

# Using lasers to shed light on musical sound

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PHY 312

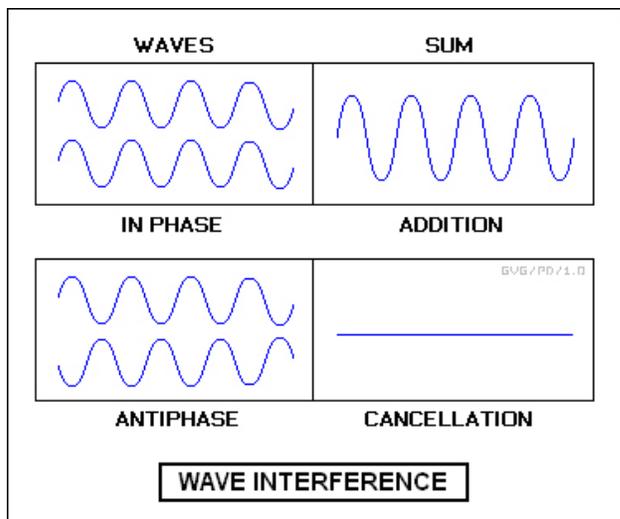
## Introduction

Ever since the invention of the laser, scientists have been trying to find ways to utilize them to help discover and solve new problems; one thing that has been studied is Holographic Interferometry. Holographic Interferometry is using lasers to measure very small displacements caused by vibrations and stress on the object. Along with being able to measure these, holograms can also diagram air flow patterns as well as pressure flows. Using these holograms, three dimensional models can be made and then various properties can be measured, including the velocities of the air flows.

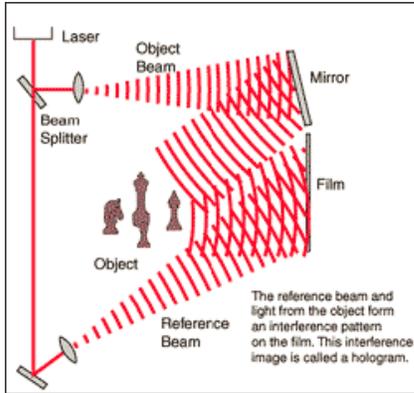
Holograms have been made and used for years for these experiments, starting around the 1960's. Anything from using them to measure stress on metal building objects to the pressure flows from jet engines and bullets. With the jet engines, better wings could then be designed according to the new physical model that exists because of Holography. We decided to take this technique and apply it to the vibrations in musical instruments. These vibrations create a displacement in the material used to make the instrument and affect the way the instrument sounds. Our goal for this project was to build a holographic system capable of measuring these displacements.

## Theoretical Background

The main theory behind holograms is the wave property of interference. Waves when interacting with other waves can interact in two main ways, constructive and destructive interference. The two waves after interacting will combine to form one wave. If the two waves run into each other in phase, then constructive interference will occur, which will increase the amplitude of the light wave output and make it appear brighter. If there is a phase difference between the two waves, they will interact through destructive interference. Destructive interference will decrease the amplitude of the final wave and, opposite of constructive interference, will dim the light wave. Holography uses this interference and creates a 3-D replicate of an object on a piece of holographic film or glass.



There are two different types of holograms, transmission holograms and reflection holograms. The big difference between these two methods is the plane on which the wave interference is imprinted on the film. The reflection hologram will have the object placed behind the plates holding the holographic film. This lets the reference beam pass through the film and then the light hits the object. Light is reflected off of the object and hits the other side of the plates. This method imprints the interference between the reference beam and object reflection in parallel with the film. Along with a more complicated developing process, this can allow the hologram to be seen in sunlight as well as light from the laser. The transmission hologram places the object in front of the plates and has the reference beam and object reflection hit the plate on the same side, having the interference pattern form perpendicular to the plane of the film. The developing process of the transmission hologram is much more simple, but the finished product can only be seen with a laser.



<http://www.hologramsuppliers.com/transmission-hologram.html>

The image in the hologram is created by the combination of the millions of different interference patterns that occur from the objects illumination and reference beam. Each spot on the object will reflect the light at a different point in its wavelength. These different phase shifts will cause different interference patterns with the reference beam and this combination would be imprinted onto the film. Through the transmission holography method, the angle at which the laser shines through the film must be the same angle to be viewed from. With that in mind, it is possible to take several different holograms with the same piece of film. If there were different angled reference beams hitting the film, these different beams would interfere with the objects reflection independently and form their own patterns on the film. The final product could then be viewed at different angles, showing different images.

