**Digital Speech Processing**
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**Lecture - 12**
**Uniform Tube Modeling Of Speech Processing Part – IV**

So, last class; we have discussed about that effect of that different kind of losses; nozzle effect of nozzle cavity on sound spectrogram and we said that with the derived that transfer function of the uniform tube single tube vocal tune vocal track. Now think about that see vocal track is a single tube model is.

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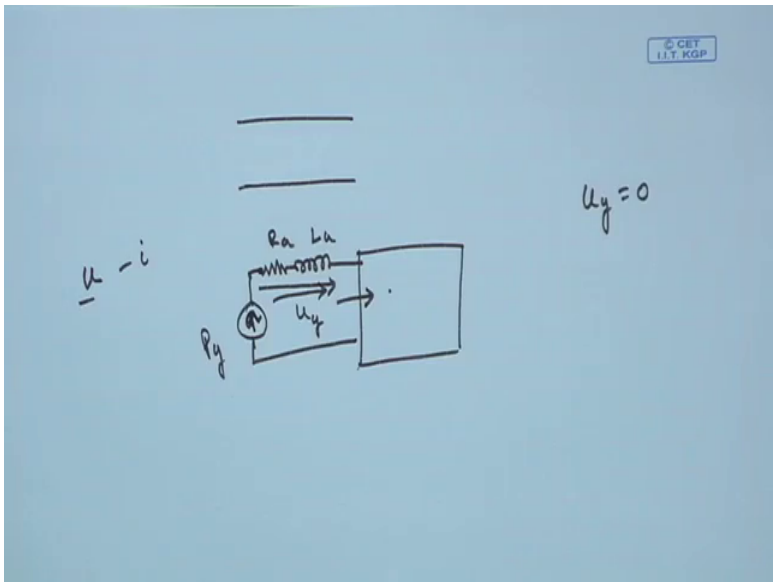


Now, can I find out that the radiation loss also, you have found out the effect of radiation loss.

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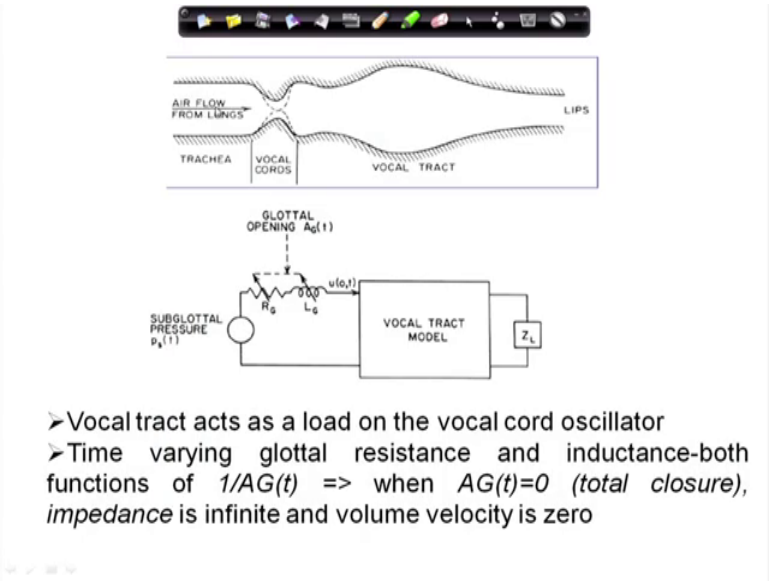


Now think about that how the glottal will connected to the vocal track if you see here the air flow from lungs passes through the vocal cords and once it passes through the vocal cords, since the vocal cord create obstruction in the airflow and due to this airflow, the vocal cord is vibrating and that vibration create the sound and goes through the vocal track and produce the sound. So, I can say whole vocal track can be; this is systems.

So, I can say this is you see that diagram. So, this is the vocal track model, next this is the vocal track model; how we excited that model using the vocal cord vibration. So, now, vocal cord vibration can an electrically simulate like this way. So, this is the airflow; that means, the air pressure which is coming from lungs; if the vocal cords are closed; the pressure is increases, once it start opening that if the pressure the this increased pressure force airflow through the vocal cords opening and that airflow causes a vibration in the vocal cords and that vibration create the sound.

Now if I say; you know that particle volume velocity U is nothing, but a analogues to electrical current i. So, if I say this is the vocal track which is a system and it is excited by a pressure which is coming from; pressure is coming from P g lungs; lungs pressure is excited the vocal track and that pressure, sorry that lungs pressure will connect will cause an particle velocity or volume velocity U in the vocal track. So, that how do you make the what?

