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398EMI Final Project

# EXPERIMENTS IN PSYCHOACOUSTICS

## 1: OVERVIEW

Psychoacoustics is the field of study pertaining to the human perception of sound. Defined this way, it encompasses a huge range of topics, from the vibrational modes of the eardrum, to the rate of fire of neurons in certain regions of the brain. This paper will only scratch the surface, with experiments in two specific areas: the ear's sensitivity to pitch, and sensitivity to phase difference.

## 2: SENSITIVITY TO FREQUENCY

The human ear is sensitive to sounds roughly within the range from 20 Hz to 20,000 Hz. This, of course, varies somewhat from person to person, and also from pitch to pitch across the spectrum. It is also a topic that is well understood and well documented, which is why I chose it as the first topic to experiment with. Being able to compare my results with others would help me to verify my methods as I got a feel for how to work in psychoacoustics. The goal in this experiment, therefore, would be to attempt to measure the frequency sensitivity of a number of test subjects, and to see if the results looked at all like published values.

### 2.1: Apparatus

There have been all sorts of very specialized apparatus designed over the years to explore psychoacoustics, from anechoic chambers designed to deaden all echoes, to spherical arrays of speakers that a listener can stand inside, to experience 3-D effects (see the Physics Today article listed at the end of this). However, the budget, time, and scope of this class were somewhat limited. To this end, I decided to start with a set of headphones, and to work backwards from there.

I decided against using a speaker array for a number of reasons. First of all, factors such as the distance of the subject from the speakers, the spacing of the speakers, and varying sound reflection from walls would be very hard to control. Second, the experiments would be very invasive to other people in the lab. Third, other people making noise in the lab would hinder the experiment. Headphones were superior to speakers in all of these respects.

The other end of the apparatus, the signal source, was supplied by a sine wave from a digital function generator. It was the middle of the apparatus that was the most trouble, because the following things were needed:

- The signal had to be amplified to an audible level.
- The signal amplitude needs to be easily tunable over a wide range
- There needs to be some way to measure the amplitude of the signal exactly as it is going to the ears

The first two requirements were easily satisfied by using a normal stereo amplifier, which I brought from home. The function generator was connected to one of the audio in using a splitter cable. The only tricky part was finding a way to measure the output. The audio outs on the stereo are not connected to the same volume control as the headphone jack, so they could not be used. In the end, I had to use a splitter on the headphone jack itself, then hook up the headphones and the oscilloscope alternately (to avoid signal attenuation).

### 2.2: Procedure

The procedure used for this was certainly far from ideal if the goal was to obtain totally objective results. However, it was limited by time constraints, and the goal of this experiment was just to get a feel for the field anyway. Besides, any experiment in this field will be affected at some level by the fact that it is people's perceptions being measured, and people will never be totally objective.

The function generator was configured to produce a sine wave, at the standard stereo input level of 70 mV (in the middle hearing range, this was reduced to 10 mV to allow for more room in adjusting the volume control). The signal was then swept through the audible range of frequencies (20-20,000Hz). At each frequency, the subject was asked to adjust toe volume control until the pitch was right at the minimum threshold of hearing. This is, of course, quite subjective, since every person's concept of threshold will be different, and also because it assumes that each person's perception of their threshold will remain constant. However, it was the best that could be done given a limited time with each subject.

Once threshold was determined, the headphones were detached briefly, so that a voltage value (peak to peak) could be read off the oscilloscope. It was pointed out that an ordinary multimeter would be sufficient, perhaps even better, for making this measurement. However, in the beginning I wanted to make sure I was getting the right signals, and for that an oscilloscope was useful.

### 2.3: Limitations

There were several limitations in this experiment. First of all, there were the human factors. First of all, each person's perception of "hearing threshold" is almost certainly different, making the averaging together of different results an iffy prospect. Second, it's possible that each person's perception of threshold would not remain constant throughout the experiment, creating a skew to individual data sets as well. Third, in the interests of time, the frequencies were swept through in sequence, and the listener was allowed to adjust the volume control. This lack of blinds in the experiment leaves room for expectations to color perceptions.

In addition, there were hardware limitations. While the function generator and oscilloscope were of "lab quality", the amplifier and headphones certainly were not. It is unlikely that the amplifier (and particularly the headphones) have a level frequency response themselves, so it is possible that some of the variations measured were a product of this, rather than of human ears. Also, this amplifier was certainly not the most noise-free available. In the middle, most sensitive hearing range (about 2,000-12,00 Hz), the signal was so small to the noise that measurements were impossible. However, the more interesting parts of the data are the ends anyway, where sensitivity varies, so this was not as bad a limitation as might be expected.

Finally, let me repeat here that the purpose of this was to get a feel for things, and to try to (roughly) reproduce existing knowledge. While all of these limitations would have to be addressed in a "true" experiment, none of them are fatal here.

### 2.4: Results

While the above limitations preclude a true statistical treatment of the data (as well as the data set; 10 subjects is awfully small), some of the gross features of the audible spectrum can be easily seen from the data. ()()()

In addition, I had hoped to compare the data with a certain amount of demographic information, to try to see the effects of age, of excessive exposure to loud music (both of these should decrease sensitivity), and of a predisposition towards music (singing or playing an instrument, which could perhaps increase sensitivity?). Again, the small statistics here make any conclusions very iffy, but the results for the first two at least do seem to be backed up.

A final side note of interest: while working with one of the subjects, we were interrupted halfway through to go over to the "hangar" and listen to a guitar amp test. We expected this exposure to loud noise to cause a temporary decrease in ear sensitivity, so upon return, we reran several data points before continuing. In this case at least, in the lower spectrum range, there was no measurable change.

## 3: SENSITIVITY TO PHASE

The human ears are, of course, sensitive not only to pitch and loudness, but also to the position of a sound. While this has always been known empirically, the way that position is detected has not always been understood. Part of it certainly has to do with variations in loudness, and variations in different frequencies, as the sound waves reflect in different directions off the structures of the ears themselves, and transmissions and reflections through the rest of the head. However, it is also possible that time delay, or phase shift, can play a part. Historically, this was thought not to be true, though recent results have suggested otherwise (see the Physics Today article on hearing in the November 1998 issue, which is available online at http://www.aip.org/pt/nov99/locsound.html. This experiment was intended to see if phase difference could indeed be perceived, and if so, what exactly it sounded like.