These interference patterns that are formed create fringes in the image. These fringes are directly related to the displacement on the object as well as the wavelength of the laser. The simple equation relating the two is:

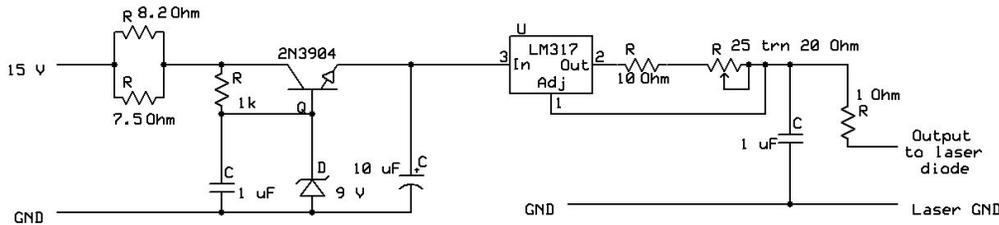
$$D = \lambda / (2 * \sin(\theta/2))$$

where D is the displacement between the fringes,  $\lambda$  is the wavelength of the laser and  $\theta$  is the angle of separation between the objects reflection and the reference beam.

## Process

Before any holograms could be made, the first step was to build the laser. Talon was primarily the one working on the design of the circuit,

while Aaron was the one who had soldered the final circuit. For our laser, we decided to use a laser diode as the laser source. Laser diodes are interesting in that each one is unique in its properties. The laser diode used here was a type ML1016R-01 that output a laser with wavelength equal to 663 nm and a power output of 30 mW. The trick to the power supply is that it must be a constant source of power. The laser diode we used is very sensitive and can be destroyed by a number of different occurrences. The diode's operating current is between 45 and 87 mA, so we had to design a source that could output that current without any jump in current when it is turned on. A jump in the current as soon as it starts, or at any point that it is on, would destroy the laser. We used Holowiki and Sam's Laser Diode Power Supply FAQ to design the power supply. The end result was this circuit:



