Noise Management & Its Control

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Lecture – 25
1-D Sound Wave Propagation: Kundt's Tube-I

Hello, welcome to noise management and it is control. This is the fifth week of this particular course which is going to run over a period of 12 weeks and today is the first day of the fifth week. What we plan to do today is specifically in this course is maybe in the first part of the week we will do some more cases for sound as it propagates in a single dimension in a Cartesian frame. So, we will still try to understand some more details about one dimensional wave propagation in Cartesian frame and specifically in that context what we will learn is about that what we learn is about details of a particular apparatus known as Kundts tube and this tube is used to measure the impedance of a sound absorbing material.

So, I think if you learn whatever if you understand what we will be discussing in context of Kundt's tube, it will help you characterize noise absorption properties of different materials which may you may be using in your applications. So, that is one thing we will discuss the and then we will start discussing about wave propagation in spherical coordinate systems because a lot of times when waves propagate, they do not necessarily travel in one linear direction, but they travel in all directions and those types of wave propagation systems can be understood using one dimensional spherical wave fronts. So, that is what we plan to do this week and as I said earlier we will start our discussion by talking about Kundt's tube.

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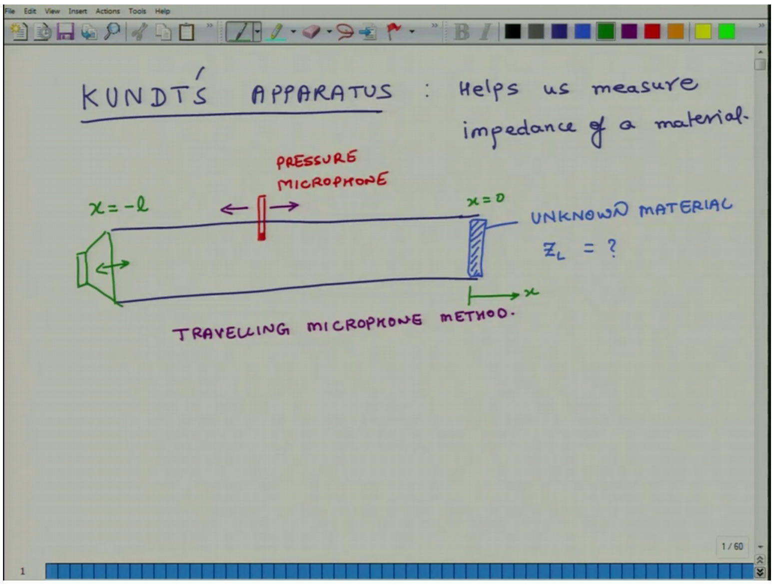

So, the spelling is k u n d t s and this is an apparatus. So, Kundt k u n d t was the name of person who developed this apparatus and what does it do? It helps us measure impedance of a system impedance of a material. So, if we have a material whose sound absorption or noise absorption properties are not known, then you can use this apparatus there are other apparatuses also, but you can certainly use this device to measure impedance or of this unknown material and how does it look like. So, it is essentially a straight tube and in this tube you place this unknown material at one end. So, this is the unknown material and let us say we want to find out it is sound absorption properties and we characterize these sound absorption properties by parameter z. So, let us say it is impedance is z L.

So, when I place this material in the tube of this size the impedance which it offers to bore wave propagation is Z L and we do not know this said L. So, we have to figure out what is the value of z L. So, you have a straight tube and then at the other end of the tube you have a sound source. So, there is a speaker and for different frequencies you can play different frequencies and those frequencies are going to propagate in this tube. So, and the finally, what you have is a microphone. So, this is a microphone and this is particularly a pressure microphone because it will measure the sound pressure level of air inside the tube. So, it is a pressure microphone and this microphone the tube is designed in such a way that there is a slot on it is top surface.

So, I can move this microphone at any location that is why this apparatus is also called a Traveling. So, this method of measuring impedance of an unknown material is also known as traveling microphone method, because I can move the location of the microphone at any point in the tube and as we have been doing in past my x axis starts from the closed end of the tube where we have this unknown material. So, x is equal to 0 is at this location and the tube is L long. So, at the other end of the tube where we I have a loudspeaker, it is x equals minus l. So, we use this apparatus to figure out what is the impedance of the material which I have placed at the end of the tube. So, how do we do it? So, this is again a one dimensional problem sound will travel only in one dimensions.