So, if I say the impedance of the vocal cords its nothing, but a resistance and inductive impedance, then let us; it is a L G and it is R G like the load. So, now, these pressures pass through that impedance and create a vocal cord or you can say volume velocity U G which is the input to the vocal track system. Now if I say these vocal track vocal cords is a time varying vocal cords because vocal cord is closing and opening closing and opening. So, once it is completely close.

So, completely close means U G is equal to 0, if it is completely close, no volume velocity because air is completely stopped, flow is completely stopped. So, no volume velocity U G is 0. So, when this U G will be 0, if the impedance in here is infinite. So, if I say; let us vocal cord opening A G is a function of t. So, opening of the vocal cord is a function of t, then impedance is nothing, but a 1 by A G t. So, when the vocal track vocal cords are completely closed, then A G opening A G t is equal to 0 and that creates infinite impedance. So, that although there is a pressure is there, but there is no flow U G is 0. So, that is why that glottal impedance is infinite volume velocity is equal to 0.

Now, this analogy let us try to derive that I know the vocal track transfer function, I know the load condition or boundary condition at the lips which is the radiation load, I know the input condition vocal cords load into the tube. Now can I implement that tube in a vocal or within circuits or in digital domains or in circuits?

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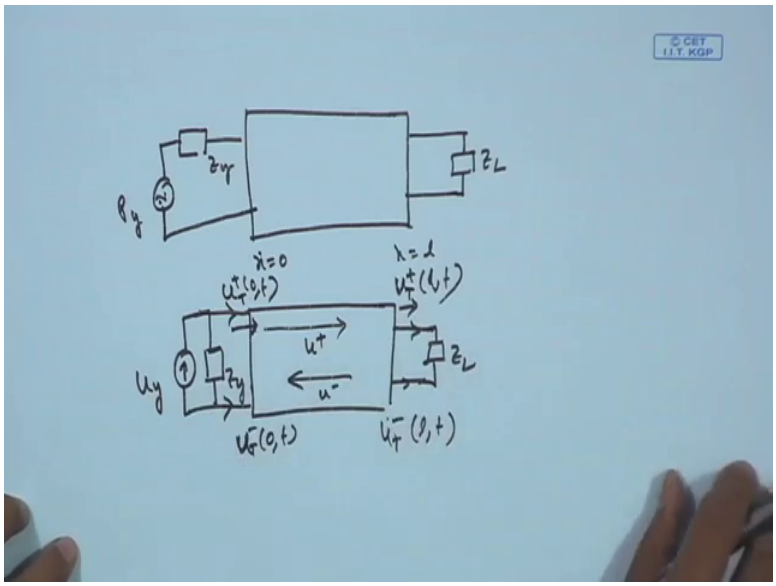

So, let us; this is my vocal track, this is the vocal track; uniform tube is the vocal track. So, here is an radiation load at the lip. So, if this is my Z L radiation load in the. So, this is x equal to 0, this is x equal to length of the vocal track is L or here is the radiation load this side, there is a some impedance in here and then there is a pressure source P g. So, this is the complete electrical model. Now if it is P g; it can be think this is P g So, if I make it replace by a current source which is nothing, but a U g current source is nothing, but a U g, then this impedance come in parallel.

So, this is Z g and this is Z L, this is the complete model. Now putting these 2 boundary condition; try to simulate this single tube vocal cord model. So, if I say this vocal track, if I say this is my input volume velocity. So, there will be output volume velocity, this is u equal say that this is u t; u t; u t plus 0 t. This is u t minus plus; you can say that l t; this is u t minus and this is l t and this is u t 0 t minus. So, this is a backward wave. So, there will be a forward wave, there will be a backward wave inside the tube which is u plus and which is u minus. So, considering all those things; can I derive this tube mathematical model of this tube considering 2 boundary condition now? So, tube can act nothing, but a delay tube is acting is nothing tube acts nothing, but a delay, let us forget about that part lets solve one by one boundary condition.

