Audio System Engineering
Prof. Shyamal Kumar Das Mandal
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture - 20
Transduction-II

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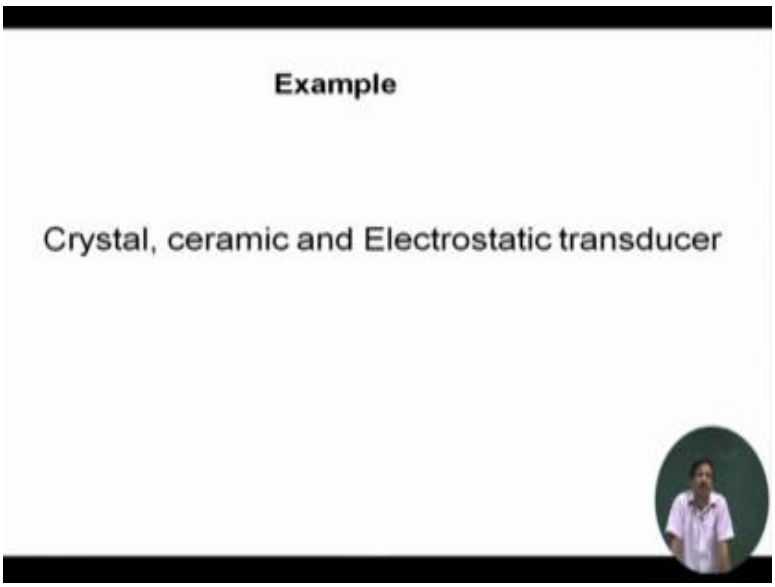

So, now we are discussing about the reciprocal transducer. In the last, so can you give me an example of some reciprocal transducer? I said in reciprocal transducer, T e m and T m e must be equal to T, and it will be real. So, in that case the example is crystal, ceramic electrostatic transducer all are reciprocal transducer. We will discuss how it is made, and then so those transducers are called reciprocal transducer.

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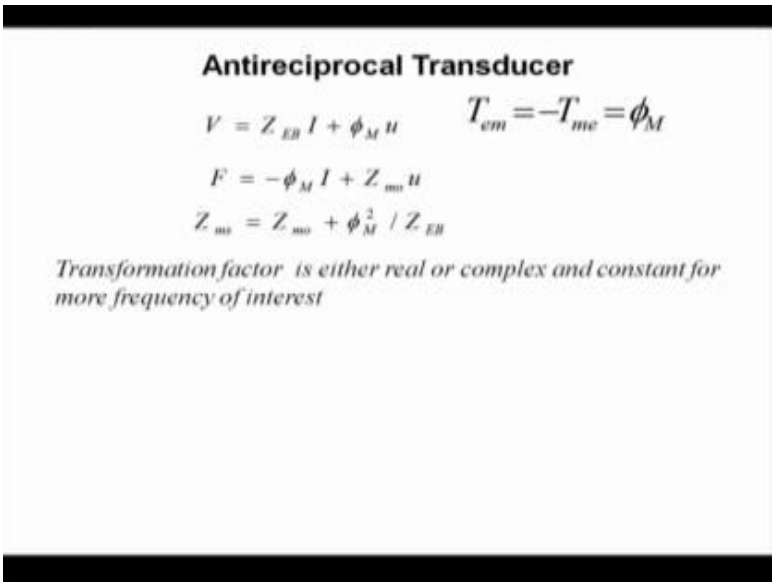

Then there is another king of transducer, which is called antireciprocal transducer. So, transformation factor is either real or complex, it may be either real or complex.

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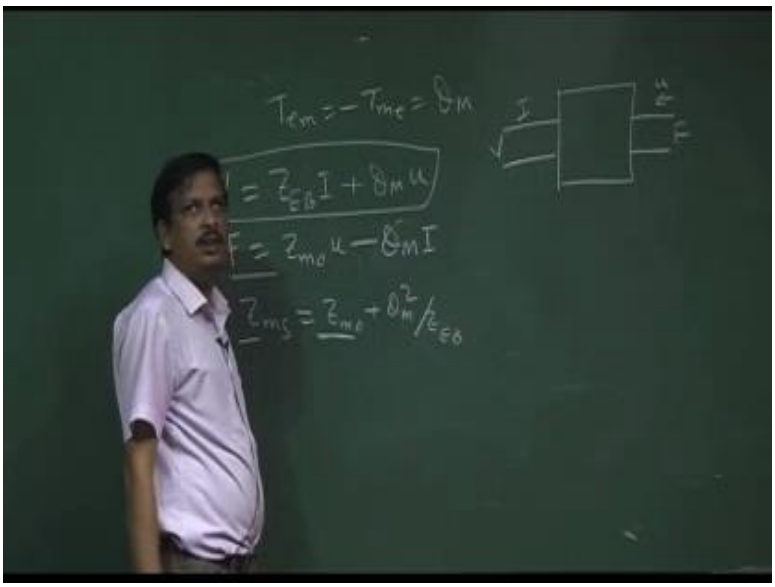