### 3.1: Apparatus

The apparatus for this part of experiment was very similar to the previous one. Rather than a single function generator split to both stereo channels, two were used. These were connected in phase locking mode, which allowed the relative phase between them to be set, and one connected each to the left and right channels of the amplifier. Since it was only the phase of the signals we were interested in, and not the loudness, the oscilloscope could be connected right off the function generators, rather than trying to split it off the headphone jack.

### 3.2: Procedure

Since it was not known at the outset what was to be expected, the procedure here was not very fixed. Different frequencies were tried, and at each, the phase was varied. Both fast and slow variations of phase were tried. Some blind experiments were tried also, where the subject looked away from the apparatus, and I set various phases, asking them what they heard. This was done both with the volume left on, to measure perceptions of relative (changing) phase, and with the sound turned on and off, to try to measure absolute phase.

### 3.3: Limitations

There were fewer limitations in this experiment. The human factors were exactly what I was interested in measuring. The major problem was one with the function generators. The digital controls on them only allowed the phase to be adjusted by 1°, 10°, or 100°. This made it difficult to work with phase changes of, for example, 5° smoothly.

**3.4: Results**

The results were quite striking. Phase differences were easily perceptible by all subjects, to some extent at least. The degree of sensitivity did seem to vary somewhat, though due to what reasons I do not know. The major perception was that of a sound moving side to side.

I had predicted that sensitivity to phase would be the greatest for sounds with wavelengths comparable to the physical separation of the ears (about 10cm, corresponding to a frequency of 3,000-4,000 Hz). I found out that this was incorrect. Phase sensitivity was actually greatest for much lower frequencies. The best range for detecting phase seemed to be roughly between 60 Hz and 800 Hz, with the peak for sensitivity somewhere around 300 Hz. This agreed roughly with the results in the Physics Today article, which listed most of its values at 500 Hz.

According to that same article, people were able to detect changes of as little as 1-2°. With this apparatus, changes of 1° were not detectable, and as noted above, it was difficult to work with other small values, say 2-4°. However, changes of 10° were easily detected, at both 300 Hz and 500 Hz.

Motion (listening while the phase was actually varied) was detected much more easily than discerning absolute position (i.e., turning off the sound, changing the phase, then turning the sound on again). Whether this is due to transient signals induced by the act of changing the phase is not certain. However, the motion was easily detected both for rapid phase changes and for slow ones. A slow change would be expected to generate less transients, so perhaps motion sense truly is more sensitive.

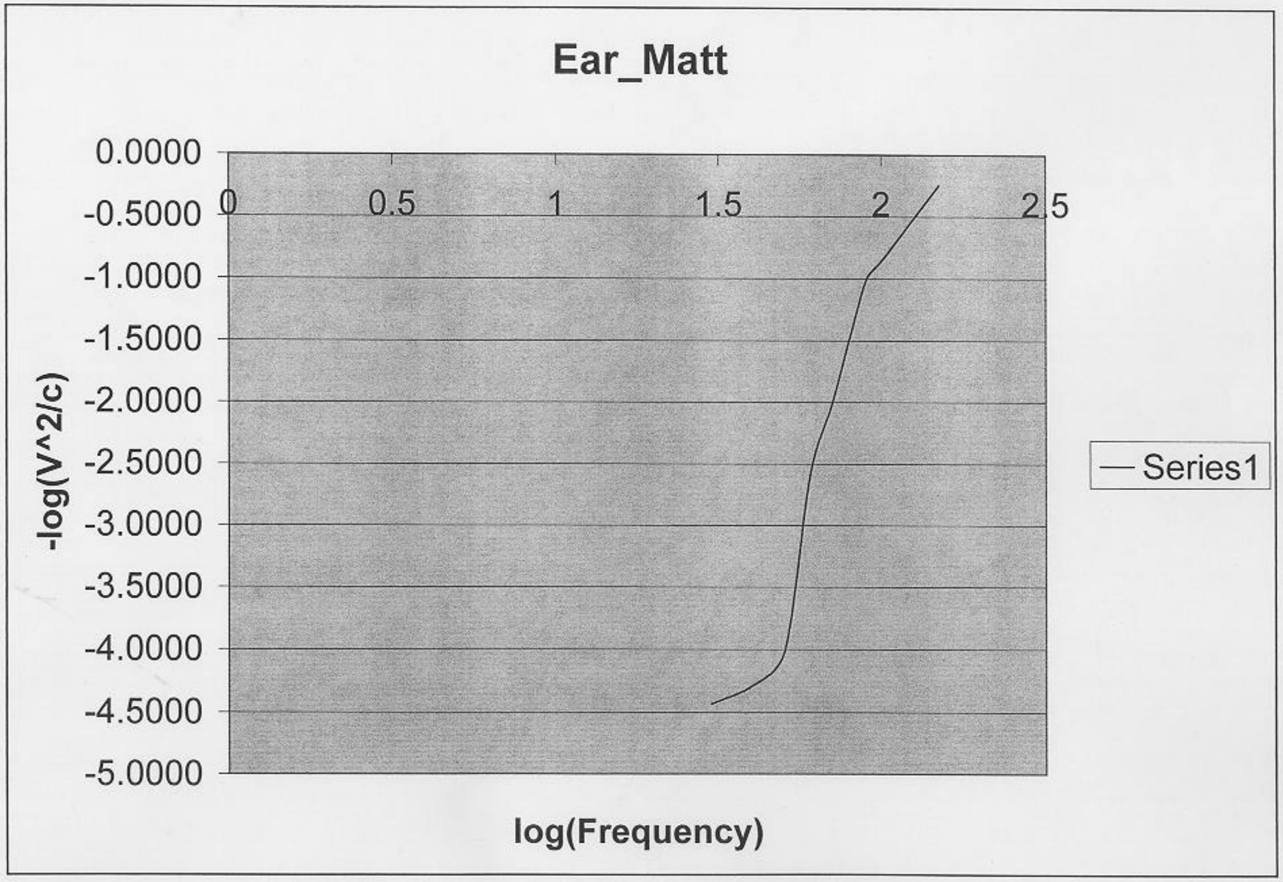
It does make sense that motion would be more easily detected than absolute position in this experiment, since phase is only one of the cues that would be used to determine position. Without the other cues added in, such as the change in loudness between the two ears, or the effects of extra reflections and transmissions, this sound probably has the effect of an auditory illusion, comparable to an optical illusion such as a hallway that is built narrower and narrower to give it the appearance of length. However, it is certain that the ability to sense phase exists.