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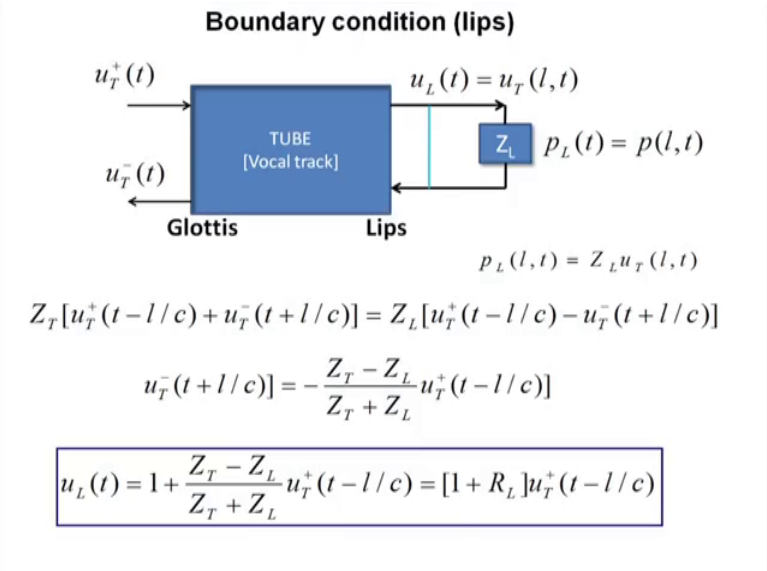


So, boundary condition at lips; so, I have a vocal track.

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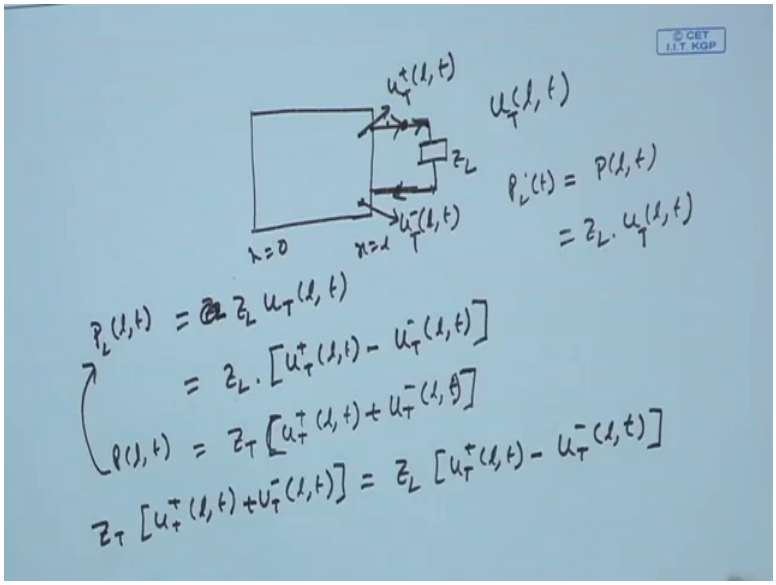


So, boundary condition at lips; so, I have a vocal track, this track has a boundary condition at lip. So, this is nothing, but a Z L.

So, this is nothing, but a u plus, u minus l t here and this is u plus l t or I can say this current which is coming out, it is nothing, but a u l t here, it is u ply here, it is U minus and here it is u plus. So, this u l t pass through this Z L and create P l t; P l t is nothing, but a P at l t is equal to nothing, but a Z L into lets complete current u l t or I can say u t, let us write that t; t track u t l t. So, now, find out that lips boundary condition. So, what is P L; P l t pressure across the load? Pressure across the load is nothing, but a Z L or you can say that Z L; let us write Z L into u t l t. So, it is nothing, but a Z L into what is u t l t; u t l t is nothing, but a u plus l t minus u t minus l t.

So, it is nothing, but this one. Now if I say what is P l t at the output of the t track P l t x equal to l in here and x equal to 0 in here. So, at x equal to l; p l t is nothing, but the Z T into u T plus l t plus u T minus l t or not and these 2 things are equal because at here; this pressure is equivalent to the pressure across the load. So, in that case I can say Z T; U T plus l t plus U T minus l t is equal to Z L u T plus l t minus u T minus l t is I can write down.

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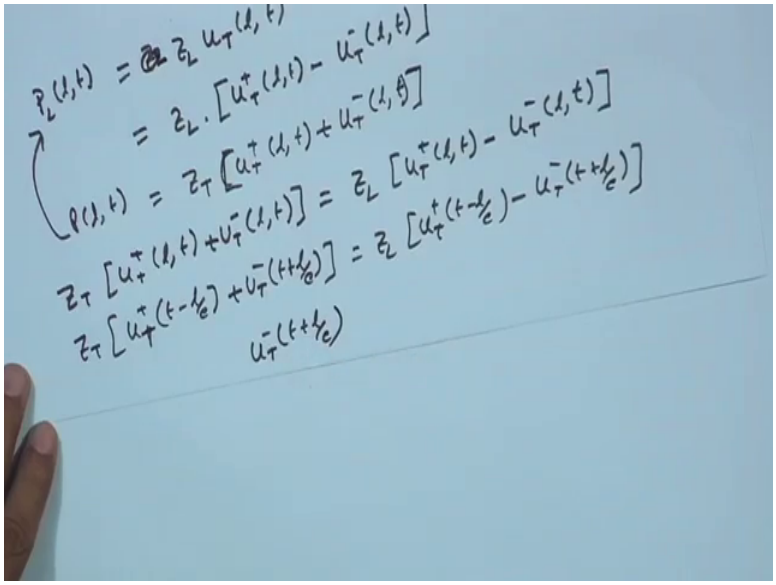

