A Thesis Submitted for S406 in Partial Requirement for the Bachelor's Degree in Applied Physics

USE OF SLOT CARS FOR MEASUREMENT OF THE DOPPLER EFFECT FOR INTRODUCTORY PHYSICS STUDENTS

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Abstract

Introductory physics students are often familiar with the Doppler Effect, but really do not have a chance to discover on a *quantitative* level. This report describes a fun way to measure the Doppler Effect using a toy slot car track and a customized slot car with a siren. With the described setup, students are able to accelerate the slot car to velocities of about 3 m/s, or just below one percent of the speed of sound. A corresponding frequency shift of about one percent above and below the siren frequency was observed, providing us with a corresponding shift of frequency of about two percent, or 60Hz, well within the audible range.

This report includes detail of design process in hopes that a motivated educator with a team of motivated students can build upon as the lab itself provides an excellent teaching tool to learn about concepts in motion in addition to the Doppler Effect.

Introduction

Objective

Introductory physics students are often familiar with the Doppler Effect, but really do not have a chance to discover on a *quantitative* level. Because the effect becomes significant only with velocities significant as compared to the speed of sound, either a) an object moving this fast becomes dangerous, or b) the effect is not significant enough to measure within experimental uncertainty. The physics department at Indiana University Bloomington has developed a solution: use a slot car to get significantly high speeds and depend on the analysis power of a computer to measure a slight shift in frequency. This project set out to achieve the following two goals

- Design, test, and build a slot car which can achieve a speed of 10 m/s (about 22 mph) such that the Doppler shift is easily measurable
- Generate a final result where students can audibly observe the Doppler effect

Theory

When sound is emitted from a moving source, a stationary observer hears sound at a slightly shifted frequency as follows.

$$\Delta f = f_{source}\left(\frac{v_{source}}{v_{sound} \mp v_{source}}\right)$$

At speeds near 10 m/s, just below three percent of the speed of sound at room temperature (340 m/s), we can make an approximation to the above formula.

$$\Delta f \cong f_{source}\left(\frac{v_{source}}{v_{sound}}\right)$$

Very simply, the shift is directly proportional to the ratio of the speed of our slot car to the speed of sound. A frequency of 3500 Hz should produce a shift of 105Hz.

Design Considerations

Careful consideration of the design of the experiment reveals that one must manage a few opposing forces. The frequency should be high enough that we can measure the Doppler Effect, yet we are constrained by the sampling rate of the software if we want to measure small shifts in frequency. We should be cognicient of the ambient frequency spectra of background noise to ensure that our function generator would not be difficult to measure due to noise at a nearby frequency. The car must be able to reach speeds high enough that the Doppler Effect is measurable, yet the noise that the car generates nor the speeds that it would realistically reach cannot be determined until the car is fabricated. The loudspeaker used must be loud enough to stand out in the frequency spectrum, yet the larger the speaker the more mass we have to accelerate to this speed. We need to try to minimize mass, yet in doing so wheels lose the traction needed for acceleration. At the same time, there is a limited array of Doppler car kits available and we must choose one that can accommodate the addition of a function generator and loudspeakers. This quickly became quite an engineering project, and would in fact make quite a nice project for a small group of motivated students learning introductory physics. Solving the problem of accelerating the car most effectively is a great tool for learning about motion as it requires understanding acceleration, traction, torque, and Newton's 2nd law.

Because a) the experiment had to be ready by the end of the current semester and b) we had to work with the equipment available, a concurrent engineering approach was the most effective tactic. First, a slot car kit was chosen which can accommodate a custom-built function generator that can be changed by adjusting a potentiometer. Now, a frequency spectrum can be generated by recording the sound generated when the car is raced down the track. With the frequency spectra in hand, suitable frequency ranges and power levels are known. Now, attention can be turned to explore how the maximum velocity attained varies with respect to the weight of the car.

Experimental Testing / Construction Specifications

The track setup

Some educators might have access to a slot car 'drag strip' via a local enthusiasts' club. As part of an introductory level general college physics course taken by hundreds of students, a stationary setup in the regular lab meeting area was necessary. The track consisted of a compressed plywood surface built on a 2"x4" frame separated into three 12 ft sections. The actual slot was created with a standard router: a deep narrow groove for the pin and a more shallow wider slot to install wide braided wire for electrical contacts. Prefabricated tracks could also be purchased. Notice the method for suspending computer microphones in figure 1. For more information about slot car track construction, consult [3].

Figure 1 The Track. The slot car track used consisted of compressed composite board

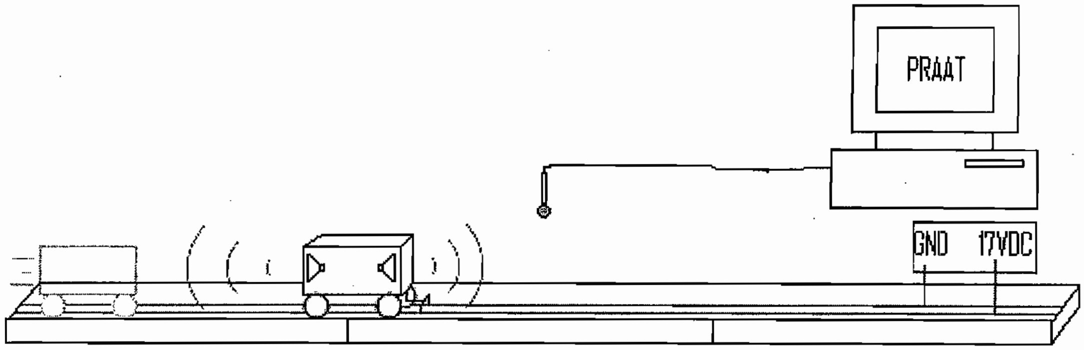


Figure 2 Block Diagram of Track. The track frame consisted of 3 12' sections built from 2"x4" lumber. The microphone was placed within a few centimeters of center. The car was powered by 17VDC via braided wire installed in routed grooves in the surface of the track.

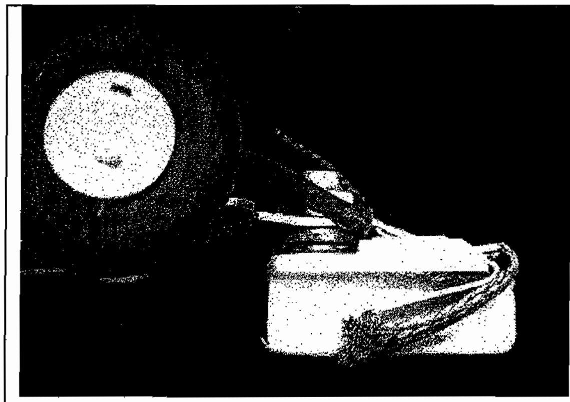


Figure 3 The Car Guide. The slot car kit contained a plastic guide which followed a groove routed in the slot car track between the power supply rails.

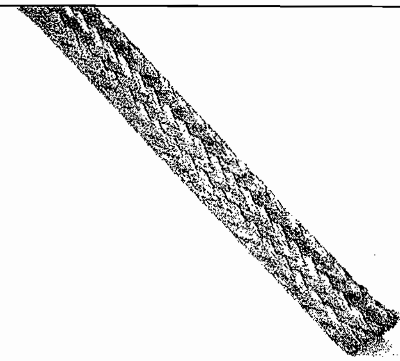


Figure 4 The Power Supply Rail Braided Wire. A thin, flat braided wire was placed in a recessed groove in the track to make contact with the apparatus at left.

The car

The car used was purchased as part of a kit, and was modified to house the function generator, batteries, and speakers (see below). The electric motor was propelled via rails which held a constant 17VDC.