Most of the positioning information was quite reasonable. Two signals in phase sounded like they were coming from inside the head (the exact midpoint between the two headphone speakers). Varying the phase by up to 90° either way produced motions to the left or right. Varying beyond 90° either way caused motion back towards the center. However, there was one additional sensation, that not all listeners were able to discern. When the two signals were exactly 180° out of phase, the sound actually seemed to be coming from a point just behind the head. Therefore, the entire motion of the sound was not just a line back and forth through the ears, but rather an oval, that went through the ears on one side, and then behind the head on the return.

I do not have an explanation for this phenomenon, but do have a speculation. It is a well known phenomenon in wave mechanics that a wave can have its phase inverted when reflected under certain conditions. Perhaps a signal originating behind the head has part of its signal inverted in the process of bouncing through the head, or around the ear. This then would have become one of the cues that humans use to distinguish sounds coming from behind.

## 4: CONCLUSIONS

There are many different aspects of the human perception of sound that can be explored. As the professor has noted on several occasions, the human ear is a nonlinear device, which makes its response to signals significantly different from the behavior of lab instruments. This paper only addresses two of the many aspects, in the hope that it could become a sort of primer for further experiments, by laying some groundwork and beginning to explore some of the methods that could be used. Some of the results that were obtained were exactly as expected; this lent credibility to the initial methods. And, some of the results were quite surprising; this made the entire effort worthwhile. Overall, I feel that the process was successful.