Now, I write down that what is u T l t. So Z T into u plus u T plus t minus l by c plus u T minus t minus l by c is equal to Z L u T plus t minus l by c; this will be plus; sorry, minus u T minus t plus l by c. Now from this equation, if I want to find out u T minus t plus l by c, I want to find out that backward wave. So, why want if I want to find out backward wave. So, let us all the forward wave term; I can write one side and on the backward wave term, I can write another side.

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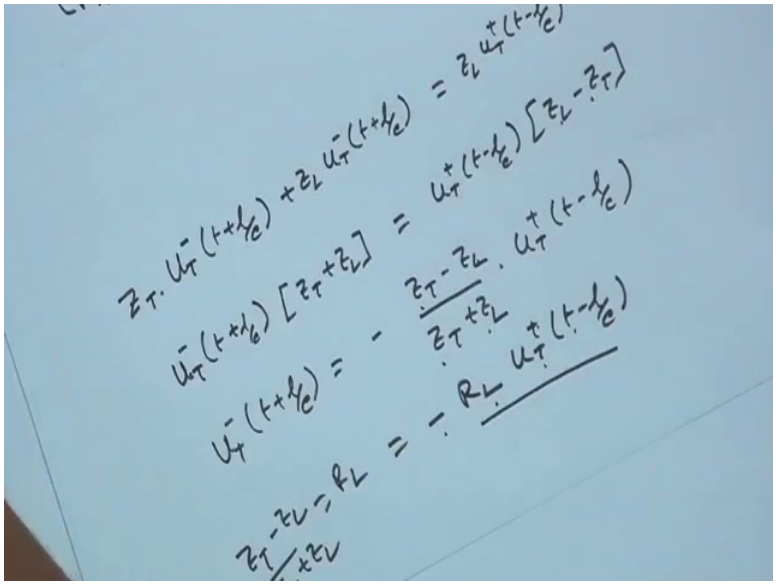

So, I can say Z T from here I can say Z T into u T minus t plus l by c, this term will come plus Z L u T minus t plus l by c is equal to Z L into u T plus will be there; so, Z L u T plus t minus l by c minus Z T into u T plus t minus l by c.

So, I can say u T minus t plus l by c into Z T plus Z L equal to u T plus t minus l by c into Z L minus Z T. So, I can write u T minus t plus l by c is equal to see this; this is Z L minus Z T take them minus sign out. So, minus Z T minus Z L divided by Z T plus Z L into u T plus t minus l by c or not; let this whole things Z T minus Z L divided by Z T plus Z L Z T minus Z L divided by Z T plus Z L, if I say this is nothing, but the R L; if I write down this is nothing, but a R L. So, I can write it is nothing, but a minus R L u T plus t minus l by c, now if I say; if it is this minus R L u T plus t minus l by c is. So, this is like same that in if you see that slides it is nothing, but a same.

So, it is in minus R L into u T minus t minus l by c is now what is the total current then what is u T or you can say the u l t; what is u l t; u l t is the current passing through Z L current which is passing through Z L which is nothing, but a ultimate volume velocity which is passing through this circuit. So, it is nothing, but a u T l t. So, I can say u t l is nothing.

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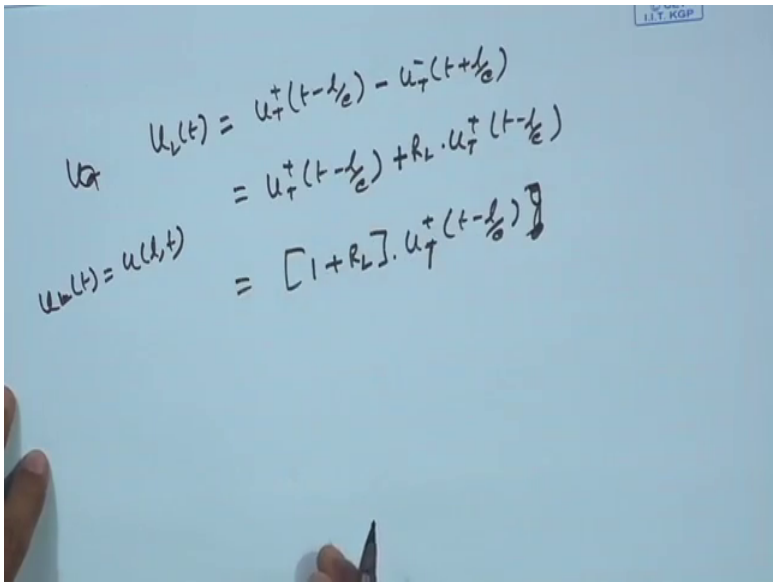