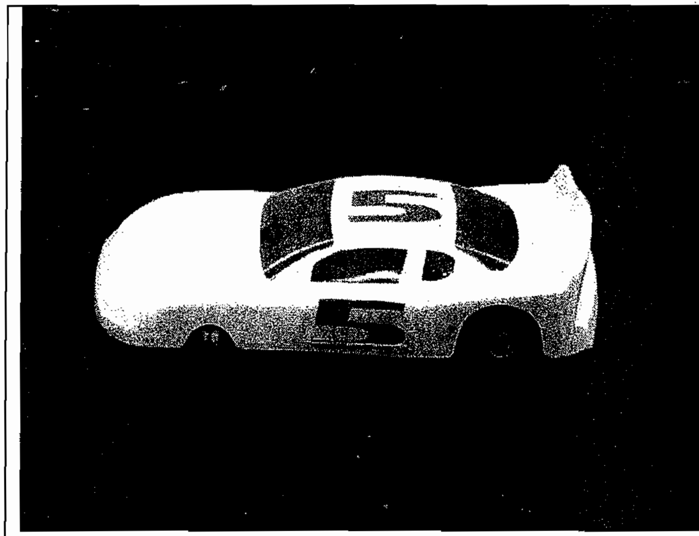


Figure 5 The slot car prior to customization

Background Noise Spectrum

Praat [1], a very powerful open-source sound analysis program, was used to analyze the sound files recorded from the slot car. The program generated the following frequency spectrum of the race car moving down the track with the siren off as shown in figure 6 below. From this plot, it appears that there is really no 'open slot' to choose as the 'screaming' frequency. Instead, we can simply choose a range which has a relative low power as compared to the frequency of the other noise. At the same time, the goal of the experiment is to provide a hands-on exercise where students should be able to 'hear' the Doppler Effect and the higher the frequency the more measurable the effect. While not necessary because Praat offers an elaborate array of filtering algorithms, from this plot we also learn that the speaker should output sound at above 35dB.

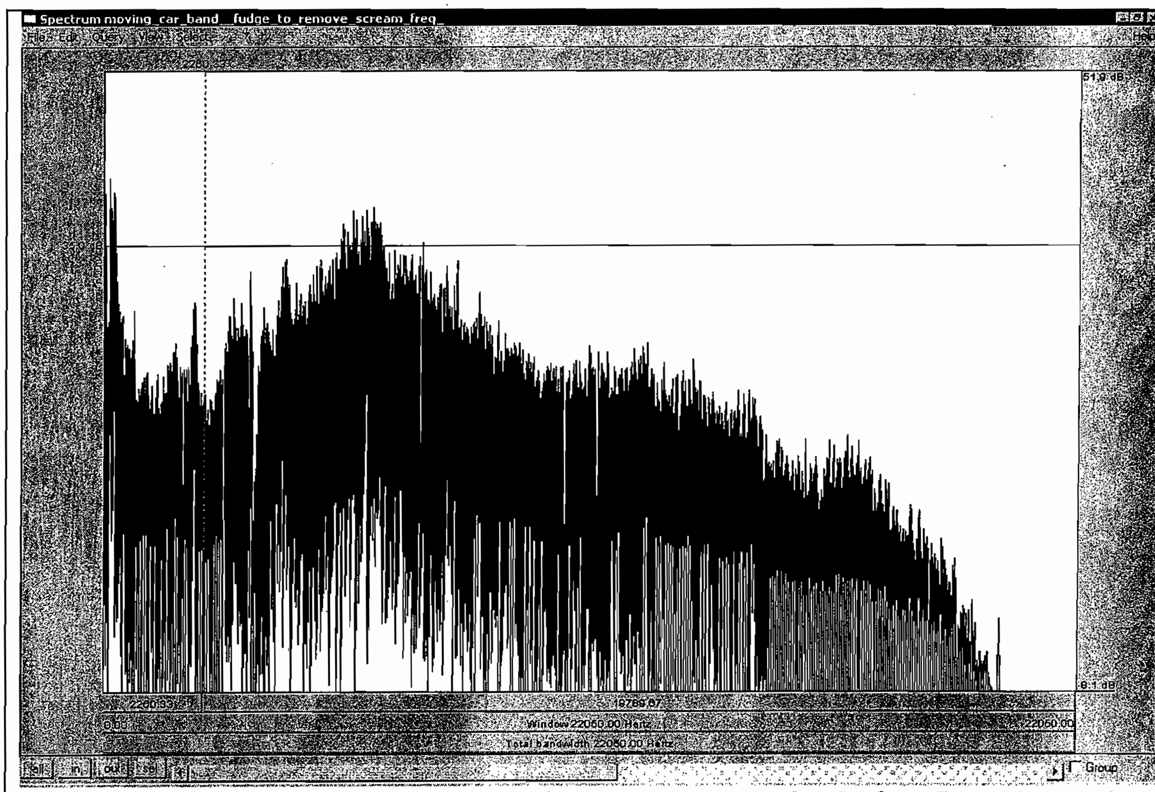


Figure 6 Spectrum Analysis of Background Noise. The screenshot taken by from Praat shows noise to fall in the 0-22Khz range and low power in the 2000-4000Hz range, the chosen frequency for our siren.

Mass versus Traction

The car used the 'stock wheels' provided with the kit, which were approximately 2cm in diameter and made from a very soft rubber. One assumes that in order to provide maximum acceleration, the mass of the car should be minimized. However, traction with the track increases with mass. In order to determine the optimal weight for the slot car, a velocity profile was produced which tells us how the maximum velocity attained varies with mass of the car.

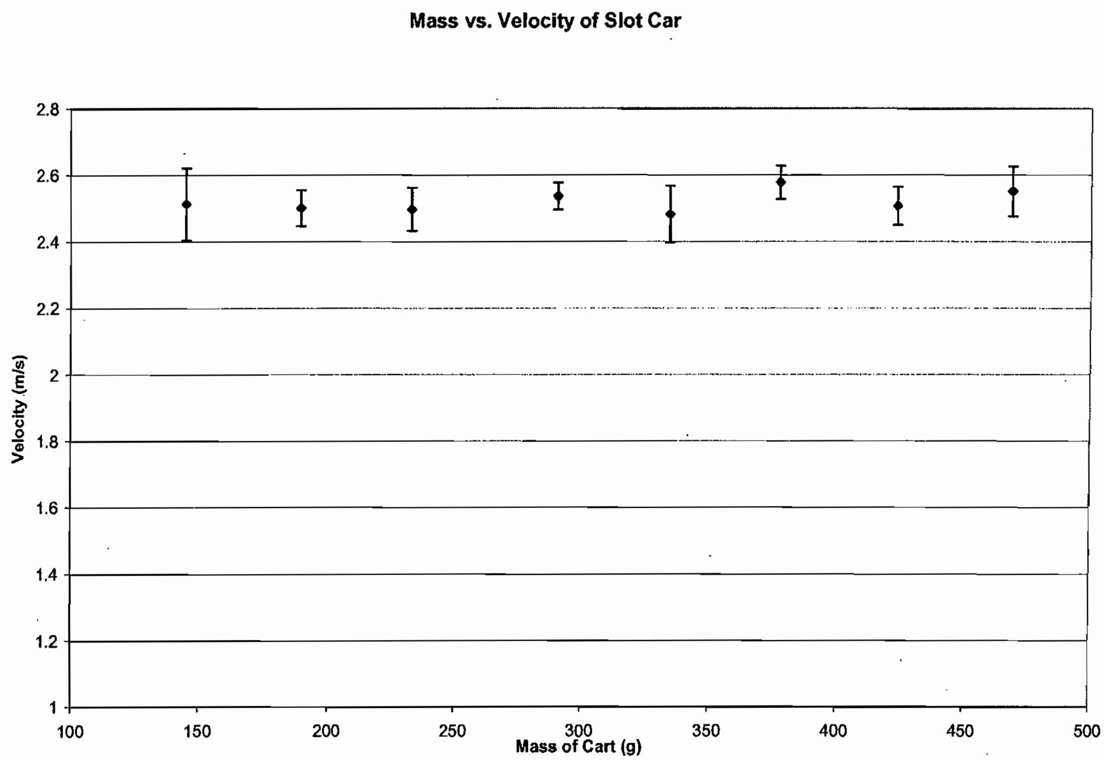
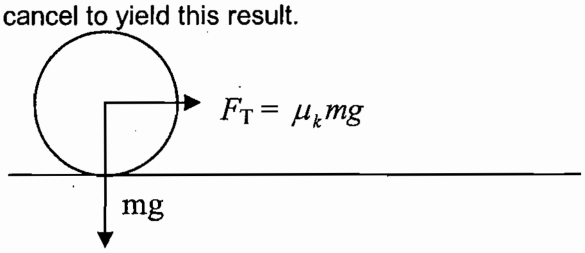


Figure 7 Car Velocity vs. Carrying Load. The velocity of the car at a specific point distance from the starting line remained constant within experimental uncertainty. As result, the mass of the car is not crucial in maximizing velocity.

Coincidently, with the specific conditions of this setup, the maximum velocity did not vary with weight within a range relevant to this experiment (See Figure 7). Because the traction increases linearly with mass and because acceleration decreases linearly with mass, one would expect mass to cancel to yield this result.



$$F_T = \mu_k N = \mu_k mg$$
$$F_T = ma$$
$$\therefore a = \mu_k g$$

When enough force is applied for wheel slippage, acceleration is a function of the coefficient of friction, not the mass of the object, as pointed out in introductory physics texts [2]. With this result, the mass of the car becomes less important as long as it remains within the stated range. The engineer is free to select the speaker and function generator he desires. The traction is the most important factor in attaining acceleration.

