**Basics of Noise and Its Measurements**
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**Lecture - 03**
**Nature of Sound**

Hello again. Once again I welcome to all of you to this particular lecture on Basics of Noise and its Measurements. I hope whatever has been taught till so far you have not had any problems, and if there are issues or few of questions you should definitely express your questions and comments through online methods and communicate it to me and also to the tutors, so that we can address those. Because what we really want out of this course is that you learn whatever we are trying to teach and you make it beneficial in context of your profession or your student related aspirations and goals. So, what we are going to discuss today is an extension of what we were talking about sound, and what is the nature of sound?

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As we had discussed in the last lecture, we had talked about vibrations, we had talked about waves and what we had described sound as, was a pressure wave. So whenever you have sound it essentially, when I say I heard sound what it really means is that I sensed a small fluctuation of pressure in the air and I sense this pressure fluctuation through my ears. There are drums in the ears, so when there is a pressure fluctuation the air particles impinge on the pressure drum and this pressure drum vibrates and that is how sound is sensed.

It is important to understand this physical meaning of sound, because then you can make measurements about sound more accurately and intelligently, analyze sound, and make specific conclusions about specific types of noise as in sounds in a away which is consistent with the reality of the physical nature of sound. As sound is a wave, it is a longitudinal pressure wave it obeys all laws related to waves. So, if you have a sound or if you have a wave it will get reflected like what happens to light, you have a beam of light or a ray of light and it strikes a mirror or in a surface and part of it gets reflected. So, you have reflection.

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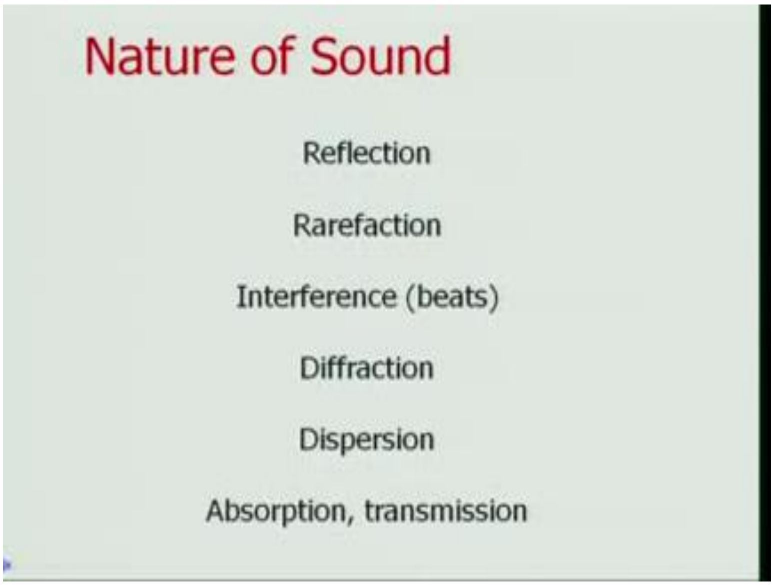


Same thing happens to sound. Sound wave also undergoes rarefaction in light waves or electromagnetic waves, if you have medium one and then you have another medium and light is traveling through two different media and if they have different refractive indices then light bends and exactly the same phenomena happens in case of sound. If you have one medium and then you have another medium, and then sound is coming not necessarily at perpendicular angle but at an oblique angle with respect to the boundary of the medium and there is a transition in the medium, and the propagation velocity is of sound in these two media are different, then it does undergo rarefaction because it is a wave, it undergoes refraction.

Similarly, waves interfere. They can interfere in constructive waves or they can interfere in destructive waves. And the same thing happens to sound and actually we will see today through a practical example how two sounds waves which have very close you know similar frequencies, how they interfere with each other to produce a phenomena called beats. We know from our physics lessons, that waves diffract and then they disperse and then they undergo absorption and transmission, they diffract especially when they hit some sharp corners then they try to bend around those sharp corners. And then they get dispersed, and they get absorbed and a part of waves get transmitted. This is true for electromagnetic waves and same thing is true for pressure waves that are sound. So, what I wanted to show you today is actually a practical demonstration on beats.