But a u T plus t minus l by c minus u T minus t plus l by c; so, u L you can say u l t is nothing, but a u at l and t. So, u at l like this. So, I can say, I put that minus value in here. So, u T plus t minus l by c minus again minus plus R L into u T plus t minus l by c; so, I can say it is nothing, but a 1 plus R L into u T plus u T plus t minus l by c; sorry, u T plus t minus l by c. So, this is nothing, but a 1 plus R L. Now if I want to draw the circuits. So, what sort of electrical circuits or transmission line kind of circuits. So, u l t; so, I can say let this is the tube. So, if I say the Glottis producing a; let there is a tube.

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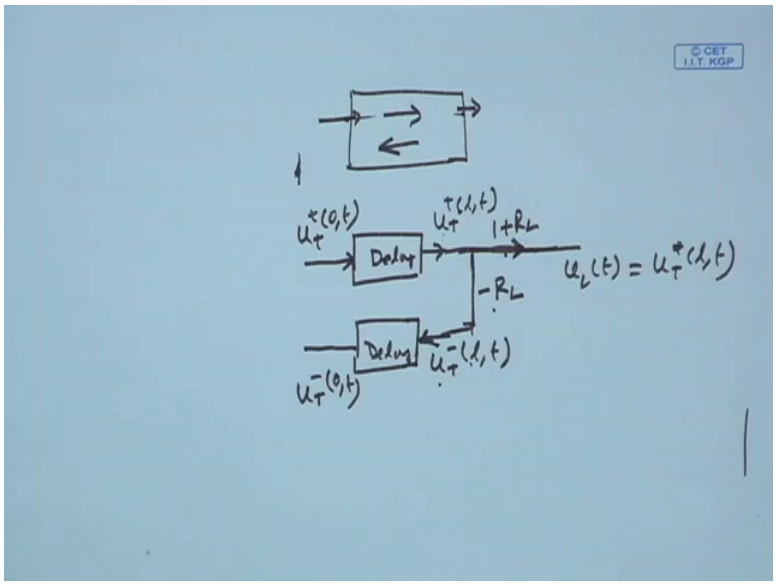


So, tube is nothing, but a delay, so if I say this is my vocal track. So, vocal track has a forward wave and has a backward wave. So, whole tube is nothing; the volume velocity in here and volume velocity here; let the volume velocity expression only different, but let it is delayed. So, what will happen; let I say; this is a delay circuits for forward wave. So, it is nothing, but a u T plus 0 t lets after the delay I get u T plus l t then backward delay either backwards lets this is u T minus l t backward wave and I can get here also backward wave which is u T minus 0 t.

Now total output of this volume output volume velocity is nothing, but a u L which is u l t which is nothing, but a u T plus u T l t. So, u T l t what is the u T l t equation u T l t equation is one plus R L u T plus t minus l by c. So, it is u T minus l by c. So, I can say it is multiply by 1 plus R L and I get that value what is t minus t minus l t it is nothing, but a

multiply by the plus this one multiply by the minus R L as far this equation this equation.

So, I can say it is multiply by the minus R L; I will get this and this whole things is nothing, but the delay is. So, it this is the boundary condition one plus R L multiply by these circuits. So, this is the signal flow diagram I can say signal flow diagram is nothing, but a 1 plus R L multiply by u T l t here and here is minus R L and flow is this side backward wave flow is this side now consider if you see the slide it is like this.