However, again, this assumes that the wheels slip. Much work could be done to devise a system where the contact surfaces provide much more traction. In fact, true enthusiasts are known to coat the wheels and tires of the setup with a material to maximize traction. Also, one could design a circuit which provides the correct voltage ramping curve to ensure that there is the maximum amount of torque applied to the tires without slipping. Since the static coefficient of friction is always greater than the kinetic coefficient of friction, the maximal acceleration would be greater. Assuming the tires do not slip, Newton's law comes into play and the acceleration is directly proportional to the mass of the car. Much larger velocities could be attained with lighter cars. The same considerations apply here as would a real drag car. This lends itself well to learning about the physics involved in drag racing, and any literature on the subject could be fairly applicable. While this fact is pointed out in introductory physics texts when looking at blocks on inclined planes, this laboratory exercise provides a fine medium for learning about friction.

Speaker and Function Generator

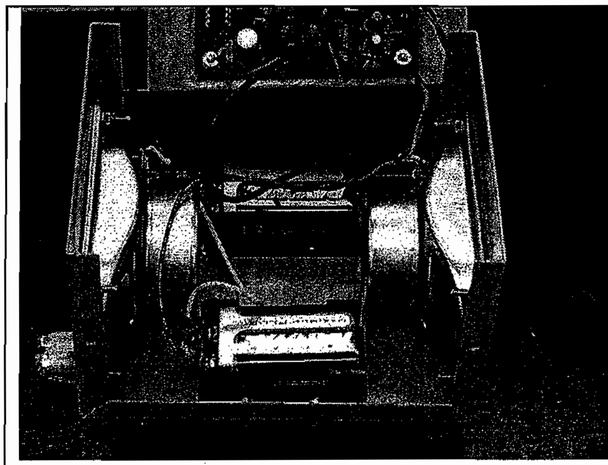


Figure 8 The customized car featured two speakers at opposite ends to solve directionality issues

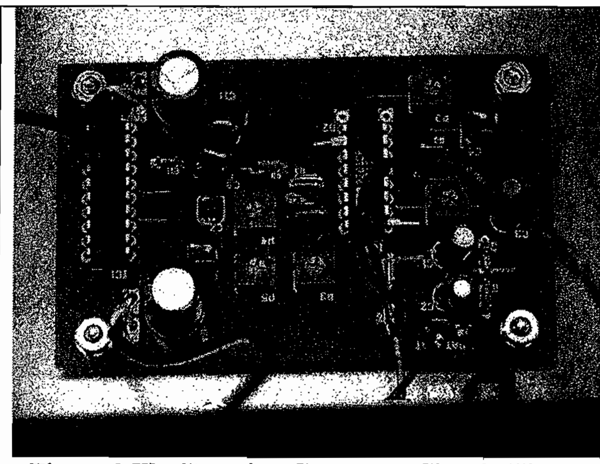


Figure 9 The Function Generator Circuit (Siren). The circuit was powered by two 9V batteries and the frequency could be adjusted with potentiometers.

One could purchase a small noise maker, but beware that most 'buzzers' available do not produce pure tones but a range of frequencies (possibly because they are intended to be annoying to get you out of bed).
An independent power source was used simply because it was the simplest way to be sure that the function generator received a constant power supply voltage as the voltage from the track itself is varied by the user.

See Appendix A for a circuit diagram of the function generator.

Stability

This proved to be both the most troublesome yet unexpected hurdle in the project. Unfortunately the problem did not arise until late in the project not enough time was available to adequately solve the problem. Since the electrical contacts are on the front of the car, if the car finds a bump in its path and the front end rises, it will loose power momentarily. When the connection is restored, there is an immediate toque in the rear wheels causing the front end to rise again. The effect is that the car skips down the track and the car does not build the 2-3m/s velocity needed and inevitably will bounce out of the track as the car is very top heavy. The car could be front-wheel driven and/or a second contact could be added on the rear end to provide a constant electrical connection.

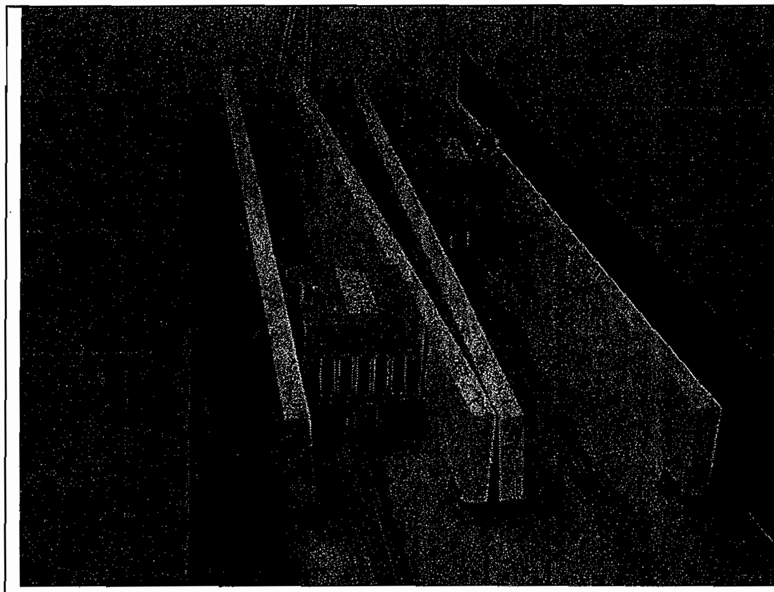


Figure 10 The braking mechanism consisted of two long planks with a rubber band at the far end

Gear Stripping

Many of the problems above mentioned took a toll on the gears in the driving mechanism. If the car had not been so massive, less torque would be necessary. The stability problem caused the toque to change drastically. Without a voltage ramping circuit, the car was started at full torque each time. With these high and sharply changing torques the gears did not seem to last longer than a hundred or so runs. The severity of this problem would vanish with some of the other problems, but the prudent engineer should use a rubber band-driven drive.

Stopping Mechanism

A mass of 500g moving at 2 m/s has considerable momentum. The last section of track (12') had the two rails intentionally shorted, which provided a back EMF within the motor itself. This provided significant stopping power when the car was moving quickly, but of course, will not bring the car to a complete stop. In our setup, we used two 1'x4'x3' boards to create a friction stopping mechanism as shown at right. The ends of the boards are connected with a rubber band, such that the stopping force increases as the car enters the trap. This provides increased deceleration as the car enters the trap to provide smooth yet fast stop.

Results

With Praat, we can see a result almost instantly. Looking at figure 11, the upper pane shows what one would expect. We see that as the car approaches the microphone, the intensity increases sharply and decreases symmetrically as the car departs. As software widely used for speech analysis, Praat automatically plots the few bands of the highest power, called formants. (These can be seen more precisely by looking at the spectrum in figure 12.) More importantly, looking at the formant window (lower pane), we see an obvious frequency at about 3500 Hz, the frequency of the siren. If one looks very closely at the format plot closely at the instant in which the car passes under the microphone, one sees a very slight shift in frequency, the Doppler Effect. With a couple clicks of the mouse, one can generate a frequency spectrum similar to that above. In this case, however, a very obvious spike occurs at 3370Hz, the frequency of the siren.

