a transimpedance amplifier that simply converts the current into a voltage, VOUT, linearly.

Op-amps (or Operational Amplifiers) are a type of DC-coupled high-gain electronic voltage amplifier with a differential input and single ended output. An op-amp produces an output voltage that is typically hundreds of thousands of times larger than the voltage difference between its input terminals. The gain of the op-amp is governed by the impedance between its inputs and output. Refer to the manufacturer datasheet for pin connections for your specific op-amp.

A suitable value for the resistor, RF, would be approximately 1MOhm. The capacitor is used to smooth the output to increase stability of the amplifier, so its value is not important. Any value between 100nF and 4.7uF would be suitable. Note that the photodiode should be in reverse bias (the wrong way around).

Connect the circuit up on the NI myDAQ Protoboard as shown in Figure 3, using the 15V power supply rail for VCC and AGND for the ground source in the circuit. It is good practice to place an electrolytic capacitor across the power rails to help remove rail oscillation and noise in your final output (values of above 1uF are best). Connect the output of the op amp to the AI0+ channel of the NI myDAQ and connect the AI0- to ground.

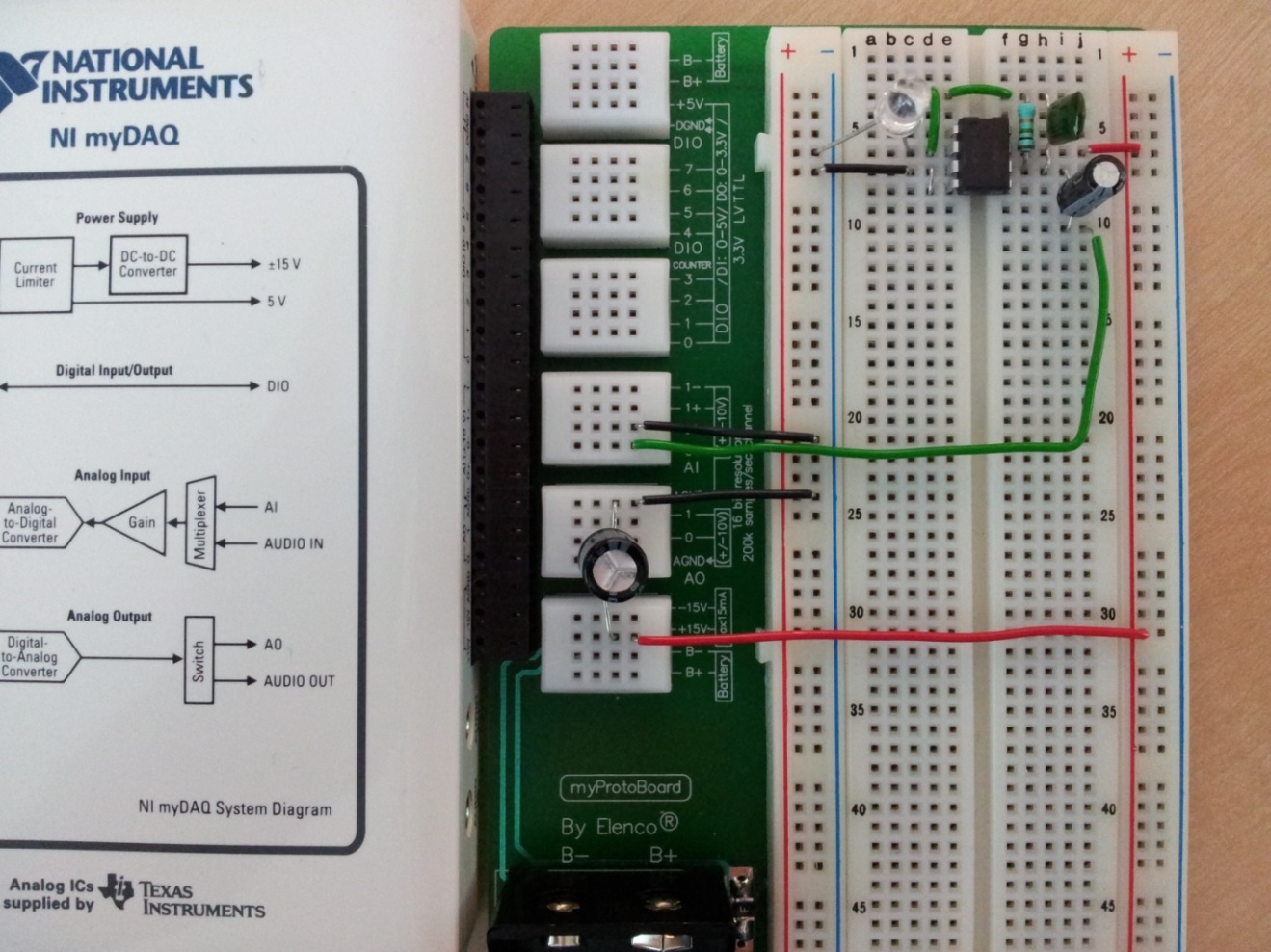


Figure Protoboard Layout

**NOTE:** *When connecting capacitors, always discharge them first by shorting out the pins. Do not add capacitors while your circuit is live to avoid current spikes.*

### Software

Getting started with the NI myDAQ is a simple process, but it is important to ensure that you install the right components in the correct order.