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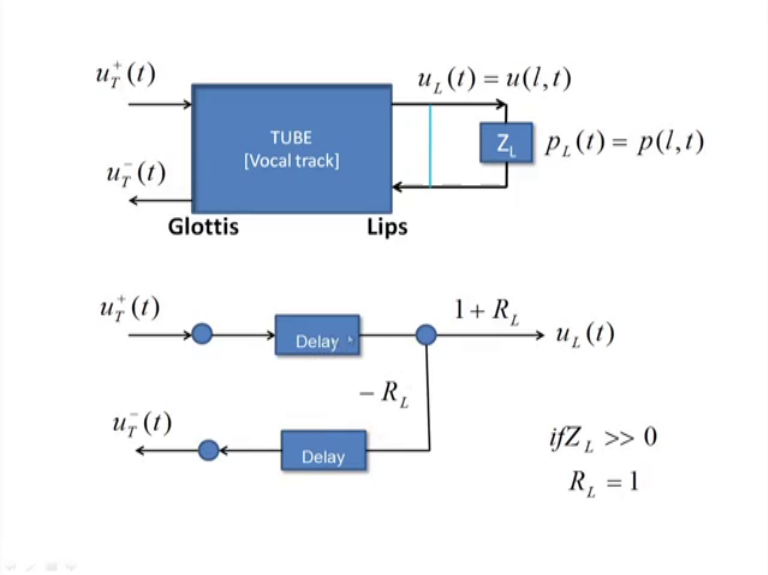


Now you u; that is a condition if Z L is much much greater than 0, much much greater than 0, then R L is equal to one if Z L; what is R L? R L is nothing, but a Z T minus Z L divided by Z T plus Z L. Now if say that if Z L is much much greater than 0, then I can say R L is equal to this condition, I will come later, this i will come after discussing the boundary condition; I will come this Z L Z T this constant scenario. So, this is the lip at the lip condition. Now if I say the glottis; glottis site; if discuss about the boundary condition at the glottis side.

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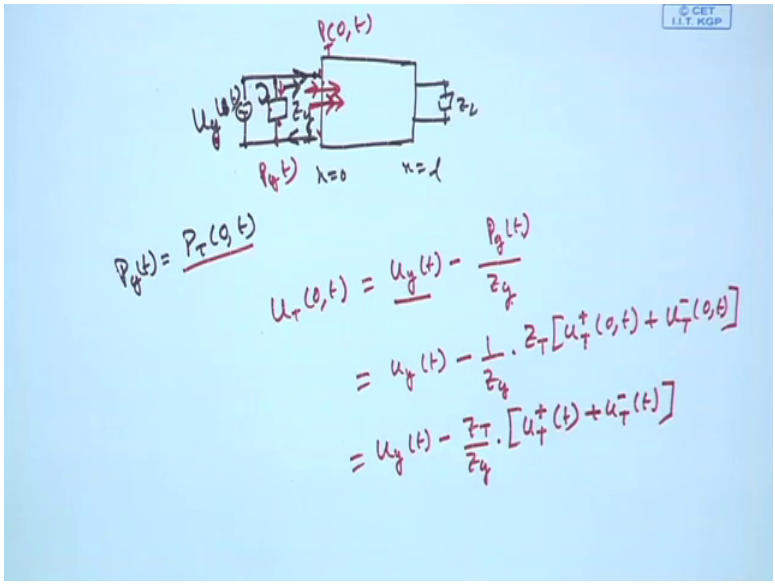


So, I can say, I know the lip side I know, lip side is nothing but Z L which is Z L; now this side I have said the special source is replaced by a current source which is nothing, but a volume velocity which is u g 0 t or u g t, here 0 is not here because z equal to 0 in here, x equal to l in here. Now the impedance glottal impedance come in parallel then z g. So, signal flow is like this, this is the forward wave-backward wave. So, I can say that P g t total glottal pressure is nothing, but a P T 0 t, the pressure across in here will be same in here also glottal pressure. Now the current is nothing, but a; this is a total current.

So, some current will flow this way and some current will be flow this way; some current will be flow this circuits and some current will be flow this circuits. So, I can say u T 0 t which is the volume velocity at the input of the vocal track is nothing, but a u g t minus. So, this is the total pressure is P g t. So, total pressure is P g t divided by Z g.

So, this current is this total pressure is P g t, then the pressure divided by the load is the current. So, this current will be minus from the total current is the current which will be passing through this to the tube. So, I can say volume velocity at the tube input is nothing, but a total u g t, total volume velocity produced by the glottist minus the volume velocity which is passing through the load glottal load u z g. So, this total current minus the load current; so, load current if the let Z g is the load and voltage is P g t; then P g t divided Z g is the current. Now what is P g t? P g t is nothing, but a P 0 t or I can say P 0

t or P t 0 t input track voltage. So, pressure at vocal track input. So, I can write u g t minus 1 by Z g into Z T u T plus 0 t plus u T minus 0 t or not. So, I can write u g t minus Z T divided by Z g into u T plus t 0 plus u T minus t x equal to 0; here x equal to 0. So, from here what I have to find out, again I want to find out the; what the volume expression of the volume velocity which is input to the track forward wave and the backward wave then I can draw the circuits. So, from there I want to find out u T plus t from this equation.