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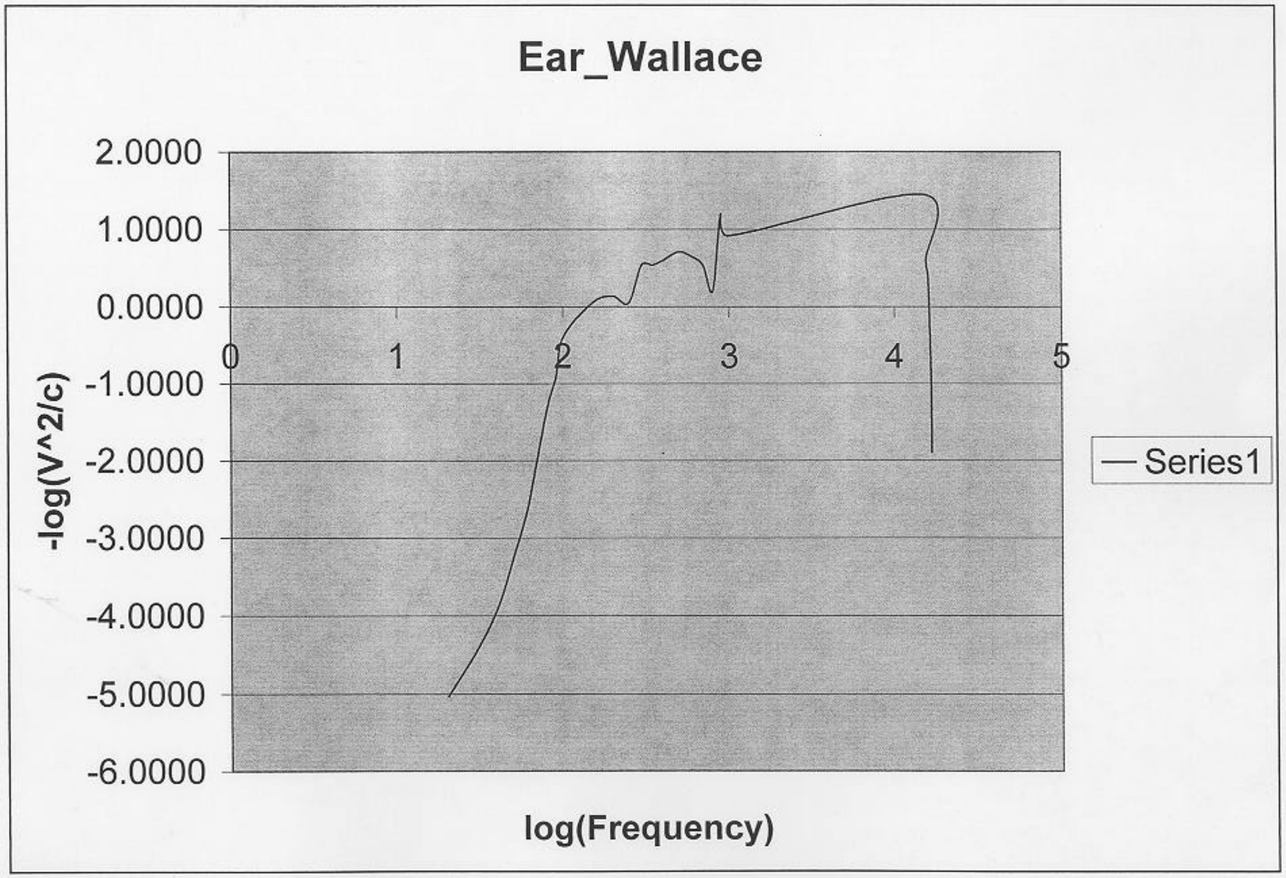
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