1. Install the LabVIEW for Education on your PC. This includes NI LabVIEW, and the myDAQ drivers.
2. Connect the cable from the computer Hi-Speed USB port to the USB port on the device. The computer will automatically recognise and install the NI myDAQ and then the NI ELVISmx Instrument Launcher will appear. The Instrument Launcher can also be opened manually from **Start > All Programs > National Instruments > NI ELVISmx for NI ELCIS & NI myDAQ > NI ELVISmx Instrument Launcher**.
3. Refer to the NI [myDAQ User Guide and Specifications](http://www.ni.com/pdf/manuals/373060e.pdf) document for further details on the device and how to connect external signals.

### Measurement & Automation Explorer (MAX) setup

Connecting your NI myDAQ to your PC and configuring MAX.

1. Navigate to **Start > All Programs > National Instruments > Measurement & Automation Explorer**
2. Expand the **Devices and Interfaces** section
3. Check the myDAQ is listed correctly and click **Self Test** to ensure it is connected correctly.
4. Right-click the device and click **Rename**. Name the device ‘myDAQ1’ and click **OK**.

### Using the myLaserListener VI

Double click the myDAQ Laser Listener.vi file (shown in Figure 4)

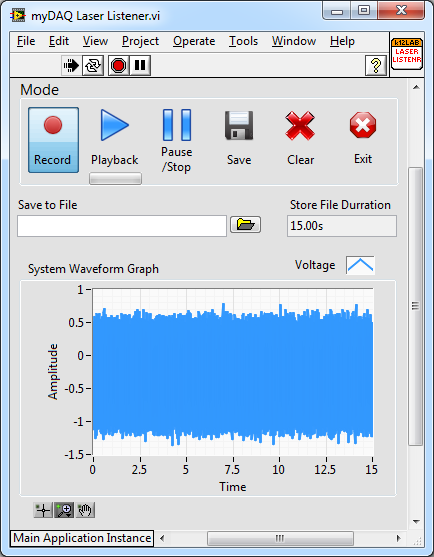


Figure myDAQ Laser Listener.vi Front Panel

1. Select a file path to save your recorded spy sounds to
2. Run the VI
3. Click the ‘Record’ Button to begin capturing sound
4. You can pause the recording using the ‘Pause/Stop’ button
5. Click the ‘Playback’ button to hear your recording played back through the ‘Audio Out’ connection on the NI myDAQ
6. Click ‘Exit’ to stop the application

### myDAQ Laser Listener Block Diagram Code

To view the block diagram (shown in Figure 5) click **Window > Show Block Diagram** or hit **CTRL+E**