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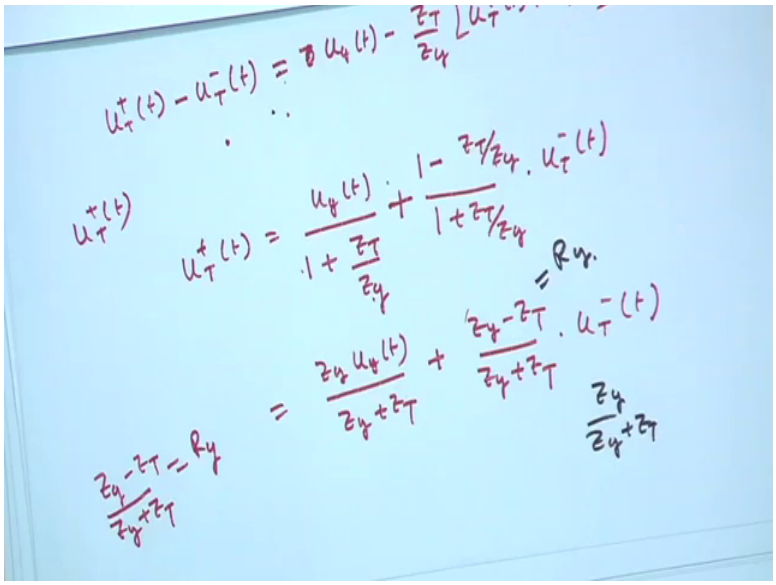

I want to find out u T plus t; how do I do it? So, u T 0 t here, it is u T 0 t, I write down u T 0 t means u T plus t minus u T minus t is equal to u g t minus Z T divided by Z g into u T plus t plus u T minus t. So, from there, I have to find out u T plus t what will be the expression the expression will be like this u T, I am write deriving it u T plus t will be u g t divided by 1 plus Z T divided by Z g into 1 minus Z T my Z g divided by 1 plus Z T by Z g into u T minus t. So, I can simplify it u g t plus u T and here also I can say u g t; sorry; there will be plus this is not into plus. So, if I simplify it Z g into u g t divided by Z g plus Z T plus Z g minus Z T divided by Z g plus Z T into u T minus t. Now if I say Z g minus Z T divided by Z g plus Z T is equal to R g, I say that this terminology these terms is equivalent to R g. So, what is the value of Z g divided by Z g plus Z T. So, Z g plus Z T will be 1 plus R g.

Let us find out 1 plus R g by 2. So, what is 1 plus R g by 2?

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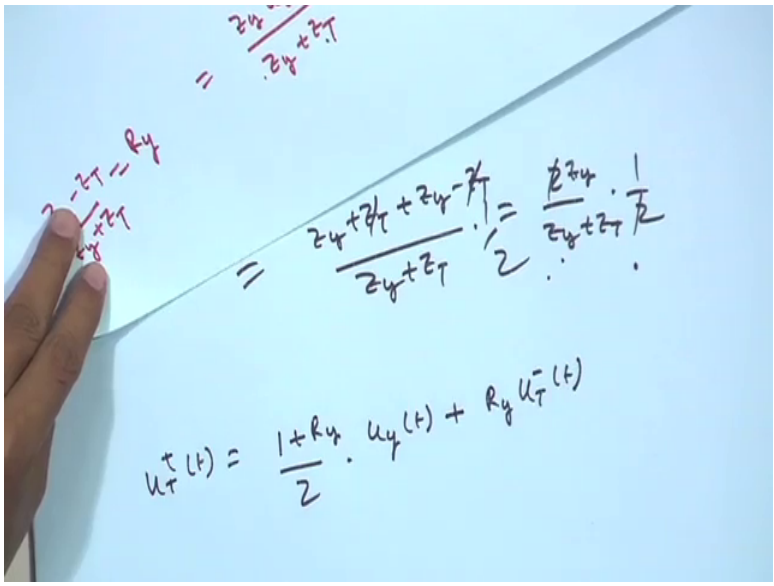

1 plus R g divided by 2 is equal to 1 plus Z g minus Z T divided by Z g plus Z g whole divided by half will be Z g plus Z T plus Z g minus Z T divided by Z g plus Z T. So, Z - Z T cancel. So, it will be 2 Z g divided by Z g plus Z T into half. So, it is nothing by, but a Z g divided by Z g plus Z T. So, I can say this term Z g by Z g plus Z T is nothing, but a. So, I can say u T plus t is nothing, but a one plus R g divided by 2 into u g t plus R g u T minus t. Now I draw the complex circuit of this side. So, I can say see this equation I tried to draw the vocal track circuits.