But in case of reciprocal transducer, T e m is equal to T m e is equal to T it is real and real component real part and both are equal. But in case of antireciprocal transducer lets T e m is equal to minus T m e and equal to lets this is nothing but a phi m. In that case, what is V, V is equal to Z E B into I plus phi m into u. Similarly, force is equal to Z m o into u plus minus phi m into I or I can write this is minus phi m I minus phi m I. So, this

is the equation. So, in that case, what is happening this is ok V is equal to Z E B into phi m u, but this is nothing but a minus phi m into I, so minus phi m into I is a can I do that things, can I realize it, no.

So, and there is another illustration, what is Z m s Z m s is nothing, but a Z m o. So, since it is T is negative. So, it will be positive. So, phi m square by Z E B. If T is equal to minus T m e, so it will be positive this state of 1 minus k c square Z m s is equal to phi m square by Z E B. So, this is the relationship between the Z m s and Z E B, Z m s and Z m o and this is the two equation canonical equation, this is called canonical equation. Now, how do you realize it, how do you explain it, minus phi m into I, we said I have two point network this side is electrical applied voltage V, current I; this side is mechanical applied force u and velocity mechanical velocity is u.

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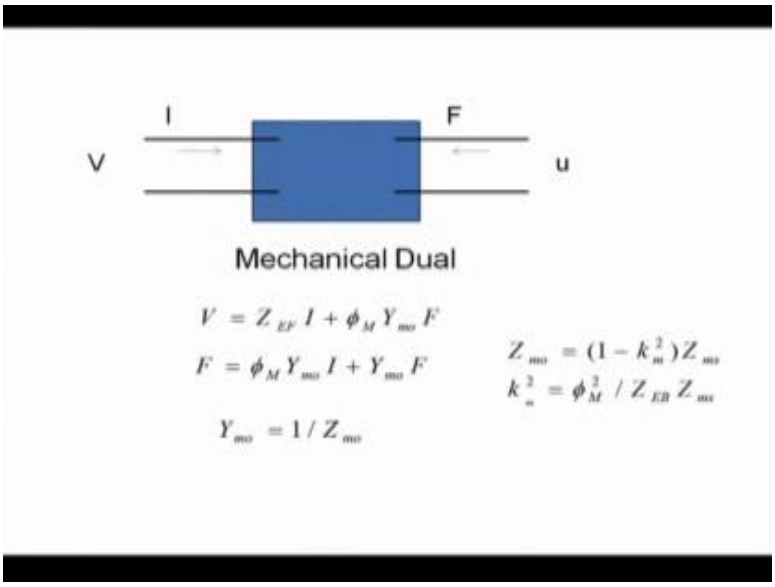

There is a there is a principle called mechanical duality; instead of that can I do like this, instead of force I can change it u, I can say that F is here. So, source is current source, I can say it is current source. So, if have a resistance R and if I applied voltage V lets voltage V then I say current I is flowing I say V is equal to I into R.

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Now, I can say also I equal to V by R or I can say lets R Y m Y into V. Well, Y is equal r is equal mechanical impedance mechanical resistance or mechanic if it is complex then it is mechanical impedance if I write a mechanical impedance then I can boot a box lets this is mechanical impedance is Z this is the load Z. So, this is 1 by Z once it is 1 by Z then I it represent by a Y into V where Y is called admittance why is called electrical admittance.

Similarly, if I say Z m o is mechanical Z ms is mechanical impedance 1 by Z m s I can say it is nothing, but a Y m s, which is hard circuits mechanical admittance. Similarly, I can write Z m o or I can write 1 by Z m o is equal to Y m o which is open circuit mechanical admittance and I change the notice in F to u to F. Now, it will come mechanical admittance. So, then what will be the equation V is equal to block V is equal to block electrical impedance into I.