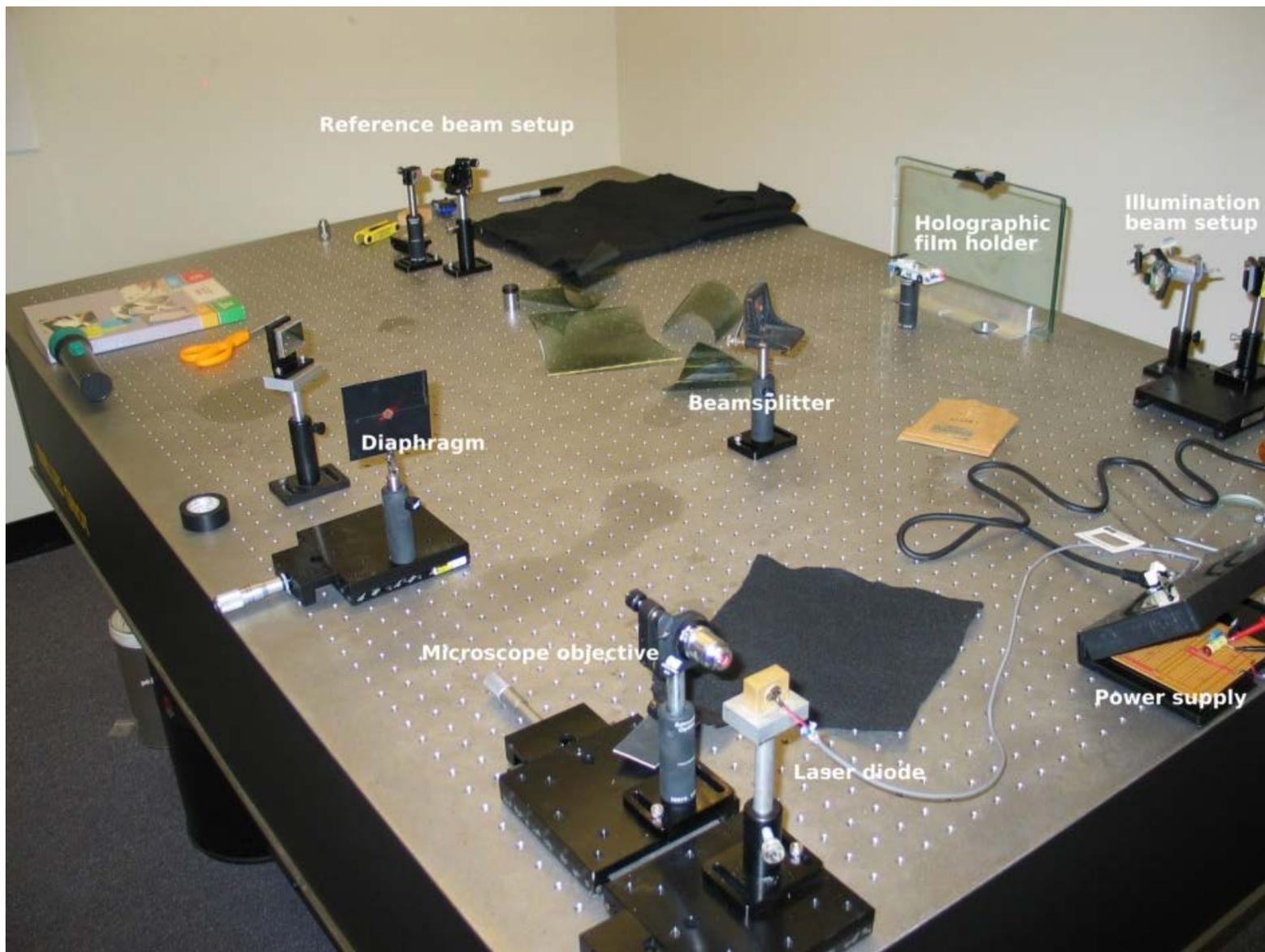
The 2N3904 NPN transistor is used to provide a slow start to the power supply as to not burn out the diode. To control the speed at which the slowdown occurs, we used a 1 k $\Omega$  resistor and 1  $\mu$  F capacitor in series. The 9 V zener diode is used to make sure that a constant 9 V is sent on to the LM317 opamp. This chip, with the help of a 10  $\Omega$  resistor and a 25 turn 20  $\Omega$  potentiometer, would send out a constant, usable current for the diode. With this set-up, we are able to send out constant sources of current ranging from 42 - 125 mA. To test and be sure that the current is stable and not having any significant jumps, we connected the output to laser diode to an oscilloscope and watched the output on the screen. We created a screen capture of the jump after turning the power source on and it was nice and even. Before we could test the circuit on the laser diode, we connected it to a test circuit consisting of four LED lights connected in parallel. We would turn it on and adjust the current so that the LED's would brighten and dim. When we saw it was working properly, we then connected it to the laser diode, being careful not to cross any soldering on laser diode as that would burn it out. One important detail in soldering the laser diode is to be careful of shocking the diode. To prevent this, Aaron was grounded to be sure that any sort of shock would then go straight to ground instead of the laser diode.

The next step involved putting the circuit together on a PC board so that it would be more convenient to carry around. In addition to soldering the circuit board together, we had to fit it into the case (an old VHS box) and solder the power supply to the circuitry itself. We had to be careful in the soldering as if any of the wires had gotten crossed on accident, it would burn out a part of the circuit. With the laser finally being finished, holograms are ready to be made.

Before holograms could be made, the laser had to be focused and the optics lined up. The laser was left on for about an hour to reach thermal equilibrium so as to be sure that temperature would not be a factor in a faulty hologram. After this was reached, the laser was sent through a microscope objective to concentrate the intensity of the beam into a dot. Due to there being too much extra light spreading from the dot, a diaphragm was made and used to block any extra light and let only the laser dot to pass through onto the optics. To get a good spread for the reference and illumination beams, two more microscope objectives were used to spread the light across the area where the holographic film would be and the object.

After deciding on how the reference beam was going to be made, it was time to determine the set-up of how the holograms were going to be made. We consulted the *Holography Handbook* by Unterseher, Schlesinger, and Hansen to find the set-up that we would want to use. There were two variations to the set-up we chose, one used one illuminating beam while the other used two. We first tried the one illuminating beam

set-up to see what kind of holograms we would get. After doing a few of those, we switched to the two illuminating beams set-up to see if the difference would be big enough to say it is better than one illuminating beam. Unfortunately, with two illuminating beams, we would have had to choose between a dim reference beam or a dim illuminating beam due to a second beamsplitter. Either way, the final image was too dim to be seen well so a one beam illumination was the final set-up. Aaron did the majority of the optics set-up while Talon helped in building posts for the mounts. Here is a picture representing the basics of our final set-up:



Before holograms could be taken, we had to cut out the film from the roll of holographic film that we had. First we had to check and make sure that there was practically no light coming into the room in any way. If there was, it warrants a risk of the film being exposed and ruined. For us to be able to see, we used a green safe light in the rooms. The holographic film we used is sensitive to red light so a red safe light normally used in darkrooms was a bad idea. To take the hologram, we exposed the film to the laser for approximately 20 seconds, making sure not to shake the table. Any sort of vibrations to the optics would wash out the final image.