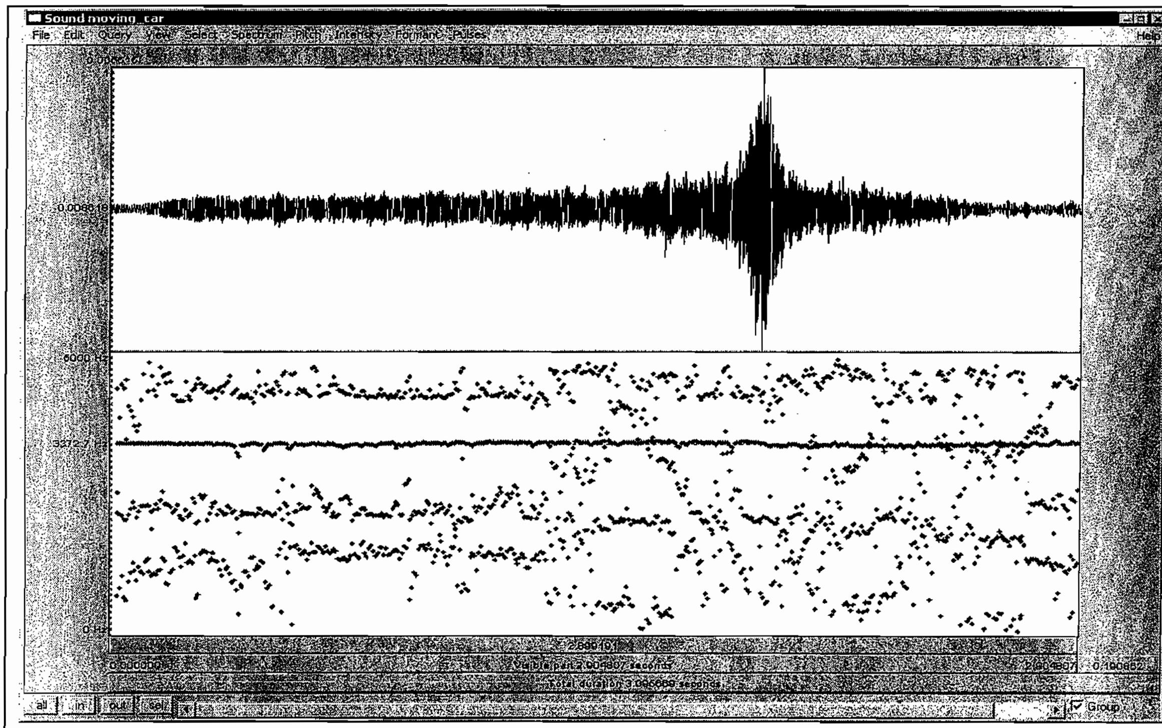


Figure 11 A Screen Shot from Praat of Raw Data Taken from the Track. The upper pane shows the raw data (plotted as amplitude vs. time). The lower pane shows the results from an FFT where we see what frequencies exist in the waveform at different points in time. There is obviously a dominant frequency at 3370Hz as we expect from the speaker, but we also other bands likely created by the electric motor or EM interference in the microphone cable.

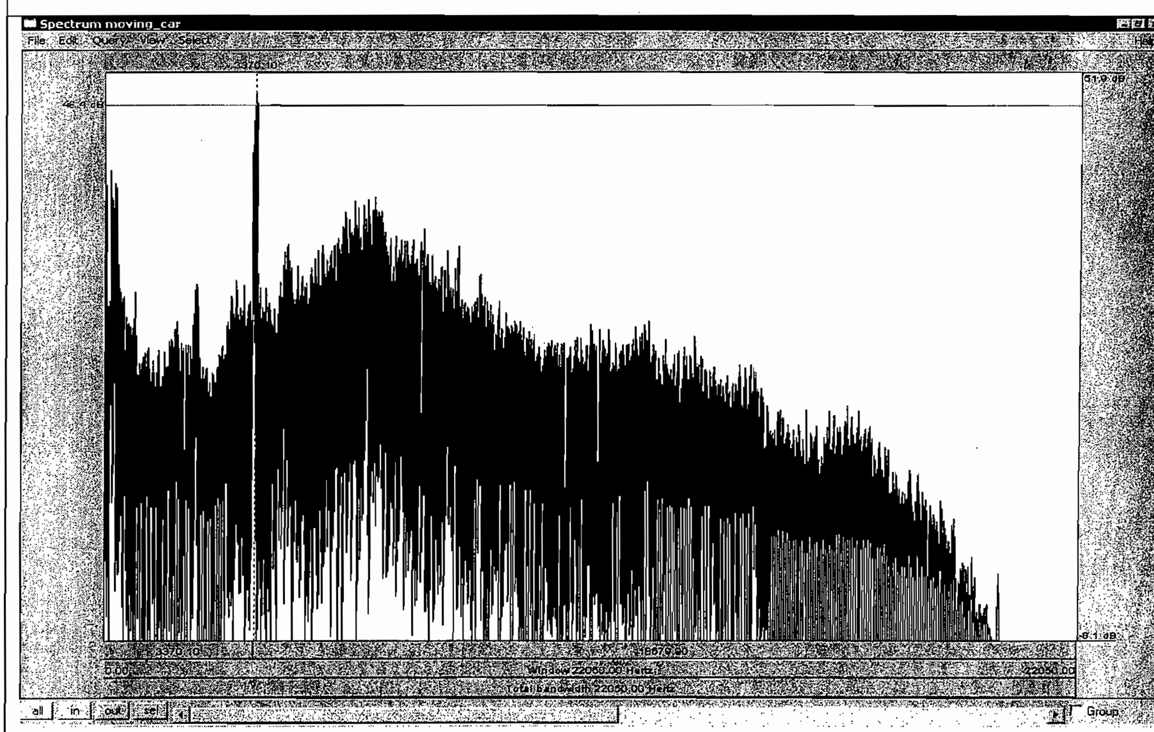


Figure 12 Recorded Sound Spectrum. There is a spike at around 3370Hz, the frequency of our siren

Analysis

Praat provides the student with various software filter algorithms. Since we have measured our siren frequency, we can simply filter out all data which does not fall within 100Hz of this value. After we have done this, Praat gives us a very nice plot which captures the Doppler Effect in a nutshell. In fact, this clean sound can now be played over the computer speakers which provide a very convincing, audible frequency shift.

At this point, instructors should have their students zoom in on the waveform just before and after the frequency shift. Likely, students will not have a clear idea that the waveform plot shown in figure 13 represents a plot of sound pressure versus time. The students should choose a number of cycles to calculate the average period of one cycle and use this number to determine the frequency as done in figure 14.

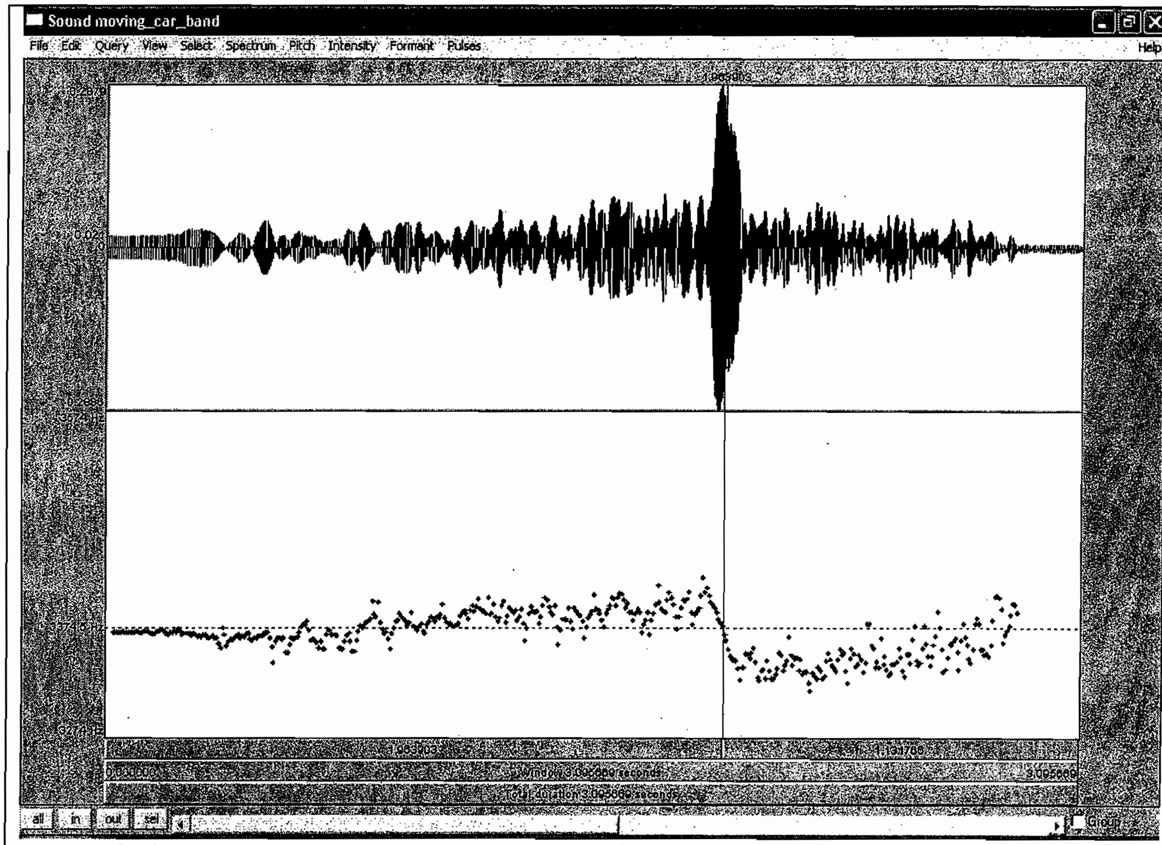


Figure 13 Filtered Data. After applying a pass-band filter (software algorithm) of 3274Hz through 3474Hz, we see an obvious frequency shift at the point of maximum intensity where the car passed under the microphone. The microphone recorded a higher frequency as the car approached and a lower frequency as the car departed. Playing this waveform over a speaker at this point would reveal an audible frequency shift.