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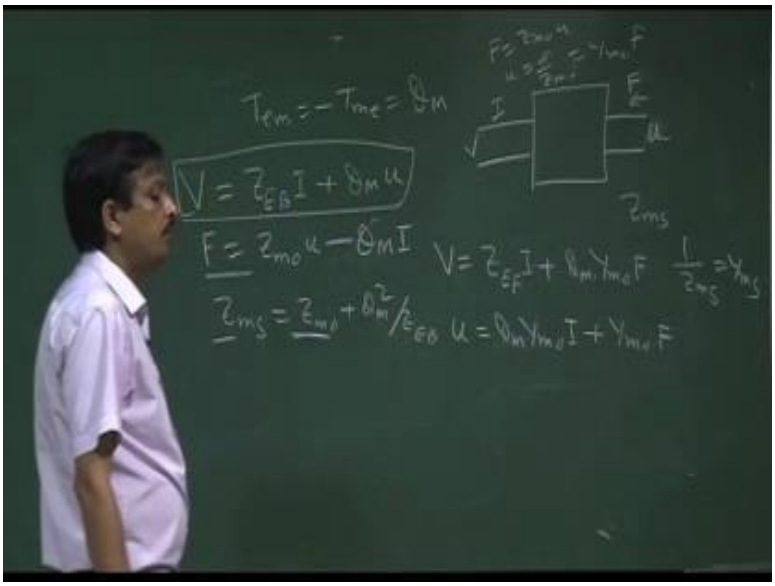

Now, if I said mechanical duality then V will be instead of Z E B, Z E F into I plus phi m into Y m o F. Why, because F is change, so F is equal to nothing but Z m o into u. I applied the mechanical duality, so u is nothing but a F by Z m o. So, F by Z m o is nothing, but a Y m o into F, so Y m o into F. Now, here F is equal to here there is no F here. So, u is equal to phi m, phi m by Z m o. So, it is Y m o into I, phi m Y m o into I plus Y m o into F, where Y m o is nothing but 1 by Z m o, equation 1 and equation 2. Now, can I draw the equivalent circuit for the antireciprocal transducer same thing can I draw by equivalent circuits for the anti reciprocal transducer. So, this is the equation number 1 Z E B, Z E F into I plus phi m Y m o F and this is equation.

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So, now I can say lets I applied V voltage here and this would be pass through a impedance which is called Z E F and current is I. And then thus should be pass through a rest there is impedance which is common is phi m Y m o admittance common phi m into Y m o is common admittance. And since it is create an extra load for I, I have to put on another impedance here which is nothing but a minus phi m Y m o. Now, in this side I have a mechanical u and admittance is Y m o, I connect Y m o this way. So, Y m o F and then I have to connect another minus phi m another load is here which is nothing but minus phi m Y m o. Now, if you drive V is equal to Z E F into I minus phi m Y m o into I plus phi m Y m o into I plus phi m Y m o F is flowing.

Now, if it is that then I can stay this, this cancel this support the canonical equation. Then F is equal to or u is equal to Y m o into F Y m o into f. Sorry this will be not connected here this will be connected here this is Y m o. So, Y m o F is flowing. So, Y m o into F minus phi m Y m o into F plus phi m Y m o into F plus phi m Y m o I, this, this cancel. So, Y m o F plus phi m Y m o I support the canonical equation my equation equivalent circuit ok once the equivalent circuit is OK.

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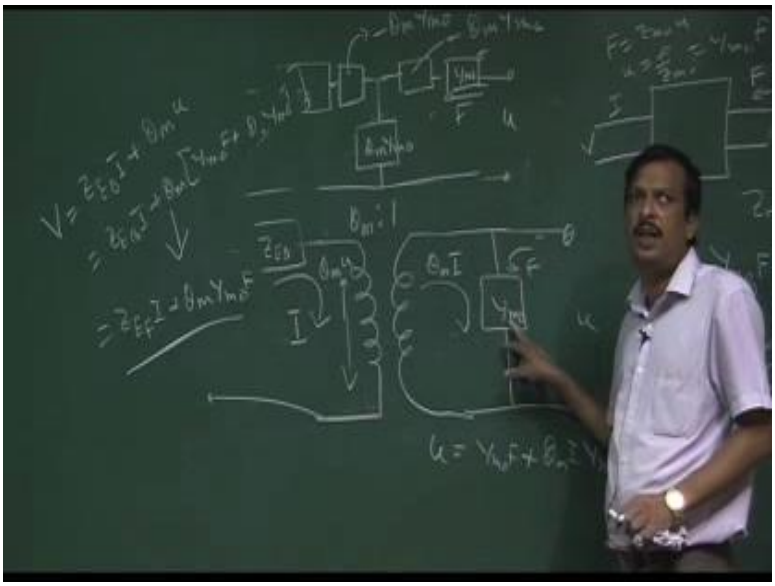

Now, can I real replace this minus phi m Y m o, I want to replace this minus phi m Y m o. Similarly, as in case of reciprocal transducer what I do I take a transformer. So, here also I can take a transformer. Let us this is phi m is to 1 that time I take 1 is to 2 phi here phi m is to 1. So, if I apply a voltage V here, V voltage in here and if I said I put on electrical impedance Z E B then the current I is produces then this side it will be phi m into I. Now, if I say mechanical side I applied a u as a voltage, so this will be phi m into u. And I said Y m o, this is Y m o F is flowing, so u F is flowing u is equal to Y m o into F plus phi m I will be there, phi m I into Y m o which is the canonical equation Y m o.