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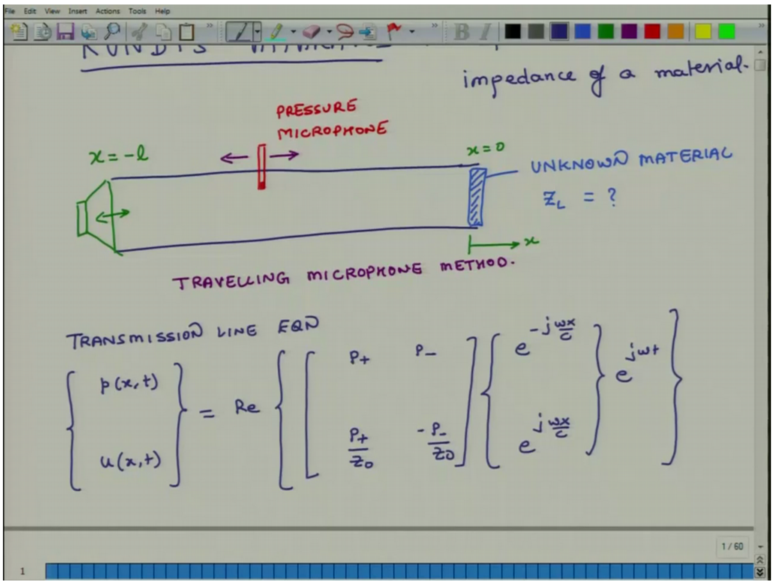

So, as we have done in past we start with the transmission line equations. So, we write down the transmission line equations. So, what are the transmission? So, what are the transmission line equations? There is an equation for pressure. So, pressure which is a function of x and t and then there is also equation for velocity. So, this equals real of P plus P minus P plus by Z naught minus P minus by Z naught e minus j omega x over c and for reflected waves I have e j omega x over c term times e j omega t and then I close the parentheses. So, these are my transmission line equations.

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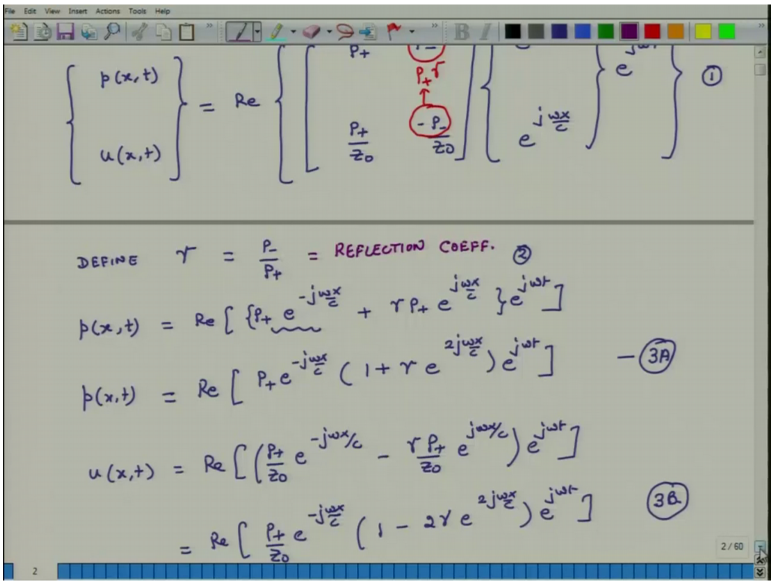

Now, what we will do here is we will define a term called gamma. So, what is gamma it is the ratio of P minus and P plus. So, P plus and P minus they are constants they can change with respect to frequency.

So, this is P minus over P plus. So, if I use. So, this I call this equation 1 this is equation 2. So, then I can write the equation for pressure from first equation as real of P plus e minus j omega x over c. So, basically I am what I am doing is I am replacing this P minus by P plus times gamma and same thing here also. So, I can take P plus outside the bracket. So, what I am doing is I am writing the first equation for pressure, after making this change. So, what I get is P plus e minus j omega x plus c plus, and P minus is gamma P plus e j omega x over c, e j omega t and this I can rewrite it as real of P plus and what I will do is I will take this entire term as common.