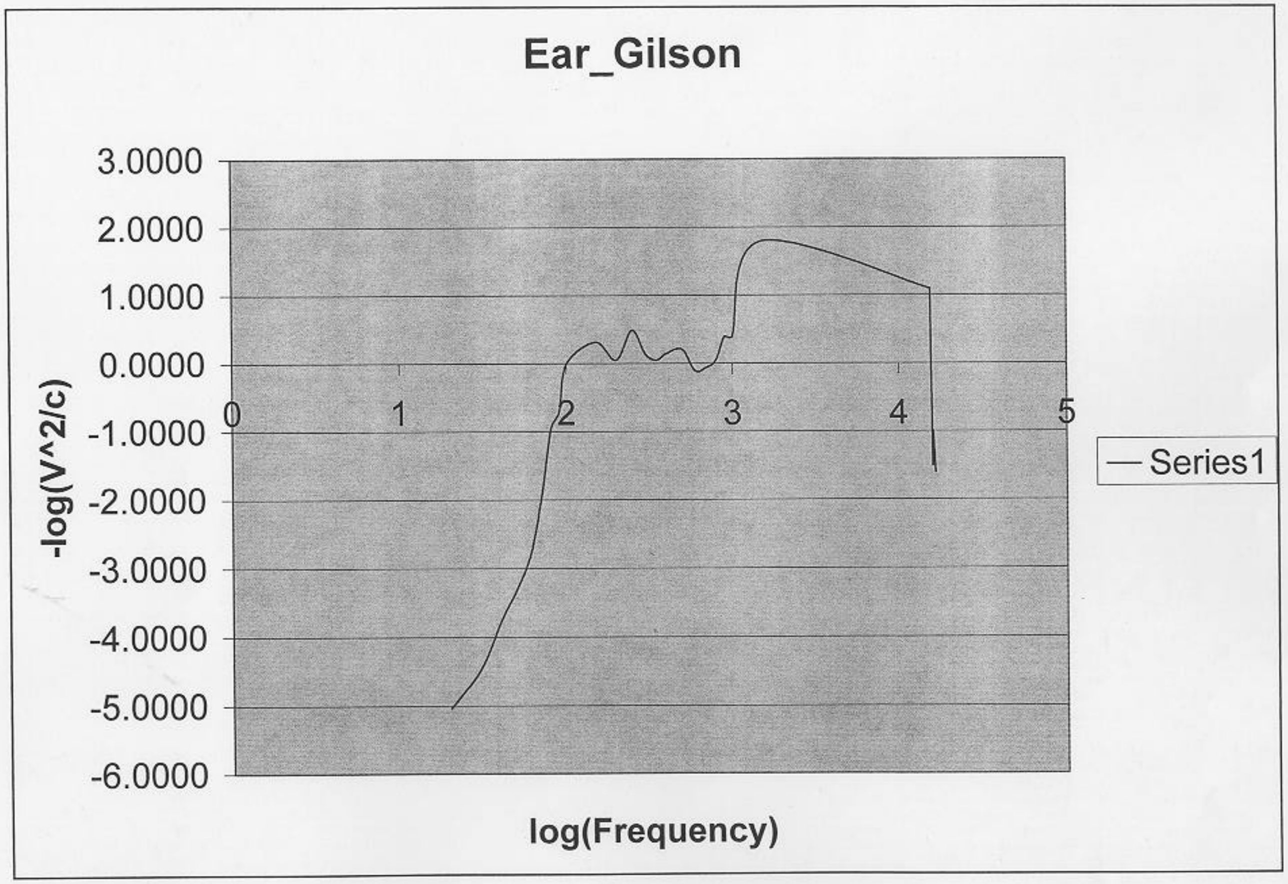
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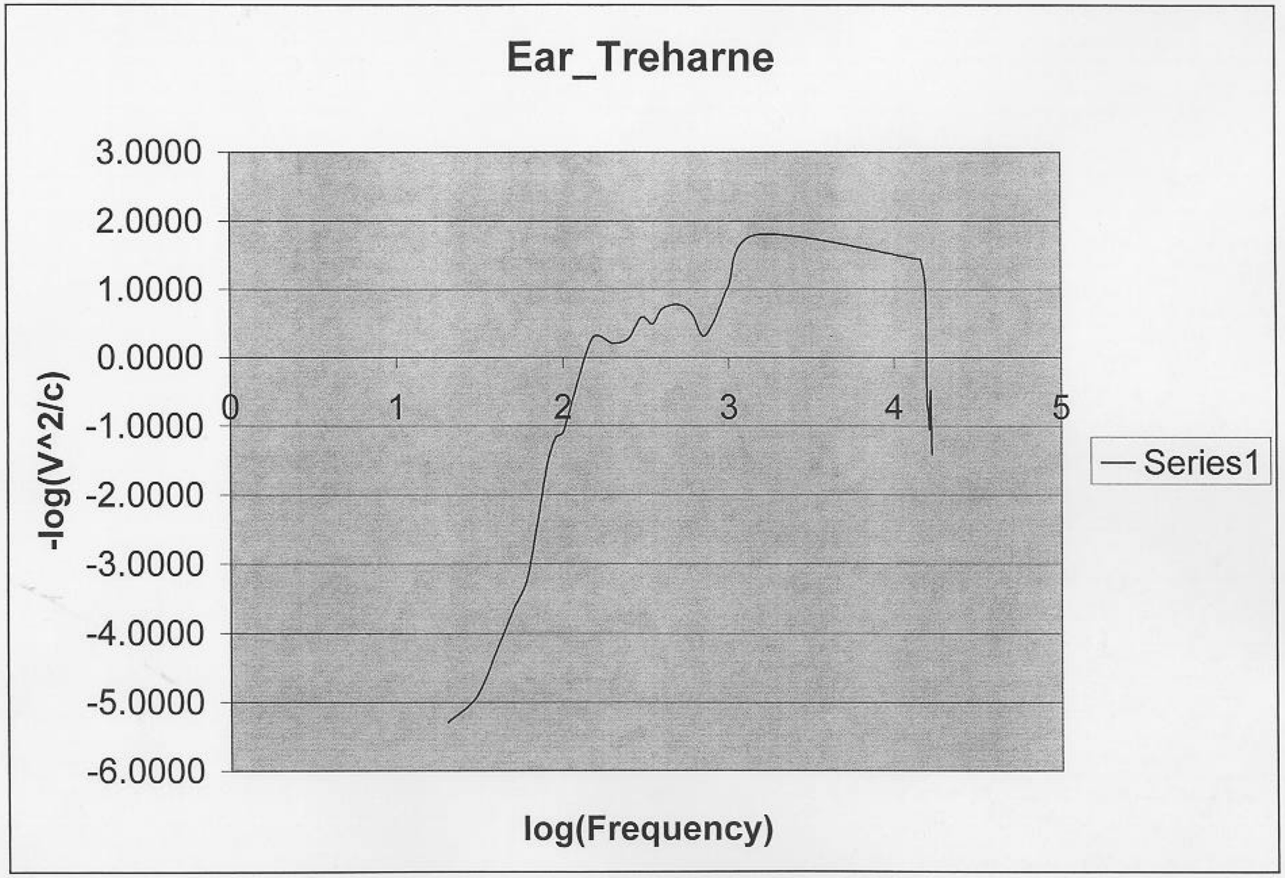
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