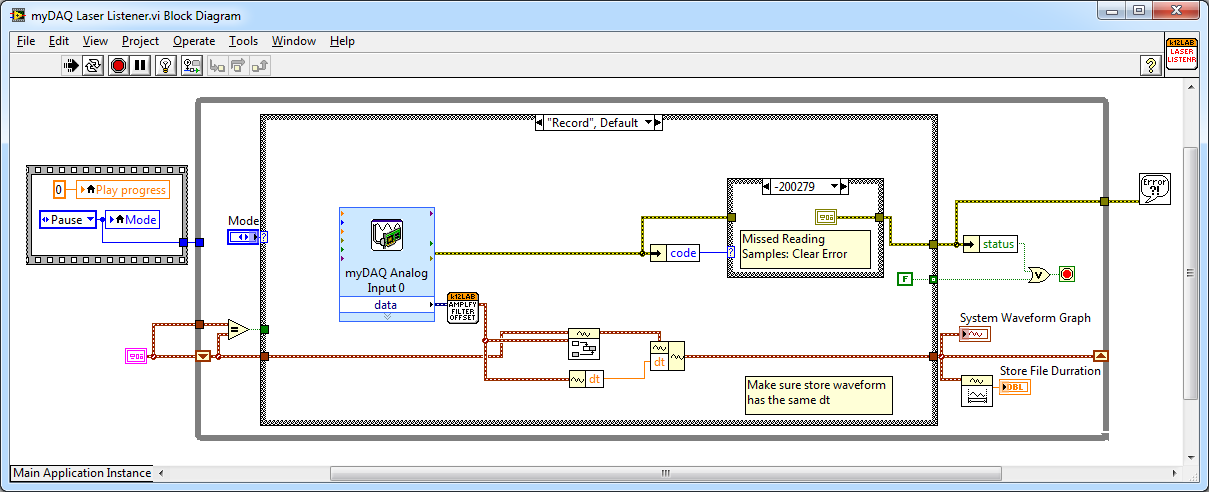


Figure myDAQ Laser Listener.vi Block Diagram

The block diagram for this VI uses a modified state machine architecture comprised of 6 states:

Record: Reads the signal from AI0, scales and filters it then stores it in the VI.

Playback: Plays the stored sound back through myDAQ Audio Output Left.

Pause/Stop: Idol state used when no action is being performed.

Save: Saves the stored sound to a WAV file prefaced by the **Save to File** Path

Clear: Clears to sound stored in the VI

Exit: Stops the VI. Note: You cannot exit during Audio playback.

# Design Considerations

A laser listener can target any object, typically inside a room where a conversation is taking place and can be anything that will vibrate in response to sound waves created by noises present in the room. Preferably, the object has a smooth surface. A laser listener can take three main forms.

### Grazing Laser Microphone

Probably the most intuitive approach to building a laser microphone, a grazing laser microphone reflects a LASER beam at an angle to the reflective surface that is to be measured. An angle such as 45° would be appropriate, allowing the photo detector to be placed at the complementary angle, and located at a near distance on the other side of the reflective surface as shown in Figure 6.

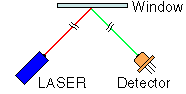


Figure 6 Grazing LASER Microphone

The reflected beam is collected onto a photosensitive detector, where the signal is amplitude modulated by deflections induced in the beam by the vibrations of the reflective surface. This signal will be directly proportional to the amplitude of the vibrations, which is therefore a direct analogue of the original sound waves. This signal can then be converted into an electronic signal by the detector which can in turn be amplified with the use of a myDAQ analogue input channel.

The limitations of a grazing LASER microphone are primarily portability issues. In the case of a LASER microphone, ideally the unit would be self contained and could be operated from a single location. In the case of a grazing type microphone, the sensor position is absolutely critical to achieve a good signal. The LASER edge must be positioned such that the amplitude modulation is a result of the LASER beam physically translating across the sensor. Therefore, the amplitude will increase or decrease the more or less the beam overlaps the sensor respectively.

### Co-located LASER Microphone

The second method is a slight variation on the initial ‘grazing’ design, with the difference being the LASER and detector are co-located (located in the same area); either with a slight angle between the incident beam (still a ‘grazing’ microphone, but with a very small incident angle); or bore sighted where the incident and reflected beam share the same paths as shown in Figure 7.

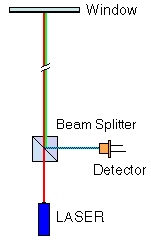


Figure 7 Co-located LASER Microphone

The principles of operation for a co-located LASER microphone are the same as in the case of a grazing type. The co-located design approach offers the advantage of setup ease and portability, as the LASER and detector can be located within the same unit and at the same physical location, unlike the grazing design.

### Michelson Interferometer LASER Microphone

The use of Interferometry increases fidelity in the microphone system and offers the best chance of successful audio recovery. However, the design of an Interferometer microphone is significantly more complex than previous designs. The use of interferometry improves on the previous designs, as the signal can be gathered interferometrically. By gathering the signal in this form, the detector alignment is not as restricted and the sensitivity to vibration is greatly improved. This is due to the nature of an interferometer, where small deviations in alignment and path length are easily detected.

A Michelson homodyne type interferometer produces interference fringes by splitting a beam of monochromatic light so that one beam strikes a fixed mirror and the other a movable reflective surface (a heterodyne detection uses beating between two light frequencies). There are two paths from the light source to the detector via the beam splitter. One path reflects off the beam splitter onto a fixed mirror, where it is reflected back to through the beam splitter and onto the detector. The other path is first transmitted through the beam splitter and onto the reflective translating surface, where it is reflected back towards the beam splitter, which in turn reflects the path onto the detector. Small tilts in either mirror will result in phase shift changes which shorten the fringe period or degrade the fringe visibility completely. The result of this process is a linear change in light intensity through a given cross section at the detector which is a direct analogue of the vibration applied to the reflective surface.