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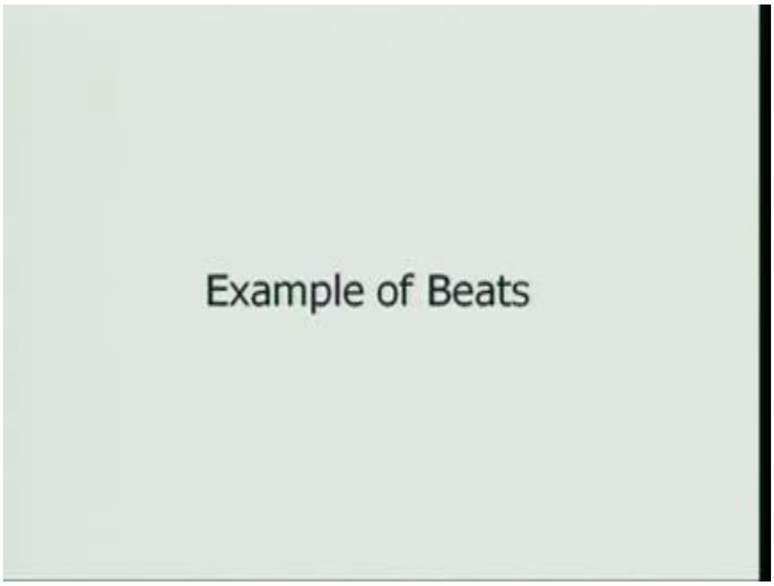


So, first we will do the mathematics and then we will look at a practical demo. So consider that you have two waves.

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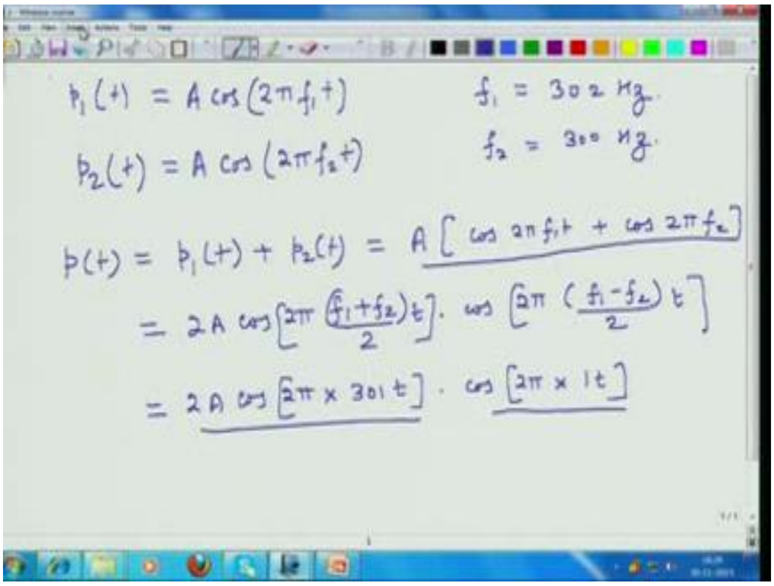


You have first pressure wave and let say, it is called p 1 and it is a function of time and that equals some amplitude times cosine 2 pi f 1 t. What I am doing is, I am having a loudspeaker and using this loudspeaker I create some sound and let us say the frequency is 302 hertz. Then, I have another sound wave and that sound wave also has the same amplitude but it has somewhat different frequency f 2. I am generating 2 sound waves. Let say my f 1 equals to 302 hertz and f 2 equals 300 hertz. If I play p 2 I hear a 300 hertz sound, and if I play p 1 I hear 302 hertz sound. Then, if I play both of these sound files simultaneously then the total pressure which will be generated will be p t p 1 t plus p 2 t and that equals A cosine 2 pi f 1 t plus cosine 2 pi f 2 t.

Now, I know from a trigonometric relations that, if I have cosine A plus cosine B I can express this these two sums cosine A plus cosine B is nothing but cosine of A plus B over 2 times cosine of A minus B over 2. So, this is trigonometric relations which we learnt in our high school mathematics, so I am going to use this. This entire term can be read it in as cosine of 2 pi f 1 plus f 2 over 2 t times, cosine of 2 pi f 1 minus f 2 over 2 t. Now, what I am going to do is put in the values of f 1 and f 2. So t is 2 A cosine 2 pi times 302 plus 300 divide by 2 is 300 1 t times cosine 2 pi, f 1 minus f 2 is 2 so into 1 t.

So, I have the overall pressure wave which is the function of multiple of two different cosine functions; the first cosine function is, 2 cosine of 2 pi times 300 1 t and the second cosine function is cosine of 2 pi times 1 t.