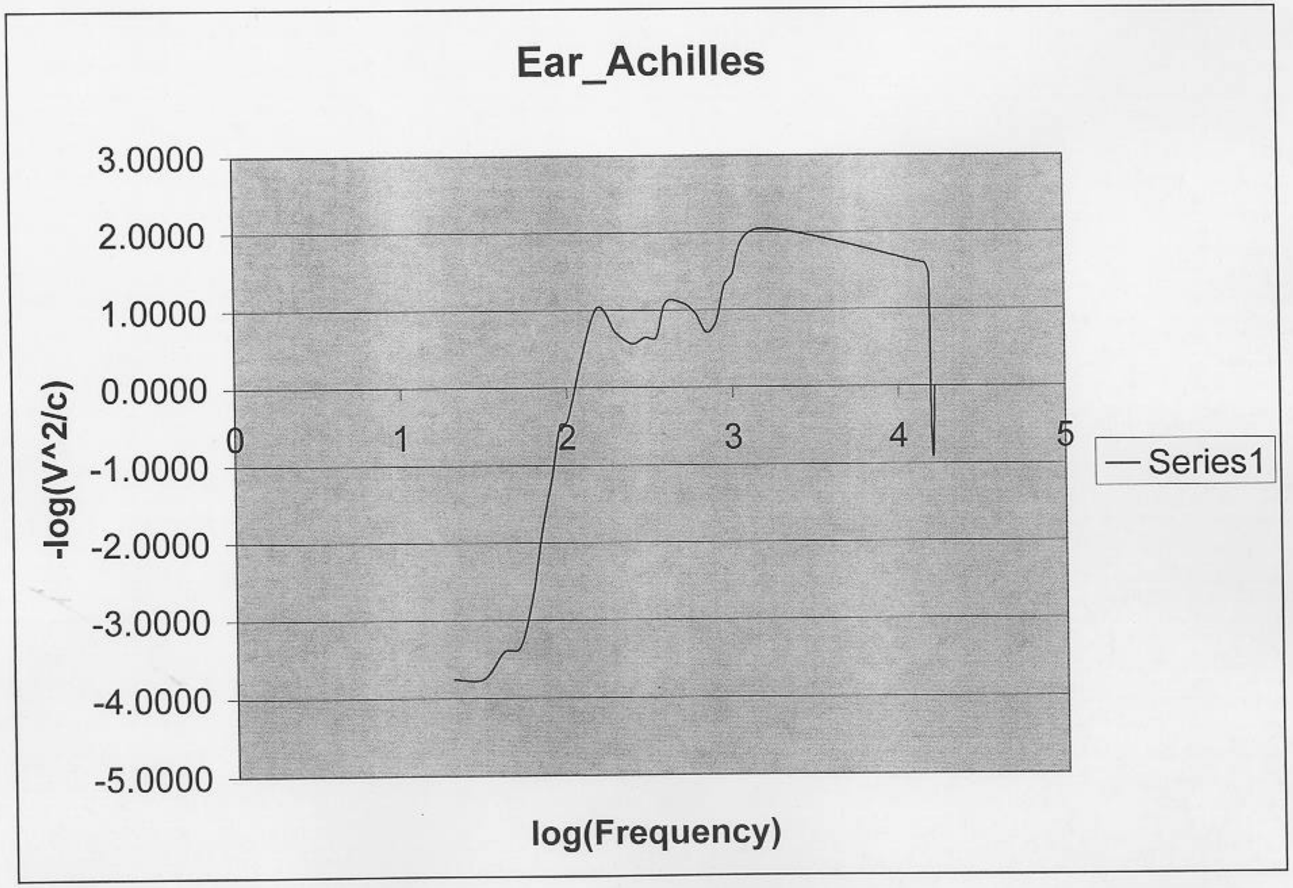
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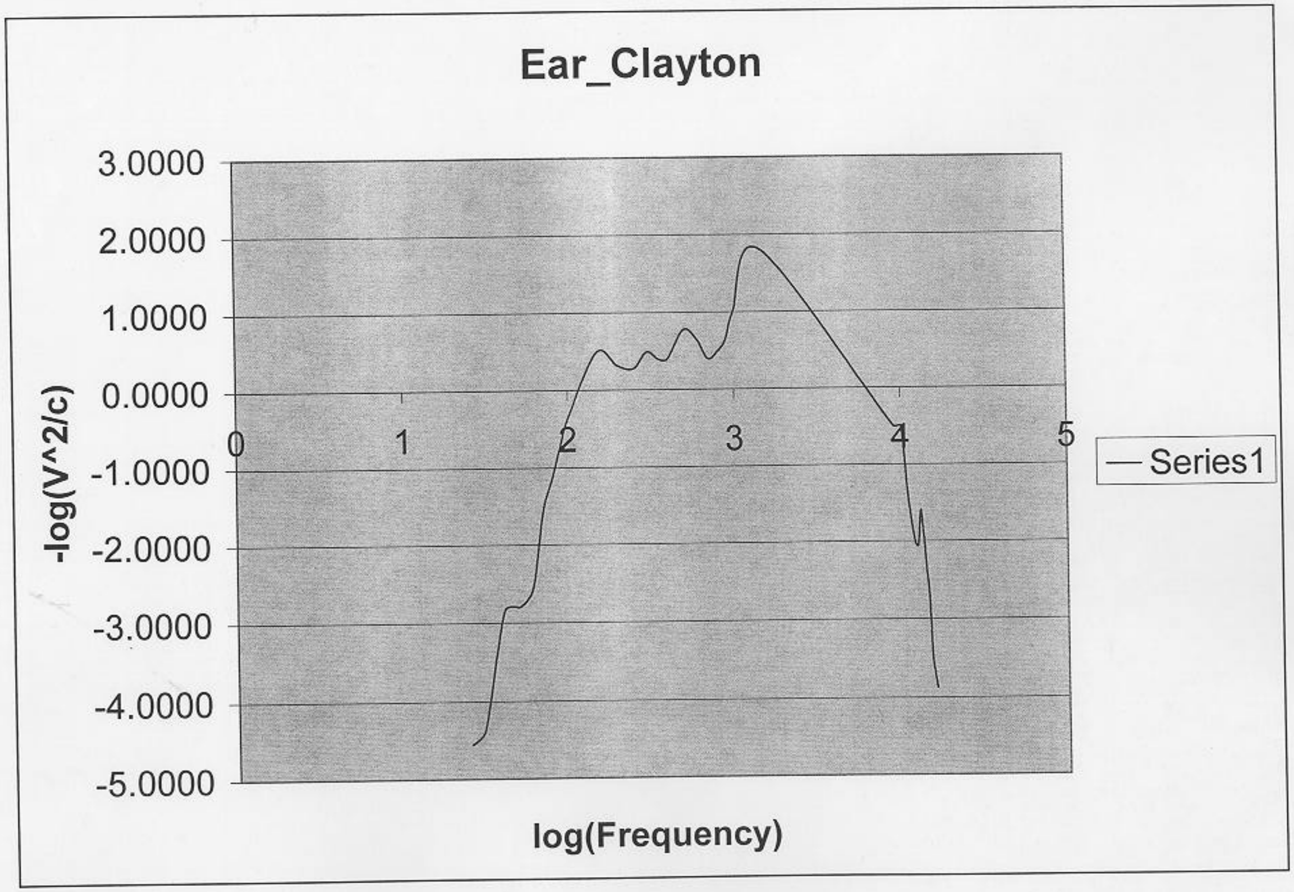