So, e minus j omega x over c times 1 plus gamma e 2 j omega x over c, e j omega t then I close the bracket. So, this is the pressure equation for pressure. So, let us call this equation 3 A, similarly if I use the first equation and I develop an expression for velocity. So, that is real of P plus by Z naught e minus j omega x over c and minus gamma P plus by Z naught e j omega x over c, e j omega t and from here I get real of P plus by Z naught e minus j omega x over c in brackets 1 minus 2 gamma e 2 j omega x over c e j omega t. So, this is equation 3 B.

So, I have expressed my relations for pressure and velocity in terms of P plus and gamma and gamma we have defined that it is P minus over P plus and we will give it a name. So, we will call it reflection coefficient reflection coefficient. So, it is the ratio of P negative and P positive.

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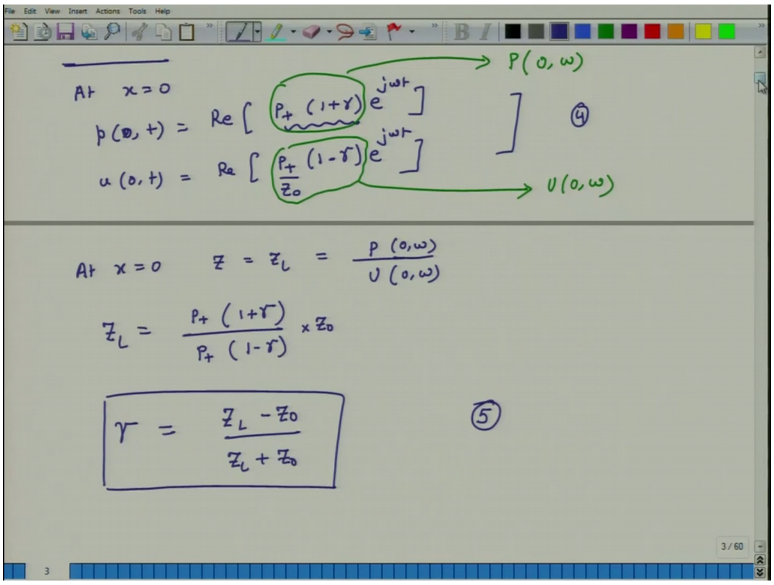

So, once we have done this mathematics then we use the boundary condition. So, what is the boundary condition in this apparatus that at x is equal to 0 the impedance of the system is Z L which we do not know, but it is some number which we do not know and it is Z L. So, this 2 should not be there. So, at x is equal to 0, we will evaluate the pressure and velocity.

So, pressure at x is equal to 0 is what real of P plus and if I put in this case x is equal to 0 in this term and this term they just become 1. So, I get P plus times 1 plus gamma e j omega t and u is real of P plus 1 plus gamma e j omega t and actually this should be not positive it should be a negative here and this is divided by z naught. So, this we call it as equation 4 and this term what is this term it is the complex amplitude of the pressure at x is equal to 0. So, I can call it P 0 omega, it can change with right similarly this term is the complex amplitude of the standing wave at x is equal to 0. So, this is u capital u 0 omega. So, now, we know that at x is equal to 0 impedance is what z and that is equal to Z L and how do we define impedance it is nothing.

But the complex amplitude of pressure right at location 0 and the complex amplitude of velocity at location 0. So, we can say that Z L equals P plus 1 plus gamma divided by P plus 1 minus gamma into z naught. So, P plus cancels out from numerator and denominator and essentially if I rearrange this I can express this as gamma equals Z L minus Z naught divided by Z L plus z naught. So, this is equation 5. So, the question is the thing is that if I know gamma, if I can figure out what is the value of gamma then from equation 5 I can calculate the value of Z L if I can figure out the value of gamma then I can calculate the value of Z L using equation 5 and what is our original goal that we want to find the impedance of this material z L.

So. So, now, we will try to figure out how to find gamma because once I can find gamma then I can calculate the value of Z L, Z naught is already known because the value of Z naught is rho naught times c rho naught is density of air and c is the speed of sound in air.