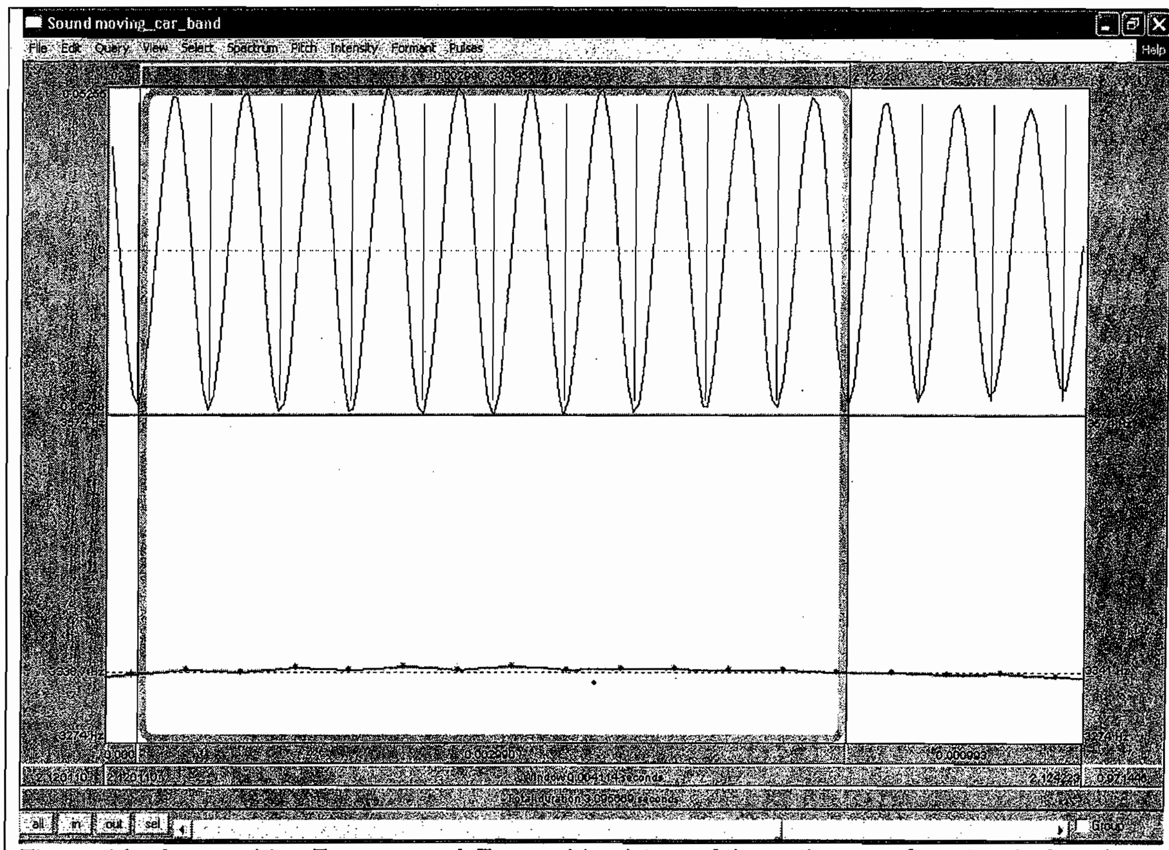


Figure 14 - Approaching Frequency. A Zoomed-in picture of the entire waveform just before the car passes under the microphone shows an approaching frequency of 3400+/-4Hz. Due to the existence of frequencies other than our siren in the waveform (noise), data taken at an arbitrary point should not be trusted.

This method is not likely to yield good results; these values represent the frequency only at the chosen points in time, and as we saw in the formant plot, the data is quite noisy. If one looks closely at the waveform plot in figure 14, there are envelopes in the overall shape of the waveform as one would expect when observing either acoustical beats or resonance nodes and antinodes in an air column. It is hypothesized that these envelopes relate to nodes in the standing wave characteristics of the room, very similar to the nodes one sees in a standing wave pattern one sees in air column resonance experiments. Attempts have been made to try to plot the positions of these as a function of distance down the track to see if they occur at regular distance intervals, but unfortunately, there appears to be more than one series of these envelopes superimposed to create the waveform. Perhaps there is another object in the room, other than the wall, from which the sound is being reflected or we are seeing a result of early sound, that reflected from the track or floor before it reflects from the wall. At any rate, these series blend together and it is difficult to distinguish which peaks belong to what series, and results of such attempts have been inconclusive. In the future one could construct a clever experiment which minimizes such effects to study nodal characteristics as a room acoustics experiment.

Analysis of this data becomes a quick lesson in the effects of a high signal to noise ratio. At periods of low signal intensity in the waveform, the surrounding noise becomes more powerful than the signal itself. Therefore, at these points, the formant plot shows the frequency of the noise, and such points should not be used for analysis. Choose a live spot to collect data points.

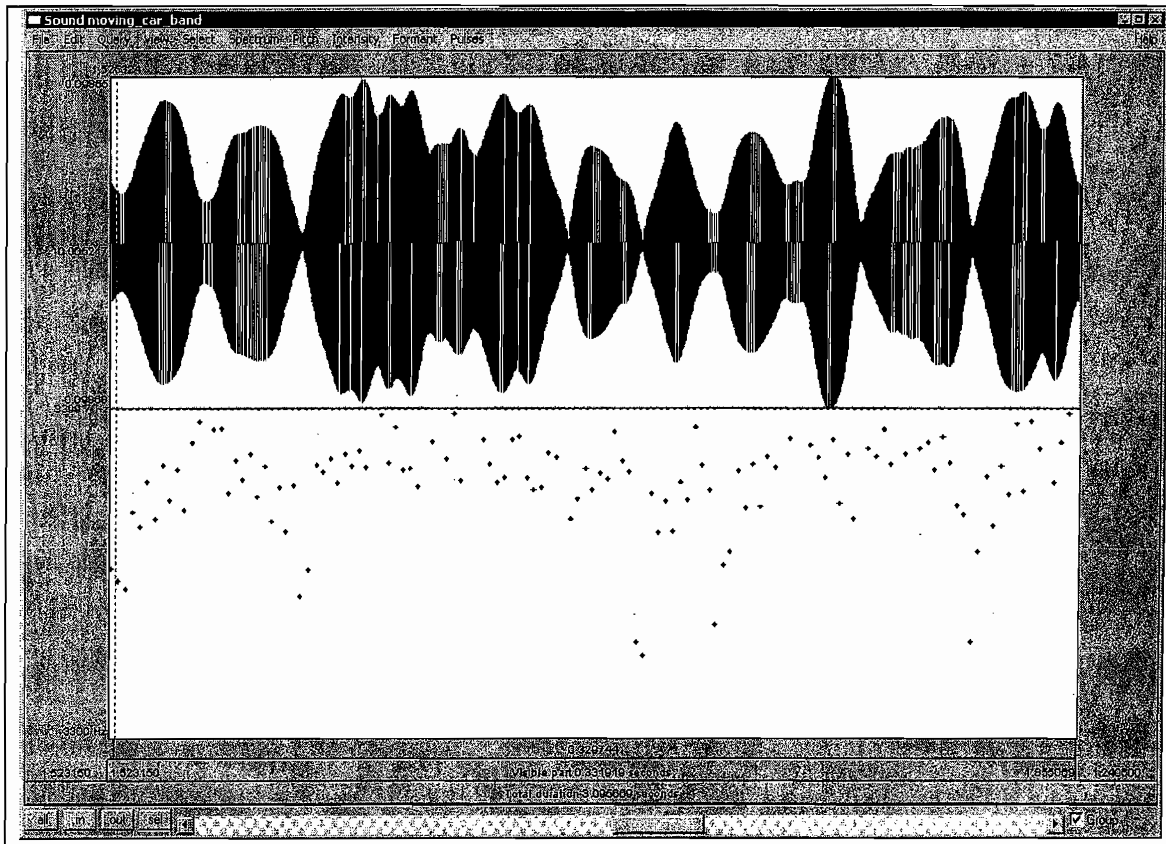


Figure 15 If one zooms in to view about 300ms of the signal, the over-all shape of the signal exhibits dead spots and live spots. When the signal is very low (dead spot), the noise is more significant than the signal itself, so the formants window (lower pane) reports frequencies uncharacteristic of our siren. Data in these areas is unreliable and should not be used. One should chose data points from the live areas.