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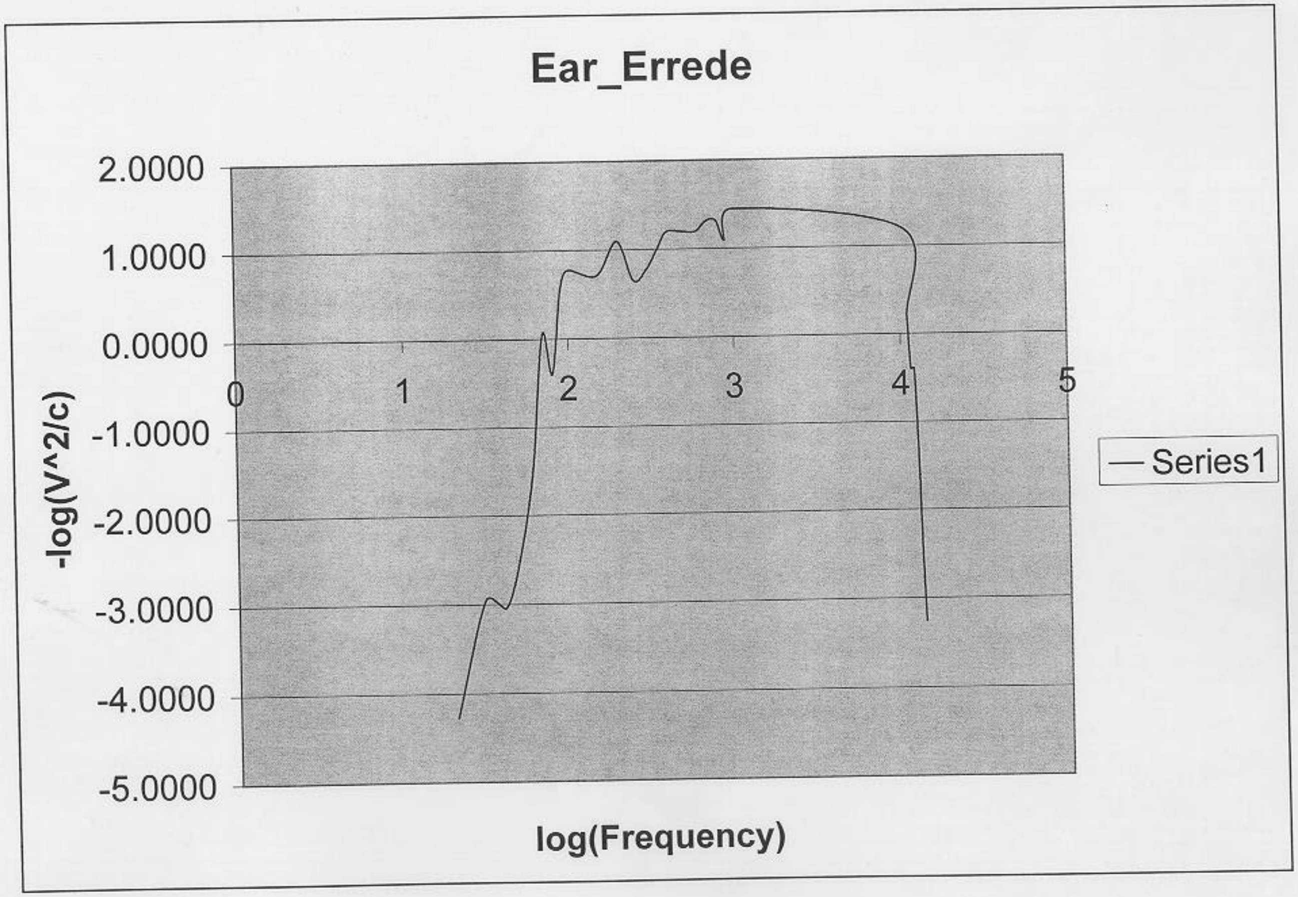
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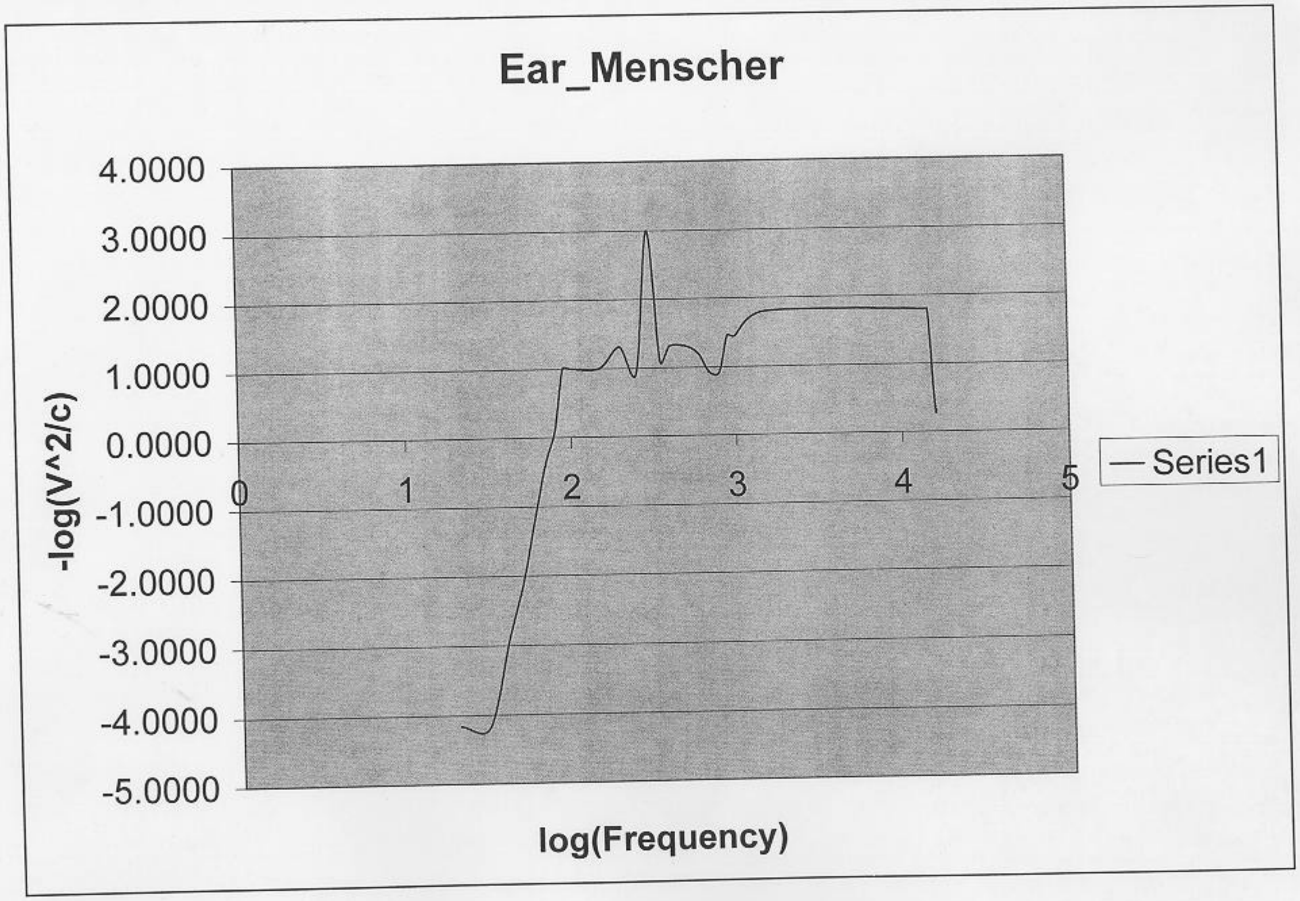