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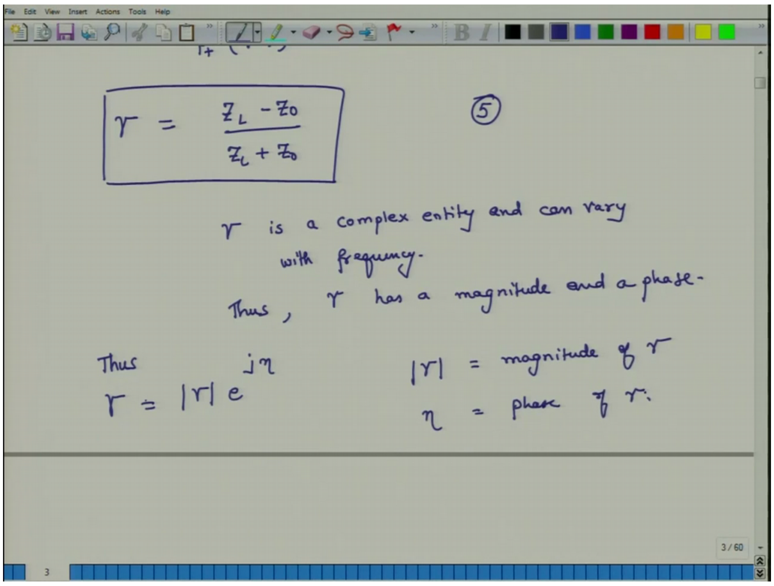

So, Z naught is known Z L if I know then I can calculate gamma and again remember gamma is a complex entity and can vary with frequency because when you take some material, it is impedance or sound absorption properties they change with frequency at certain frequencies it can absorb a lot of sound, at other frequencies it is absorption characteristics are very poor.

So, it is a complex entity and also it can vary with frequency gamma can vary with frequency. So, if that is the case thus we can say that gamma has a magnitude and a phase. So, thus I can express gamma as with some magnitude and if it has a phase then the phase term can be expressed as j times eta, where this is the magnitude of gamma eta is the phase of gamma. Now we will go back to our equations 3A and 3B and we note that this entire term this is what this entire term is the complex amplitude.

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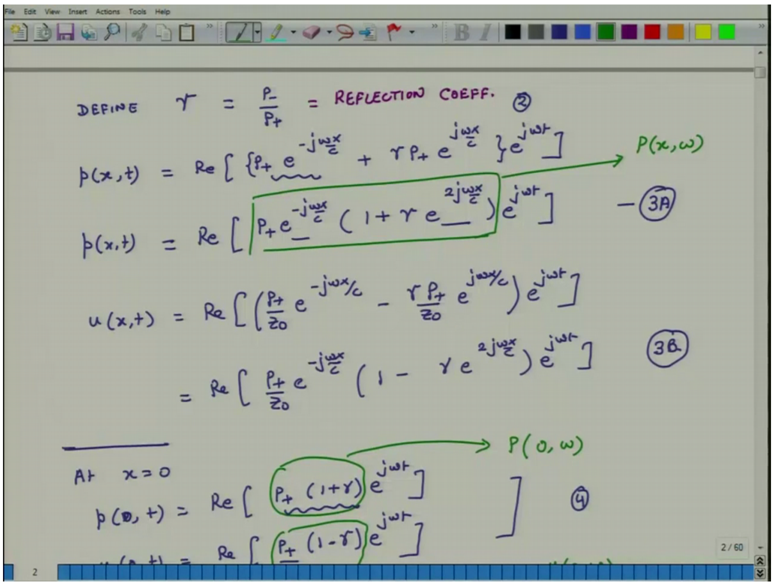

It is the amplitude of complex pressure, right it is the amplitude of complex pressure if I remove e j omega t from this entire term that is the amplitude of the complex pressure and this amplitude changes from position to position because there is e j omega x into the system, right.