For this reason, the best method is to simply zoom in to near the frequency shift region as shown in figure 16, and pick a good average value and uncertainty for the departing and approaching frequency. The data shown here yielded an approaching frequency of 3399 +/- 3Hz and a departing frequency of 3330 +/-3Hz.

Students may study the motion along the track to determine its acceleration and velocity which requires determination of the frequency shift at multiple points in its path. One could do as discussed above and choose points corresponding to live spots in the waveform. However, noise exists still within these envelopes. When Praat calculates the formant points, it simply plots the frequency of greatest power within a specified time window. When these windows are very small, it is likely that noise will overpower the signal. When the windows are larger, the noise becomes less significant, and the formants are much more likely to represent the signal itself. Praat sets the default window size to .025s, and this default value has been used in all plots presented thus far. By changing this value to .10s, we can generate a much cleaner formant plot. As shown in figure 17, the student can much more easily see how the frequency changes as the car speeds

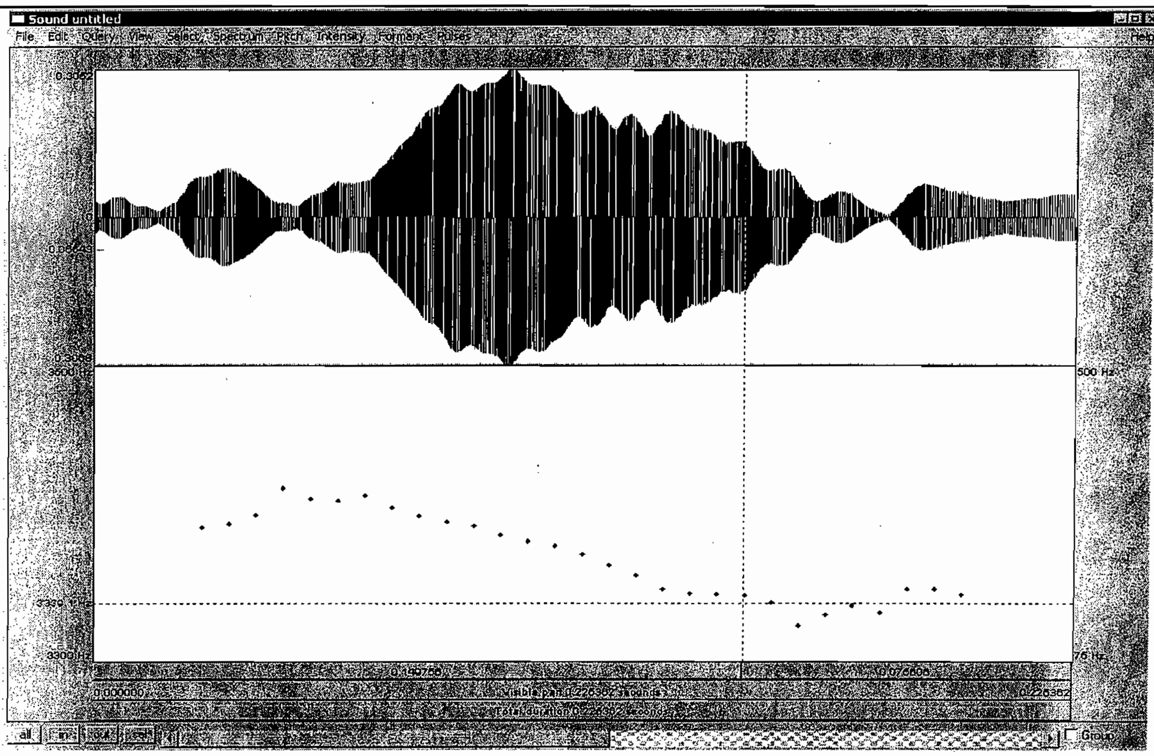


Figure 16 The Frequency Shift. Students can use the mouse to determine the change in frequency of the siren as the car passes under the microphone

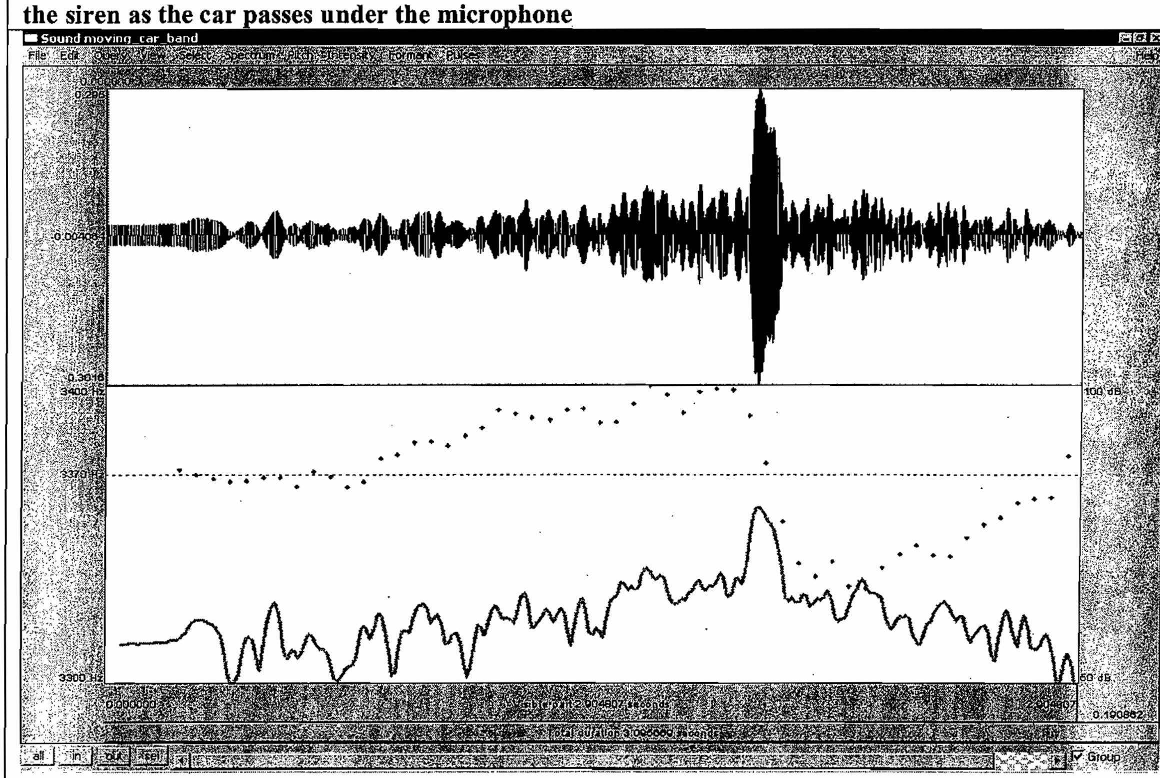


Figure 17 Frequency Formants Using a Larger Window Size. Students can increase the timeframe used to calculate the formant values to minimize the impact of noise seen in <u>Figure 13</u> Filtered Data. The intensity plot in the lower pane can guide students to avoid suspicious data points at low intensities. Note the evidence of noise in the beginning of the run when the measured frequency is *below* the siren frequency.

down the track. In this figure, notice the evidence of noise overpowering the signal at the beginning of the run when the measured frequency is *lower* than the siren frequency. Results are not reliable at this sound intensity level and as such this section of data is not used in subsequent calculations. Note that the dramatic shift in frequency occurs at the same point of maximum intensity (when the car passes under the microphone) in the upper pane and the linearity of the data before and after this shift.

Using these frequency values, one can apply the formula given at the beginning of this report to calculate the velocity of the car at any given time. Figure 18 shows a plot of the velocity of the car as it moves down the track from the frame of reference of the starting line. The velocity curve was linear during both its acceleration, as we expect when the tires are slipping discussed in the Design Considerations section. The car had an average acceleration of 2.2 +/- .2 m/s^2 during its acceleration. The deceleration of the car, is constant as well, with the measured value of 4.5 +/- .2 m/s^2, significantly higher in magnitude than the acceleration as it relied on a back EMF within the motor (the rails of the track were intentionally shorted).