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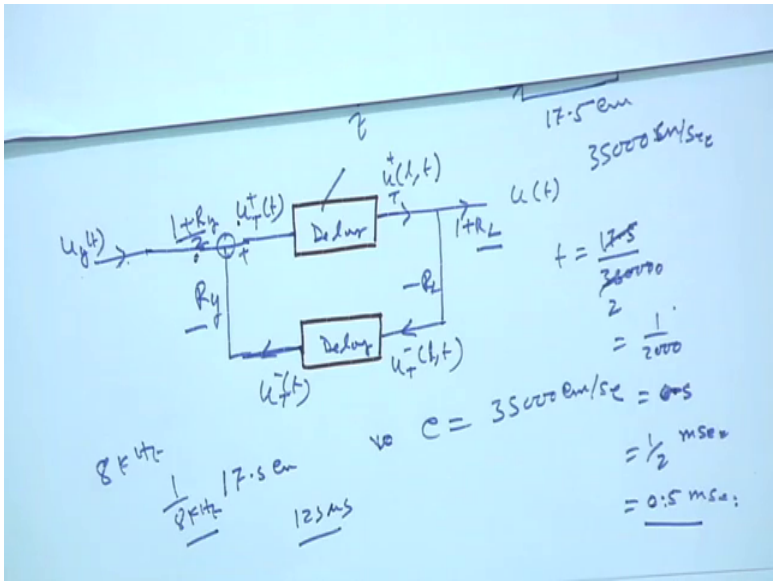


So, let this is my tube; say again, this is my delay in the forward wave this is my delay in the backward wave I take this blue pen. So, this is the delay circuit.

So, this delay circuits this is delay. So, I can say this is U G is coming from here u g t is coming from here glottal volume velocity is coming from here. So, if it has to be u T. So, this is nothing, but the u T plus t u T plus t u T at that u T plus. So, this is nothing, but a 1 plus R g divided by 2 multiply this plus backward wave has to be added here which one is nothing, but a R g. So, u T plus t is nothing, but a one plus R g by 2. So, u g t multiply by 1 plus R g by 2 system dialer signal flow diagram plus delay this is nothing, but a u T minus t R g and lip side what I get if it is u T final output lip side we get this kind of this which is nothing, but a one plus R L and this is nothing, but a signal flow diagram.

So, this will be the sign this is nothing, but a minus R L has to be fine and this is nothing, but a u T minus l t this is nothing, but a u T plus l t. So, if I consider whole tube is nothing, but a delay and put this 2 boundary condition, now if I know R g and R L, I can derive the circuit diagram or transfer function also. So, in digital circuits how the delay is implemented this delay can be replaced by z to the power minus n; n is the number of sample delay.

. So, suppose I have a seventeen point five centimeter long tube seventeen point five centimeter long tube; so, how much delay if the sound velocity is 35000 second 0 centimeter per second 350 meter per second. So, this how much time sound will take from here from come from here to here seventeen point five centimeter is the tube length. So, time is distance divided by the velocity. So, you can get it. So, how much time will required to cover seventeen point five centimeter if the velocity is v; v is velocity c of the sound is equal to 3 five 0 0 centimeter per seconds I can easily find out that things and once I get that things. So, I can say this is 352; I can put one. So, this one t by 2000.

So, I can say half 0 or can say 0.5 half milli second half milli second 10 to the power; 3 is half milli seconds 0.5 milli second. So, 0.5 milli second time will take from tube come to here to here. Now if I say that in digital domain if this circuit, I want to implement if it is sampled at eight kilo hertz then single sample delay means single sample delay means one by eight kilo hertz is the single sample delay. So, 1 by 8 kilo hertz I think 125 micro second, then how much delay will required 0.5 milli seconds I can calculate the number of z is required. So, I can listed out delay, I put z to the power that number of n delay will be simulated and I get the digital circuits if I know the R L and R g. So, next this kind of mathematics you can practice later on next we d then we discuss about the multi tube modeling. So, next class will discuss about the multi tube modeling.

So, single tube modeling we derive the signal flow diagram you do not have to remember it if you understand that things if you able to derive these equation then from the equation I can draw the signal flow diagram for a single tube model considering 2 boundary condition now instead of the single tube if I consider that production system is nothing, but a multiple tube, then what would be the task and how do you implement it. So, next class, we will start there.

Thank you.