When using a cheap LASER, mirror and beam splitter, the beams will become diffused to a fairly large degree which will result in a magnification effect on the fringes produced by the interferometer. As a result, the intensity of the light inside this magnified fringe area will fluctuate dramatically with vibrations of the reflective surface. The signal can then simply be collected as a temporal waveform that carries the amplitude modulated signal.

This particular approach also contains some deficiencies; the most obvious one being the very large differences in path length for the two beams. Ideally, both legs of an interferometer should be of equal length. This is due to the temporal or longitudinal coherence of the LASER, where the phase coherence of the LASER beam changes over time. If the two jointly arriving beams are not synchronised (due to this path length discrepancy), the constructive and destructive interference is degraded, or non-existent, thus limiting the devices sensitivity hugely. A Michelson Interferometer is shown in Figure 8.

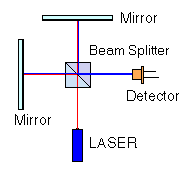


Figure 8 Michelson Interferometer LASER Microphone

An operating design concept based on the Michelson interferometer is shown in Figure 9.

*dm*

*dt*

*dd*

*ds*

*Source*

*Detector*

*Target*

Figure 9 Schematic of the Michelson Interferometer. The LASER emitter, beam splitter, reflecting mirror, target, and detector are all shown, along with the approximate path of the laser beam.

The interferometer compares the relative phase of two paths of LASER light. The path directly through the beam splitter, reflecting off the top mirror, and reflecting off the beam splitter to the detector is shown in equation 1. Equation 2 shows the path initially reflecting off the beam splitter, then reflecting off the target, and passing through the beam splitter to hit the detector. The two paths cover different distances:

for path 1 (1)  
 for path 2 (2)

Therefore, the electric fields of the two beams will probably be out of phase upon arriving at the detector. By using the sinusoidal electromagnetic wave equation shown in equation 3:

(3)

we find that for these two paths, the electric field strengths at the detector are:

(4)  
(5)

And the overall total electric field is:

(6)

(7)

### Path Length Calculation

The principle that allows the interferometer microphone to detect sound is the vibration of the reflective surface caused by ambient sound waves. This means that the path length on the target leg, component *dt* varies in time. For convenient mathematics, we allow *dm*and***Ed****(t)* to be time dependant. We can now split the distances *dm(t)* and *dt(t)* into constant variable components:

*Note: δ represents a small change in the component of the path length, not the Dirac or Kronecker delta functions, which are not relevant to this project.*

so now we have:

) (8)

Equation (8) includes terms representing oscillations on two different orders of magnitude. The variations in the target and mirror distances and occur with frequencies characteristic of sonic vibrations, approximately 3-5kHz. In contrast, the oscillation of the LASER, represented by ω, will be in the order of several GHz for a MASER and 1015Hz for visible light LASERs that will be used for this project. Therefore we can treat and as approximately constant over a few oscillations of the LASER radiation. Accordingly, we define our zero point of time and the quantities *dm0* and *dt0*such that:

and

are integral multiples of 2π. This reduces equation (8) to

(9)

### Intensity Variation Optimisation

The detector measures the electromagnetic intensity, given by

(10)

(11)

Differentiating *I(t)*, we find that for a small change in the intensity variation is

(12)

Ideally, the interferometer should be set up to maximize the magnitude of and thus provide the greatest detectable signal, so we set:

(13)

Therefore

or

The left condition leads to the maximum variation, while the right condition leads to a minimum of zero variation (which would render the project useless). In reality, this result isn’t really useful since we can’t regulate the position to that accuracy, but it will be useful later on.

# Design Considerations

For practicality, a grazing laser microphone is most suitable for this proof of concept project. Although the Michelson interferometer would produce significantly better results, it is a much more complex build and would require higher quality components and a laboratory grade gas laser if the device is to be used at range. Laser pens use silicon chip lasers, so the coherence path length is very short as the device itself is also short. Coherence is a change of phase over time due to the nature of the way a laser produces light. In a Michelson design, this change in coherence would cause a loss of fidelity and increased noise in the signal if the distance from the object is greater than twice the coherence length. Due to this, the Michelson design has not been explored in this proof of concept project, but has been included for completeness.