Similarly, here if I say that V is equal to Z E B into I plus phi m into u, now again like a reciprocal put the V is equal to Z E B into I plus phi m into Y m o F plus phi m Y m o Y m o I. Now, if I simplify these things, it will come Z E F into I plus phi m Y m o F reciprocal equation will come. So, I can draw the equivalent electrical circuit of that. So, in case of reciprocal transducer, electrical side is parallel to the transformer here Y m o is parallel to transformer, and it is admittance; instead of impedance I said it is admittance. So, this is called antireciprocal transducer. So, those theories will be used in construction of transducer.

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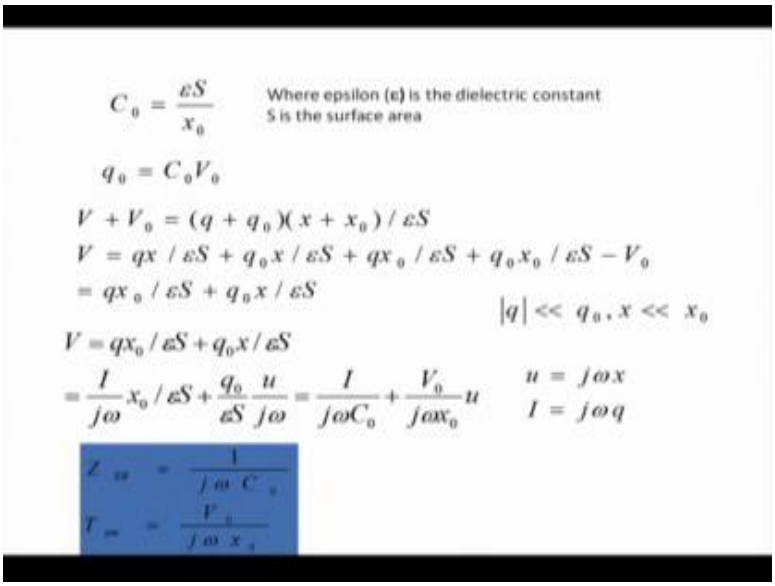

Next, start what I said can you give an example of antireciprocal transducer example for electro dynamic transducer all electro dynamic transducer are antireciprocal transducer. Let us start with a reciprocal transducer construction. So, let us what is the reciprocal transducer construction. In case of reciprocal transducer I certain capacitor electrostatic transducer is the reciprocal transducer. So, I can say I can draw back electrostatic transducer first.

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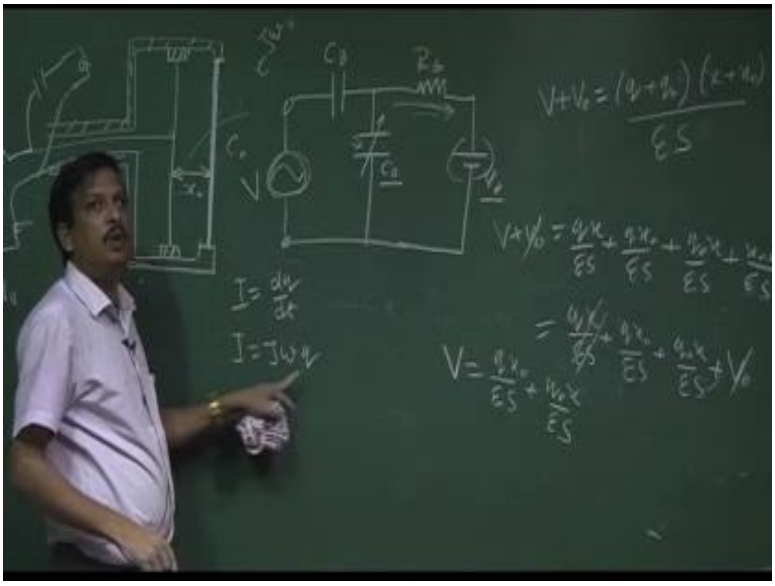

Let us I draw electro side transducer. So, there will be a wire, there will be a on the casing, which I have casing like this free hand drawing. So, if lets bear with me that it will not be not that good that you can draw, not that good. So, let this is the casing and here my diaphragm is connected. So, in between, there is a plate and plate attached the diaphragm. And I have isolation here - electrical isolation here, and I have another plate. So, I have another plate.