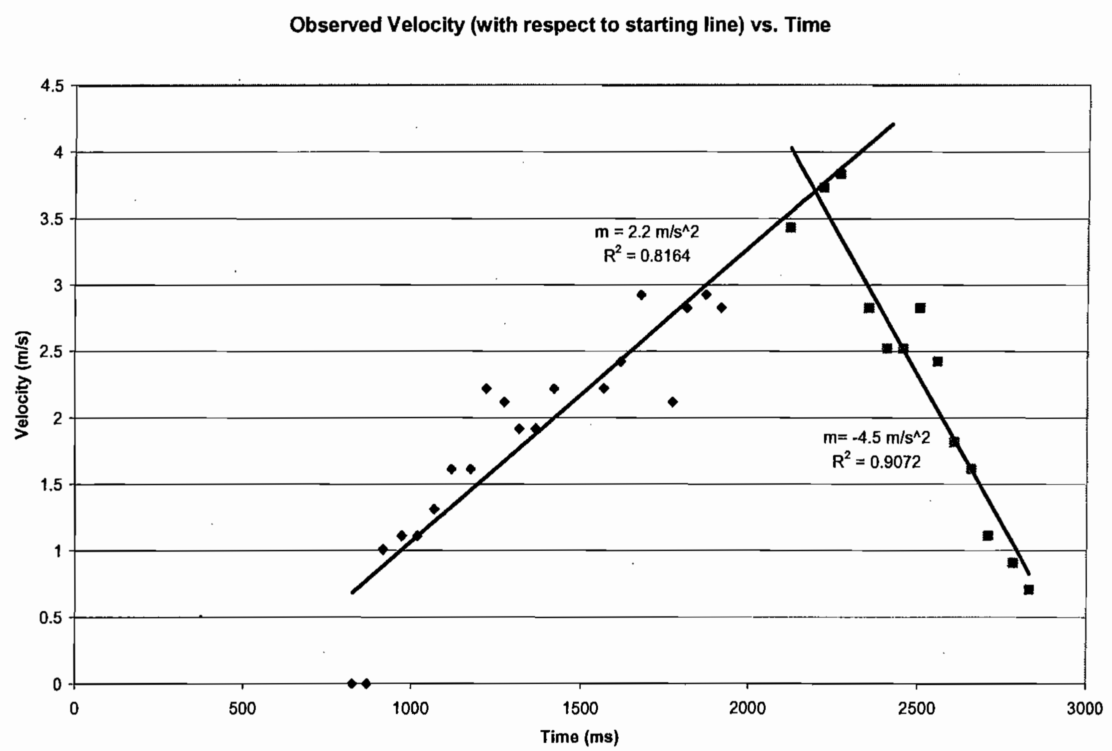


Figure 18 Velocity Plot. The frequency values allow us to determine the velocity of the car as it moves down the track. At 2.2s, we see the velocity drop sharply as it enters the last third of the track with the leads tied together.

Conclusion

The major objective was achieved: while the car did not attain the velocity goal of 10 m/s, the car did realize velocities great enough to observe the Doppler Effect, both quantitatively and audibly. The students found the lab an engaging break from the ordinary. After completing the lab exercise (See Appendix B), students seemed to be convinced that the Doppler Effect actually *worked.*

A group working on a second prototype might investigate ways to improve the traction between the tires and the track. This group could a) significantly improve traction to a point where the tires no longer slip and b) decrease the mass by using a light-weight, prefabricated siren. The decrease in mass alone should improve stability, but a new design should work to lower the center of mass of the car. A new design should also work to improve the quality of the data analyzed. While noisy data is a good pedagogical tool, elimination of such is a better one. The nature of how the envelopes in the waveform relate to room acoustics should be studied in greater detail. Perhaps students could enclose the track with a tunnel lined with acoustical foam or the noise or envelopes could be removed using some convolution technique.

The second prototype makes a great project for a group of highly motivated introductory physics students (high school or college) with a fearless leader. Aside from the Doppler Effect, the project provides an excellent medium to learn many of the topics covered in the first semester of physics (velocity, acceleration, friction, Newton's laws, torque). The project provides fairly simple applications not far from text book problems, yet exposes students to physics in the 'real world' in a fun way.

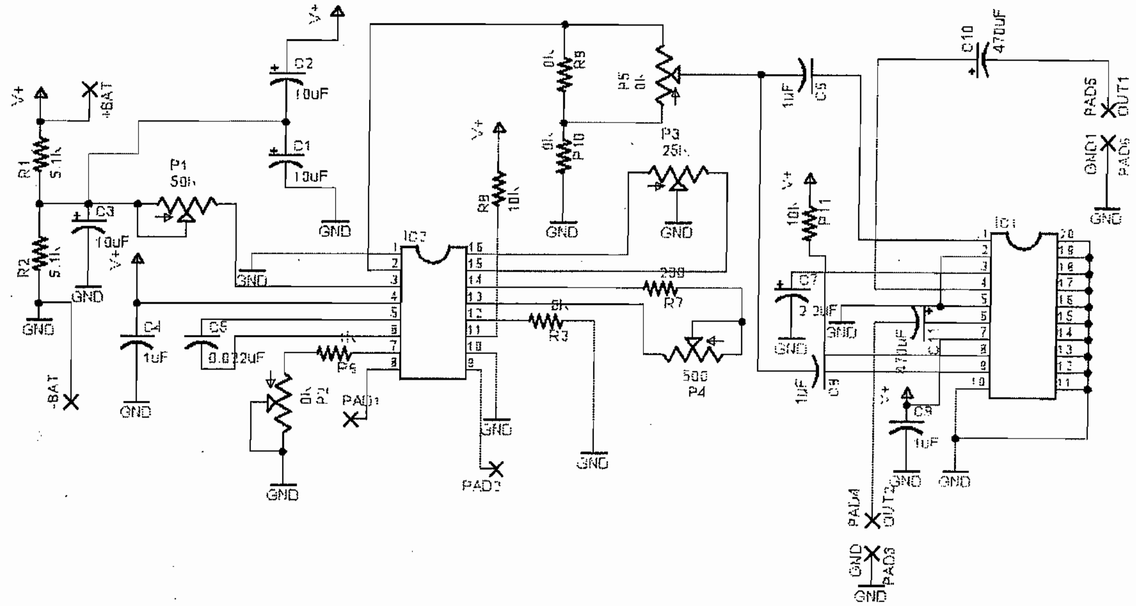
References

[1] Boersma, P., & Weenink, D. (n.d.). *Praat: doing phonetics by computer*. Retrieved December 10, 2005, from Institute of Phonetic Sciences, University of Amsterdam Web site: http://www.praat.org

[2] Halliday, Resnick, & Walker. (n.d.). Properties of Friction. In *Fundamentals of Physics, 6th Ed.* (pp. 101-102). New York, New York: John Wiley and Sons, Inc.

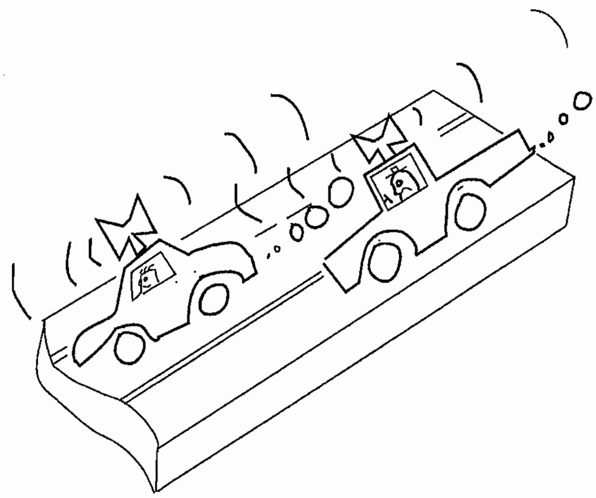
[3] Frost, C. (2003, June). *Track Construction.* Retrieved December 10, 2005, from British Slot Car Racing Association Web site: http://uk.geocities.com/slot_racing/trackbuild/part1.htm

Appendix A
Siren Function Generator Circuit Diagram


IC2
IC1
GND
V+
+BAT
-BAT
PAD1
PAD2
PAD3
PAD4
PAD5
PAD6
OUT1
OUT2
GND1
C10
470uF
C5
1uF
C8
C1
10uF
C2
C3
C4
C6
0.022uF
C7
C9
C11
470uF
P1
50k
P3
25k
P4
500
R7
R3

Appendix B
Indiana University Bloomington
P201 Doppler Lab Manual

The Doppler Effect



Introduction

When a sound is emitted from a moving object, a stationary listener will hear a different frequency than that emitted by the source. If the source is moving toward the listener, the frequency is higher than the transmitted frequency. If the source is moving away from the listener, the frequency will be lower. This effect is known as the Doppler effect. In this lab you will investigate the Doppler effect using a highly modified slot car equipped with a loud tone generator. The sound of the car as it moves down the track will be recorded and analyzed using the lab computers.