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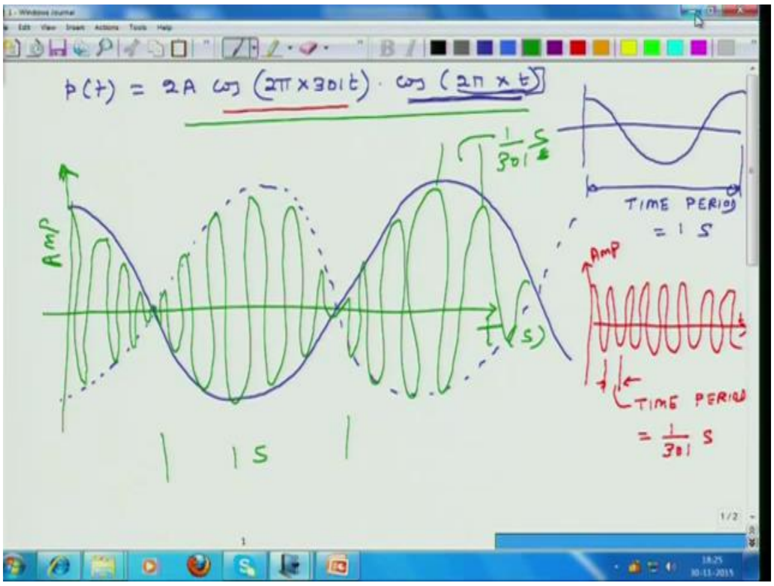


I will just read write it. P t equals 2 A cosine of 2 pi times 300 1 t times cosine of 2 pi times t. Now, if I am going to plot this function, it will appear like it this, and this is going to be the time period, and this will be 1 second, because the frequency here is 1 hertz, 302 minus 300 divided by 2 is 1 hertz. If I plot this function then it will look like this and here this is going to be the time period, and please remember that the blue curve and the red curve they are not to scale, but the time period here I have shown it to be 1 second and in this case time period is equal to 1 over 301 second. It is very thin, but here for purposes of illustration I have expanded it in the time direction. This is my time axis and this is my amplitude.

The overall function will be essentially a modulation of this red signal using this blue thing. So, I am going to draw that also. What I will do is, now I am going to draw this entire thing and to do the entire thing what I will do. This is my amplitude, this is my time. First I am going to draw this 1 second hertz thing. So it is going to behave like this and I will also draw its mirror image. This blue line is the envelope of the overall function, and within this envelope there will be pressure fluctuations, and they are going to be like this. You have to pardon my drawing, but I hope you get the picture.

What you will hear if I play a 300 hertz tone and a 302 hertz tone, if I play them simultaneously what you will hear is, a tone which as a frequency of 301 hertz, but it will go up, the volume will go up and then the volume will come down, then it will go up and then it will come down and so on and so forth, and it will go up and down and up and down once every second. So, the period of modulation is one second. However, this time period is 1 over 301 second, that is what it looks like. So what I will do is, I will show the same stuff may be little bit more cleanly, I have some graphs of the same thing and then I will actually play sounds.

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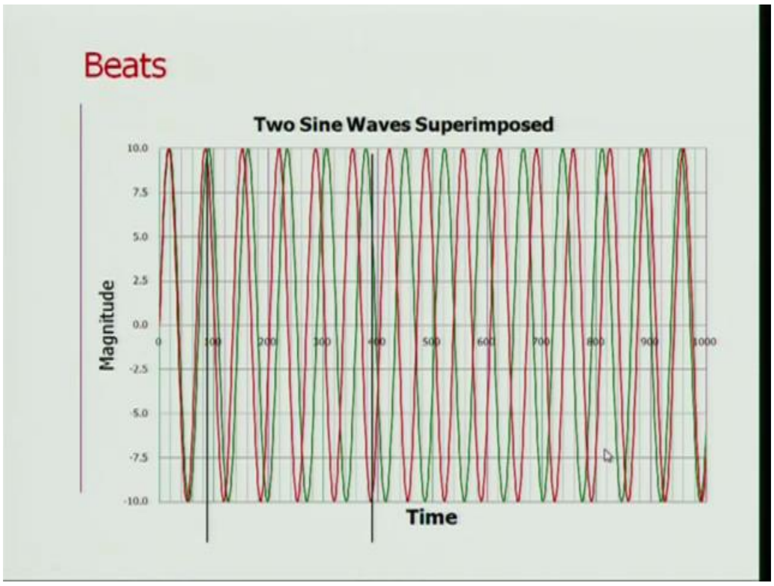


So, what you are seen here are two curves, a 300 hertz tone and 301 hertz tone and what I have done is that I have zoomed in so you can see the differences. So, 2 sine waves I have super imposed, in this case I have super imposed sine wave, it is not cosine.