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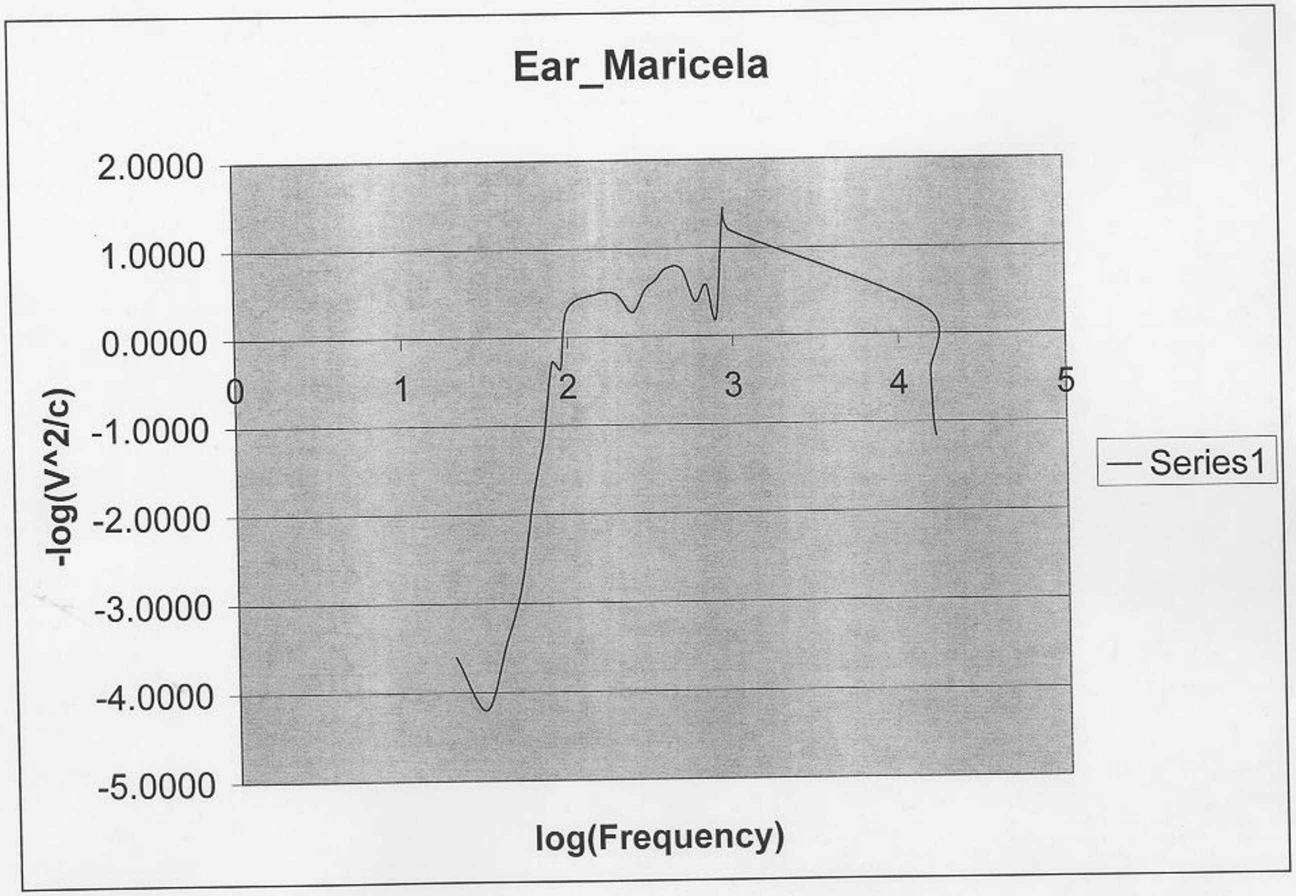
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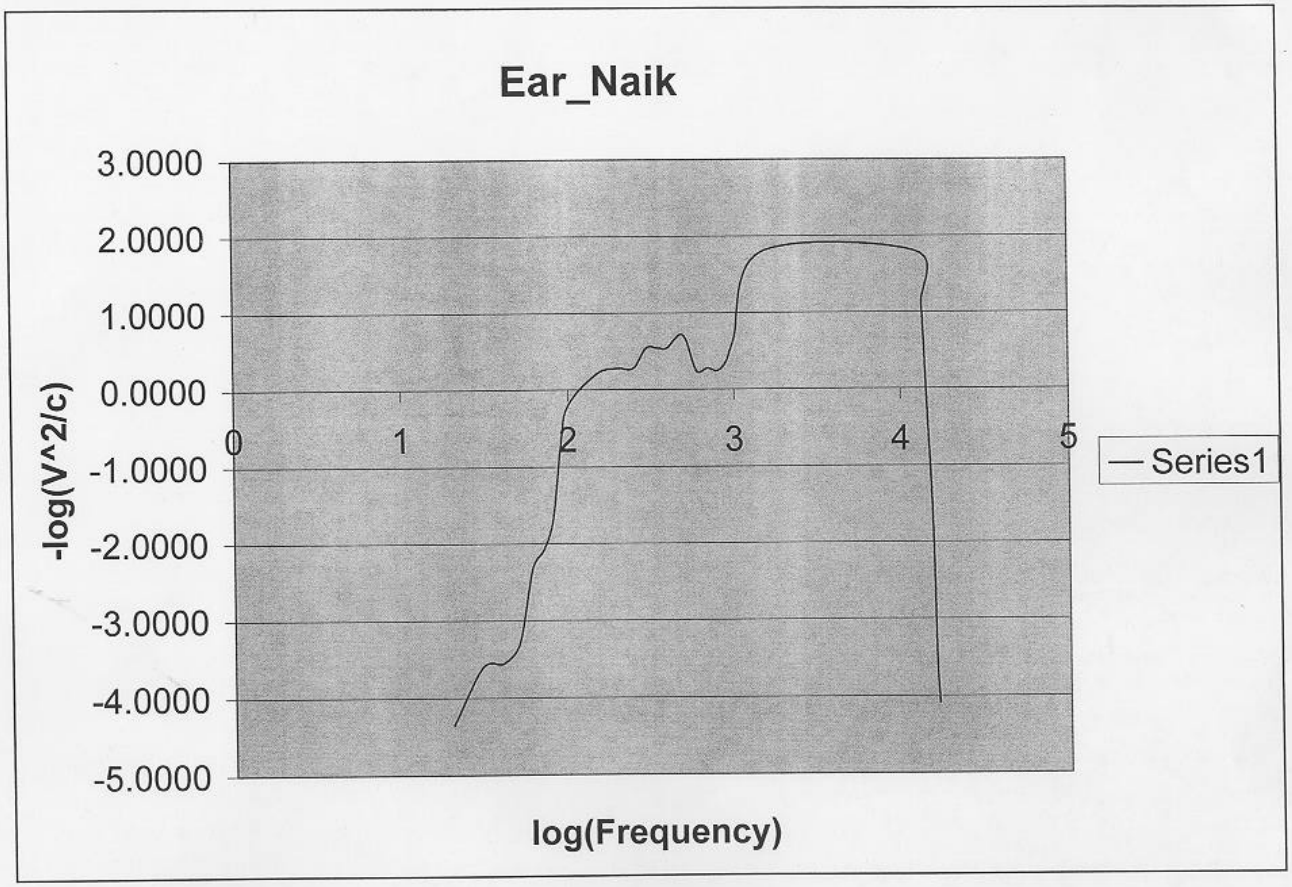
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