In this lab you have two goals. First is to determine whether the apparatus and analysis tools available are sufficient to detect the Doppler effect. Second is to determine the velocity of the cart as a function of time using the Doppler effect.

Theory

The frequency change due to the Doppler effect of a moving source with fixed receiver is given by the formula

$$\Delta f = f_{source}\left(\frac{v_{source}}{v_{sound} \mp v_{source}}\right)$$

where the minus sign is used when the source is approaching the receiver and the plus sign is used when the source is moving away from the receiver. If we assume that the velocity of the source is much much smaller than the velocity of sound we can say

$$v_{sound} \mp v_{source} \cong v_{sound}$$

and our equation for the change in frequency becomes

$$\Delta f = f_{source}\left(\frac{v_{source}}{v_{sound}}\right).$$

This relation is valid for this lab since the maximum speed of the cart is about 2 m/s which is less than one percent of the speed of sound. For the source approaching the receiver both velocities are in the same direction so Δf is positive and added to the source frequency to get the apparent frequency at the receiver. When the source is moving away from the receiver, the two velocities are in opposite directions, Δf is negative and is subtracted from the source frequency.

Finally, solving for the velocity of the source we get

$$v_{source} = \Delta f\left(\frac{v_{sound}}{f_{source}}\right)$$

Although we will investigate only a moving source with a stationary observer, keep in mind the Doppler effect also applies to situations where the receiver is moving and the source is stationary as well as to situations where both the source and receiver are moving.

Procedure

The apparatus consists of an electrically powered cart that travels down a slotted track. The Cart has a built in sine wave generator that emits a single frequency tone. The tone emitted by the car as it travels down the track is recorded with a microphone located near the midpoint of the track. The sound data will be filtered and analyzed using the Praat sound analysis software program. A switch on the cart turns the sinewave signal on and off. As the sound generator is quite loud you are asked to turn it on only when needed.

Because there are only six tracks the class will be divided into six groups. Each group may have more than two students so make sure everyone in the group participates in doing the lab. The tendency is to let one or two people perform the lab and the others sit and watch. Try not to let this happen to your group. If there is time, rotate responsibilities so that each person gets a chance to do every aspect of the lab.

You should proceed in your investigation using the following steps:

1. Determine the stationary frequency of the sound source by recording a sound file.
2. Make a few practice runs to get used to how the cart behaves under full acceleration then record sound file for a moving car to detect Doppler shift.
3. Filter the sound file to remove extraneous noise from the sound file.
4. Analyze the frequency shift of the tone as a function of time.
5. Calculate and plot the velocity profile of the cart as a function of time and distance.
6. If you have time. from the velocity profile calculate the acceleration of the cart as a function of time and determine the cart's maximum acceleration as well as where the maximum acceleration occurs.

There are a lot of instructions in this procedure so don't lose sight of what you are doing. In a nutshell you will learn how to record a sound and view it using the Pratt program. You will learn how to print a window using hot keys and you will learn how to filter and analyze your data using the Filter and Formant utilities in Praat. If you get stuck on how to do something don't hesitate to ask for help.

Determine the stationary frequency of the sound source.

To do this you will record the sound emitted by the cart.

1. Open the PRAAT program by double clicking on the PRAAT icon.
2. From the menu on the **Praat OBJECTS** window select **NEW – RECORD MONO SOUND**. The Sound Recorder appears. Check the sample rate is selected to 22050.
3. Place the cart about one meter from the microphone with the loudspeaker facing toward the microphone.

4. Turn the microphone on by pushing in the button on the microphone. Then click on the **record** button in the Sound Recorder window. Observe the sound level displayed by the meter is at between one fourth and three fourths of the height of the meter. If the volume is lower or higher, open the volume control and adjust the gain of the input channel to get the recorded sound in this range. (The volume control can be opened by left clicking on the "show hidden icons" button in the lower right corner of the screen, then right clicking on the speaker icon.)
5. When you are done, press the **stop** button.
6. Press the **start** button again, after about one-half to one second, press the **stop** button. This erases the old data and records new sound data. As a general rule keep the sound files short. This makes them quicker to load and analyze.
7. Enter "**stationary tone**" in the **Save to list** box then click on the **Save to list box.** This will move the sound data to the **Praat Objects** window.
8. Before doing anything else, save the sound file to disk as follows:
   a) Select **Write-Write to WAV file.** The Write to Wave file window will appear.
   b) Check that the file name appears in the filename box and click **Save.** If you lose track or accidentally mess up your file you can retrieve the original file using the **Read** option in the **Praat objects** window.

ANALYZE THE STATIONARY SOUND FILE

1) To analyze the file click **Edit** on the selections to the right of the object list. A "Sound" edit box will appear that displays the sound file as a function of time. Note that it is titled with the name of the object you are editing (in this case the Stationary Tone file. Now expand the box to fill the whole screen by clicking on the full screen icon in the upper right corner of the window.
2) Because the window displays the whole sound file you will not be able to see individual cycles of the sound. To zoom in, hold down the **Ctrl** key and the **I** key at the same time. Repeat until you can see two or three individual cycles of the sound. If you go too far use CTRL-O to zoom back out.
3) You can now use the mouse to select the peaks of two adjacent cycles by clicking on the first peak and dragging to the next peak. The time and inverse time (i.e. frequency if one complete cycle is selected) will be indicated above the selection box. Record the time (period) and frequency for one cycle in your lab report. The frequency should be somewhere in the range of 500 to 1500 Hz.
4) With one cycle selected the accuracy is not good so select ten cycles instead. Now the time indicated is for ten cycles so you must divide by ten to get the true period of one cycle. Similarly you must multiply the inverse time by 10 to get the frequency for one cycle. Because we are calculating time over ten cycles we are minimizing error in our selection. Again record the period and frequency based on 10 cycles. Verify they agree within experimental accuracy with your results from the single cycle measurement.
5) Print a copy of the edit box with the ten cycles selected as follows:
   a) Open a blank MS WORD document.

b) Click on the Edit box to make sure it is selected. Then hold the Alt and PRTSC keys down at the same time. This will copy the window to the clip board as a picture.
c) Click in the Word document and select Edit-Paste from the menu. A picture of the edit box will appear in the word document.
d) Print a copy of the edit box by clicking on the printer icon and paste it into your notebook.

You have now successfully determined the stationary frequency of the sound source.

Operating the Cart.

Assign one person to operate the cart (Driver), another person to start and stop the sound recorder (Sound Operator) and a third person to collect the cart and return it to the starting line (Pit Boss).

1) Operating the cart is simple. First, adjust the voltage on the power supply to 14 Volts (More than 14 volts will burn out the motor!). Place the cart at the start position with the guide in the slot. There is a pushbutton switch by the track near the microphone. Loudly announce "**Clear Track X**" (your track number. If no one else says "Clear Track Y" at the same time, visually check your track is clear of obstacles and people. Then announce "**On Your Mark**" at which time the Pit Boss turns the sound generator on. As soon as the Sound Operator hears the sound generator he/she starts recording by clicking on the Record Button. The Sound Operator then says "GO" at which time the Pitt Boss pushes and holds the RUN button down. The cart will streak down the track with blazing speed. When the cart button reaches the stopping gate, the Sound Operator clicks the stop button, the Pitt Boss releases the **RUN** button and the Gopher retrieves the car, turns off the sound generator and returns the car to the start line.

   Note: If someone else announces Clear Track Y at the same time you do, collaborate with the other group so you both don't run your cars at the same time.

2) Practice launching the cart until you get the routine down.
3) When you have achieved a good sound run, save the sound file to the Object window list, then save the data to a file using the READ menu in the Object Window.

VERIFY SOUND DATA QUALITY

Display the Sound Run Object using EDIT. Observe that the amplitude as the cart passes the microphone is not so loud that the signal is "clipped" (signal goes from –1 to +1 and individual signals are clipped – i.e. flat on the top and bottom of the peaks and troughs.)

If all looks good, continue. If the signal is clipped then turn the volume down using the volume control window and try again until you get good data.