Afterwards, we had to have all of the developing chemicals set up and ready. We had four tubs for the chemicals: one had the developer solution (1 part developer per 10 parts water), another had a stop bath solution (16 mL stop bath per 1 L water), the third one was a rinse tub while the final tub had the fixer solution in it (1 part fixer per 4 parts water). After the hologram was done being exposed to the laser, we

brought it to the darkroom for development. We set it in the developer gently agitating it until it turned about 60-70% dark. We then put it in the stop bath for approximately a minute and then in the rinse tub for a few minutes. After the first rinse we put it in the fixer so that the hologram would be more permanently set in the film and then rinsed it again. After the second rinse we clamped it in front of a fan for it to air dry.



A hologram we made of a toy car.

After having developed working holograms it was time to try and get one of a resonating violin. The first step was making sure we could get a hologram of the violin itself, without resonating the violin. We spread out some chalk dust on the violin to make sure that enough light could be reflected onto the holographic film and then took a holograph of it. The violin itself was too dim to create a bright enough image. With the results from that, we went on to start making holograms of a resonating violin. There were two attempts made to make the violin resonate. One was to have a speaker play a frequency at which the violin plays a note, while the other was to have a metal rod connected between a mechanical vibrator and the violin itself. The mechanical vibrator worked out better, which will be explained in the results.

## Results

Several holograms were made to determine the proper distance to have the object away from the holographic film. Our final distance turned out to be a few inches from the film as that gave us the brightest image. In addition to object distance, different currents were tried in getting a brighter image. We first tried a current of 65 mA, which gave us a fairly good image. We tried 70 mA and 75 mA, but neither one of these provided any better images. The best values at that point were 65 and 70 mA, so we tried a middle number of 67 mA and that gave us our brightest images, so we stuck with that. Unfortunately the violin, with the chalk dust, was not coming out real bright in our holograms. So we attempted to get as much current as we could into the laser to make it as bright as possible. We tried a current of 85 mA and it turned out to give us our best images.

With still images taken, we next tried to get a resonating image of the violin. Our first attempts were taken with a speaker. The speaker would resonate the violin nicely, but it also resonated the optics on the table. With a resonating optics set-up, all of the images taken were washed out

of the final hologram and so we tried lowering the volume of the speaker, but that still washed out all of the images. We then turned to a rod connecting a mechanical vibrator to the violin. With this, the sound was dampened and the vibration would travel from the vibrator, through the rod, to the violin. This worked in that none of the optics were resonating. This was tested by placing another object in front of the violin to see if we could see it with the violin resonating. This hologram came out with the new object in the image, but the violin had washed out. We tried several different frequencies (477.2 Hz, 466.2 Hz up to over a 1000 Hz) and none of these seemed to work. We were unable to find a frequency and amplitude combination to resonate the violin to a point where it would have resonating fringes in the image without washing out due to the vibrations.

## Conclusions

Since we were unable to develop any resonating violin images, we did not have any real results to use for our project. Any resonating violin images were washed out and we could not get any good images. Things we would try in the future are possible different methods of resonating the violin, as well as trying to find a better frequency and amplitude combination. Also, to get better images, we would try and find a better light ratio between the reference beam and the illumination beam. The light ratio is a crucial part in creating a bright image and more work on that could result in better imaging of holographs. One last thing that could help is a stronger laser. We found that a higher current going into the laser diode created a better image, but due to the diodes limitations we could not get a higher power output. If we had had more time, we could have used a more powerful diode and have possibly created even better images.

## Resources

[http://www.holowiki.com/index.php/Types\\_of\\_Lasers](http://www.holowiki.com/index.php/Types_of_Lasers)

<http://www.repairfaq.org/sam/laserdps.htm>

<http://www2.ph.ed.ac.uk/~wjh/teaching/mo/slides/holo-interferometry/holo-inter.pdf>

<http://www.eng.warwick.ac.uk/OEL/previous/interferometry.htm>

F. Unterseher, J. Hansen and B. Schlesinger, *Holography Handbook: Making Holograms the Easy Way* (Ross Books, Berkeley, 1982)