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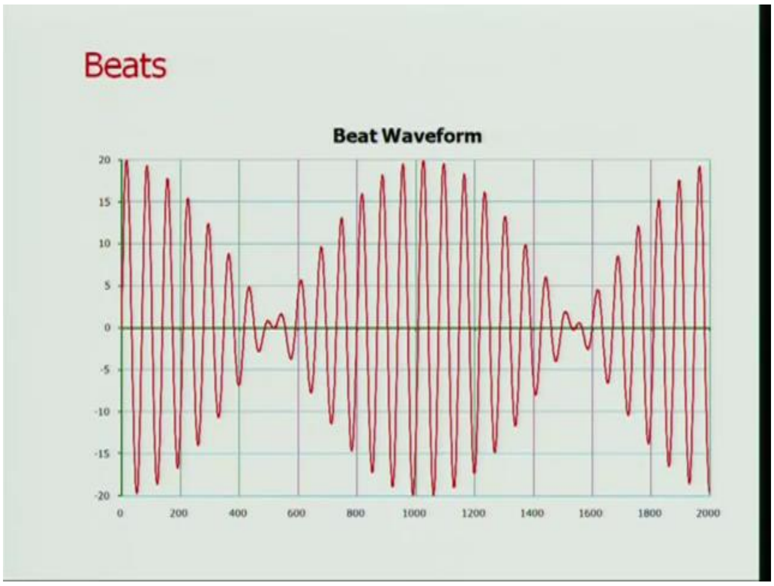


When I add them up this is how it looks like. Next, what I will do is, I am going to play the sound. First thing I am going to do is I am going to play this 300 hertz pure tone. I am now going to play it a 302 hertz pure tone and what you will see is that it will sound very similar, very slight difference. This was 302, this was 300. And now I am going to play both the sounds together. So, you will hear the beat phenomena that the tone will be same, but it will go up and down up and down.

That is the beat, and the frequencies of this thing beating are going up and down up and down is one time is second that is 1 hertz. So, that is the beat phenomena which we have just now demonstrated, that how sounds interact and interfere with each other and if the frequency is two interacting sounds or interfering sound their frequencies are very close to each other and then you can hear some beats. So, that is about beats and this is the beat waveform. The next thing I wanted to talk about is typical sound pressures

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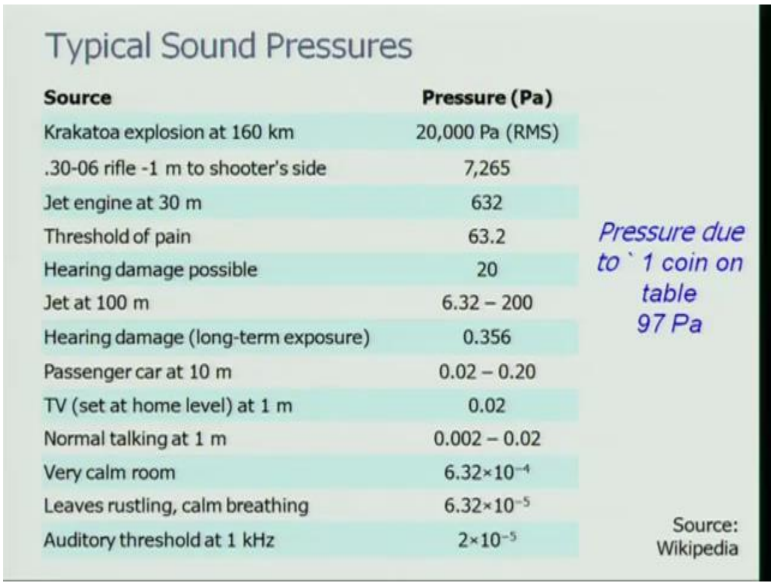
## Typical Sound Pressures