# Further Work

## Software experiments

After building your first Laser Listener, try experimenting with different processing techniques in LabVIEW to try and make your signal cleaner.

The filtering process alters the frequency content of a signal. For example the bass control on a stereo system alters the low-frequency content of a signal, while the treble control alters the high-frequency content. Changing the controls alters the signal that you hear. Two common filtering applications are removing noise and decimation. Decimation consists of low pass filtering and reducing the sample rate.

The filtering process assumes that you can separate the signal content of interest from the raw signal. Classical linear filtering assumes that the signal content of interest is distinct from the remainder of the signal in the frequency domain.

### Analogue vs Digital Filters

An analogue filter has an analogue signal at both its input *(x)t* and its output *(y)t*. Both *(x)t* and *(y)t* are functions of a continuous variable *t* and can have an infinite number of values. Analogue filter design requires advanced mathematical knowledge and an understanding of the processes involved in the system affecting the filter. The existing filter in the ‘Offset.vi’ subVI is an ‘Express VI’ that uses a menu based configuration screen (by double clicking on the filter on the block diagram as shown in Figure 10). Try experimenting with the parameters to see how it affects your sound.

Because of modern sampling and digital signal processing tools, you can replace analogue filters with digital filters in applications that require flexibility and programmability, such as audio applications like this project. You can replace the analogue filter with a digital filter to make further improvements to the sound if you wish. You will require a copy of the LabVIEW Digital Filter Design Toolkit to design digital filters from scratch.

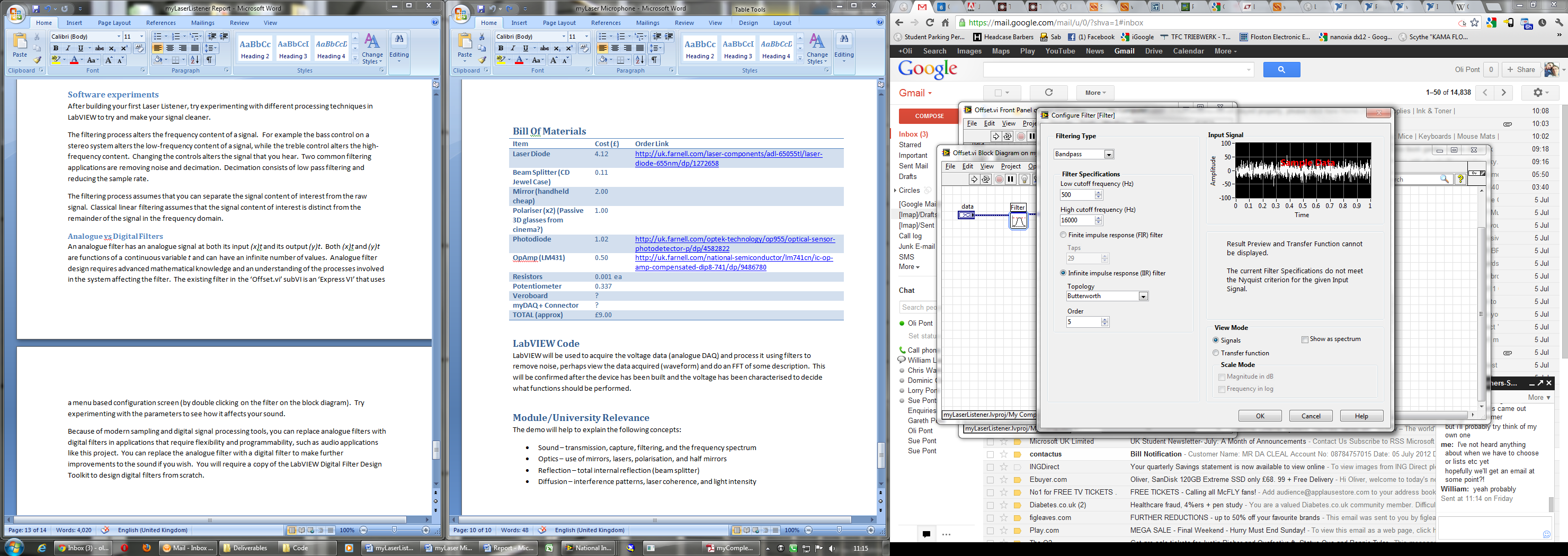


Figure 10 Filter Express VI Dialogue Box

# Help & Troubleshooting

<http://forums.ni.com/> The NI Forums are a great place for help

[K12Lab.com](http://www.k12lab.com) Find other lesson plans and inspirational content for myDAQ and LabVIEW

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