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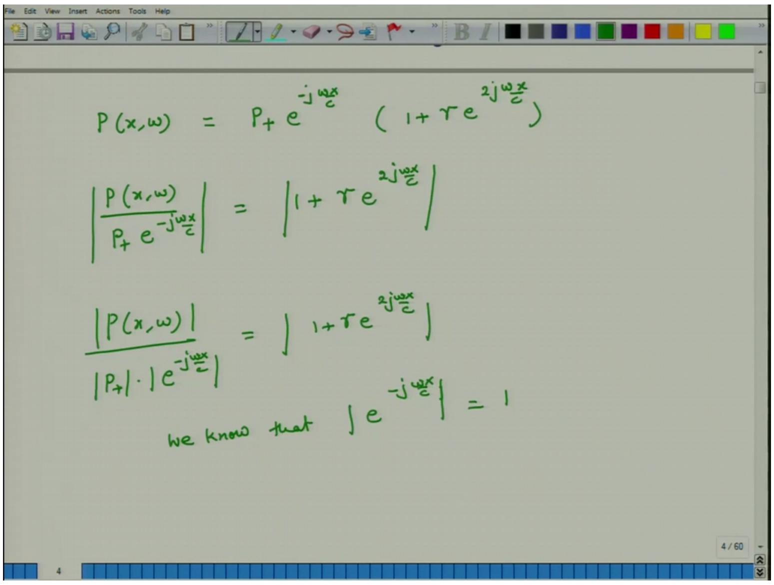

So, we will write that expression P complex amplitude of pressure in the tube is equal to what? It is equal to P plus e j omega x over c on negative times that into 1 plus gamma e 2 j omega x over c, this is the complex it is the amplitude of complex pressure right what I will do is, I will divide both sides by P plus times e minus j omega x over c. So, I get P x omega divided by P plus e minus j omega x over c and that equals 1 plus gamma e 2 j omega x over c, and then what I do is I take the modulus of both sides. So, on the left side I have a numerator and a denominator and the modulus of the entire thing is modulus of the numerator divided by modulus of the denominator, right.

So, I can rewrite it as modulus of numerator divided by modulus of denominator which is P bar, times modulus of e minus j omega x over c and this equals modulus of 1 plus gamma e 2 j omega x over c. Now we know that modulus of e minus j omega x over c is what is one because when I express e to the power of j times something it there will be cosine terms plus j times sine term. So, the modulus will be always 1.

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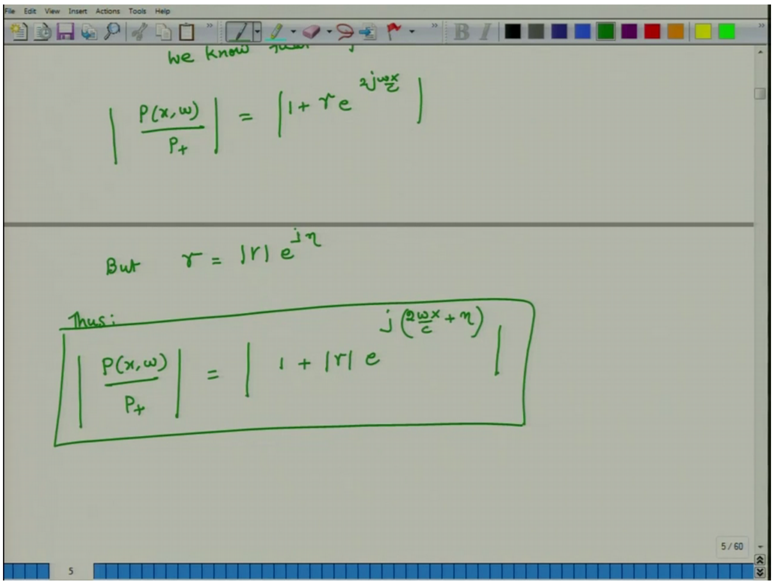

So, I can say that modulus of P x omega divided by P plus equals 1 plus gamma e 2 j omega x over c and finally, we know that that gamma as an amplitude and a phase e times j times eta, thus modulus of P x omega divided by P plus equals modulus of 1 plus modulus of gamma, times e j 2 omega x over c plus eta and the entire thing I have to take a modulus.

This is the relation. So, what we have done till so far, in today's lecture is we have developed an expression for Z L in terms of gamma and now we are trying to figure out a way to calculate gamma. So, we have to we can use equation 5 to compute Z L if I know gamma and now we are trying to figure out a way to compute gamma, and in that process what we have done till so far, is we have arrived at relation 6 which says that the modulus of complex amplitude of pressure wave inside the tube divided P plus is nothing, but modulus of 1 plus modulus of gamma times exponent j 2 omega x over c plus eta.

So, what we will do is we will close today and we will continue this discussion tomorrow and we will close our discussion on Kundt's tube in tomorrow's lecture. So, with that ah

I wish you a great day and look forward to seeing you tomorrow.

Thank you.