| Source | Pressure (Pa) |
|---|---|
| Krakatoa explosion at 160 km | 20,000 Pa (RMS) |
| .30-06 rifle -1 m to shooter's side | 7,265 |
| Jet engine at 30 m | 632 |
| Threshold of pain | 63.2 |
| Hearing damage possible | 20 |
| Jet at 100 m | 6.32 – 200 |
| Hearing damage (long-term exposure) | 0.356 |
| Passenger car at 10 m | 0.02 – 0.20 |
| TV (set at home level) at 1 m | 0.02 |
| Normal talking at 1 m | 0.002 – 0.02 |
| Very calm room | $6.32\times10^{-4}$ |
| Leaves rustling, calm breathing | $6.32\times10^{-5}$ |
| Auditory threshold at 1 kHz | $2\times10^{-5}$ |



It is very important to understand, what these values are like because what, that will help us understand is that why later in the course is, why do we plot a graphs related to the sound on logarithmic scales. So consider a coin, 1 rupee coin. That is the 1 rupee coin and you take the mass of it and you multiply it by g, which is 9.81 meters per second square, then you will get the weight of the coin and then you measure the diameter of the coin so you get the cross sectional area. Then you place that coin on the table, so you have mass times gravity so that is the weight and then divide it by the cross sectional area and then what you can calculate is the pressure which is being generated by the coin on this table.

I will show it here and when you do the math at least for this particular coin, because there is these coins come in different sizes, for this particular coin I calculated that the total pressure at which is due to this 1 rupee coin when I place it on a table is something like 97 pascals which is nothing because you can very easily lift a coin and it does not press your finger and or anything like that.

Now, let us compare these 97 pascals to typical sound pressure levels which are generated in everyday sounds which I hear. So the faintest, the lightest sound which I can hear would be something similar to a mosquito. Suppose, you think about a mosquito which is about one meter away, about these distance from my ear and it is buzzing and if you measure it, it somewhere in the 1000 hertz range. That is the faintest sound which you can hear through your ears. When that sound is being generated that is the least possible sound which can be heard, then that pressure fluctuation which my ears are sensing corresponding to the least you know the faintest sound possible from perception standpoint that is this thing, 2 into 10 to the power of minus 5 pascals or 20 pascals. And that is known as auditory threshold at one kilo hertz.

So, you have a 97 pascals being generated by a 1 rupee coin, and then the lightest sound which you can hear or which I can hear is 20 micro pascals of pressure fluctuation. If I have a room which is very calm, suppose I am in this room and no one is talking there is no fan or AC going on, no one is talking, no chit chat, no noise coming from outside then also there is some residual sound and that pressure fluctuation is about 632 micro pascals. So again, extremely small compare to this 97 pascals value. If I am talking like I am doing right now, I am not shouting, I am not talking very lightly or very softly either, my shouting that is generating a pressure fluctuation of 2 millipascals in this range, 2 millipascals to 20 millipascals. Again, extremely low compared to 97 pascals number, then you have this TV, it is running in a room, it is little loud let say and that generates about 20 millipascals of pressure.

Then you have this passenger car, you have a car running on a road let say it is about 10 meters away so that generates about 20 millipascals to 200 millipascals of pressure. Again, extremely small compare to this 97 pascals pressure being generated by coin on the table. Then if you keep on hearing noise or sound at 0.356 pascals or 356 pascals or 356 millipascals, again extremely small compare to 97 pascals number. And if you keep on hearing for sustained period of time long period of time then you may have damage to your ear. If this pressure exceeds 20 pascals, then you may have probably immediate hearing damage is possible. If the pressure exceeds 63, then you will actually start feeling the pain. First your ear will get damaged and then you hear the pain. But even at 63 pascals that number is still less compare to the 97 pascals pressure which is generated if I place a light 1 rupee coin on a table.

So, the point what I am trying to make is that when we talk about pressure fluctuations due to normal sounds, we are talking about extremely small amplitudes of pressure fluctuations extremely small pressure fluctuations. These pressure fluctuations are orders of magnitude lesser compare to most of the pressures which we experience in our day today lives.

The point is that, whatever instruments which are suppose to measure these pressure fluctuations they are suppose to be extremely sensitive in terms of measuring in, and also we should be able to eliminate other electronic noise when we are measuring them, so that the data which we are measuring is true and it does not get corrupted due to some electromagnetic or some other factors. So, that is an important thing to consider when we are taking sound pressure measurements. So, that closes this particular module and I look forward to having you in the next lecture tomorrow.

Thank you.