Let us draw it clearly, so that it can match. So, lets it is here and it is connected to here and up to here, it is connected up to here. So, two plates are parallel. And one wire is touches this plate, and one this is another ground steel ground, and another wire touches this plate. So, this between these two plates let us I apply a fixed voltage bias voltage V. So, if I apply a V 0 voltages in here, then the capacitor this is the capacitance this distance is x 0 and capacitance is C 0. So, I cannot apply then I have to connect and signal relative signal on top of that.

So, let us draw the equivalent circuits instead of this circuit. So, what I do I put a capacitance and then I say this is my variable capacitance this is the c this transducer this one. So, this is variable capacitance C, and let us this capacitance is initially charged by putting a voltage V 0, and capacitance value C 0, which is variable and lets this is C B and this is R B. So, what I draw that lets there is an options that this can be connected the voltage will supply to there by a resistance and this can be connected this voltage V is applied here. In between there will be a capacitance by which a source is connected alternative voltage source is connected. So, I applied there is a AC voltage when I applied signal voltage I will be applied here. So, signal voltage I can draw like this and V 0 is the static voltage.

So, let us describe the function in details. So, initially, there is no signal voltage. So, V 0 voltage is applied and the capacitor is charge to c 0. And the gap, so at voltage V 0, the capacitance of this capacitor is c 0 and the resistance R B is charge the capacitance. So, the value of R B should be very high, so that none of the AC current alternative signal which I supply the capacitor will pass this side, this battery side. So, this R B should be very high, so that none of that signal voltage should pass this R b and goes to battery side lost. So, it is reduces loss. And why c b is there, it there is source. So, this source will be not affected by this DC voltage, so DC voltage will be block by the C b capacitance. So, C b should be very high compare to c 0.

So, if the electrical side I can neglect the effect of C B and R B. So, R B and C B is required C B block the DC set to entered in the applied signal and R B resist the signal should lost on other side. Now, if I apply a V 0 voltage then c 0 will be charged; once c 0 is charged the difference between the two plate is x 0. So, I can write c 0 is nothing but a epsilon or naught epsilon I am not write correctly. So, epsilon s divided by x 0. Epsilon is the dielectric constant, s is the surface area of the plate and x 0 is the distance between the two plate that is the capacitance. And the charge on the capacitor q 0 is nothing but a c 0 into voltage V 0 charge on the capacitor c 0 into V 0. So, if it is q 0 is equal to c 0 into V 0, and c 0 is equal to epsilon into s.

Now, I apply a V voltage of signal - variable signal V on this terminal. So, total voltage is nothing but it V plus V 0 is equal to the charge will be change from q 0 to lets applied voltage V, the charge is change from q 0 to q. So, q plus q 0, q amount of charge is induces here extra charge. So, q plus q 0 into so displacement if the charge is increase displacement will be reduce or charge is decrease displacement will expands. So displacement is change from x 0 to x n divided by epsilon into s equals capacitance is nothing but a dielectric constant into. So, V is nothing but q by c. So, if it is V 0, then V 0 is nothing but q 0 by c 0 is nothing but a q 0 by epsilon s into x 0 that is why I put x in upper side and epsilon s is lower side.

Now, if I simplify this, so V plus V 0 is nothing but it q x by epsilon s plus q x 0 by epsilon s plus q 0 x epsilon s plus x 0 q 0 divided by epsilon s. Now, see that x 0, q 0 and epsilon s is nothing but q x by epsilon s plus q x 0 by epsilon s plus q 0 x by epsilon s plus V 0, x 0 q 0 by epsilon s is nothing but V 0, so V 0, V 0 is cancel. So, variable voltage V is nothing, but it these three terms. Now, this voltage is the AC varying voltage, so that voltage induce charge is q. So, q is much, much less than q 0. And I say x is also much less than x 0 the change of displacement and change of the charge is very less in that case this term I can ignore. So, I can say V is nothing but a q into x 0 by epsilon s plus q 0 into x by epsilon s.

Now, if you say what is q, q is the charge; charge is nothing but what is the relationship between q and I is nothing but a dq by dt derivative of d q by d t. So, if the V is very in complex manner, so let V is very in term of e to the power J x, J omega x or J omega then I can say I is nothing, but J omega q. So, d by dt derivative nothing but a J omega q and or q is equal to I by J omega. Similarly, I can write what is u, x and u relation

between the x and u. So, u velocity is nothing but dx by dt. So, u is nothing but J omega x. So, x is nothing but a u by J omega.

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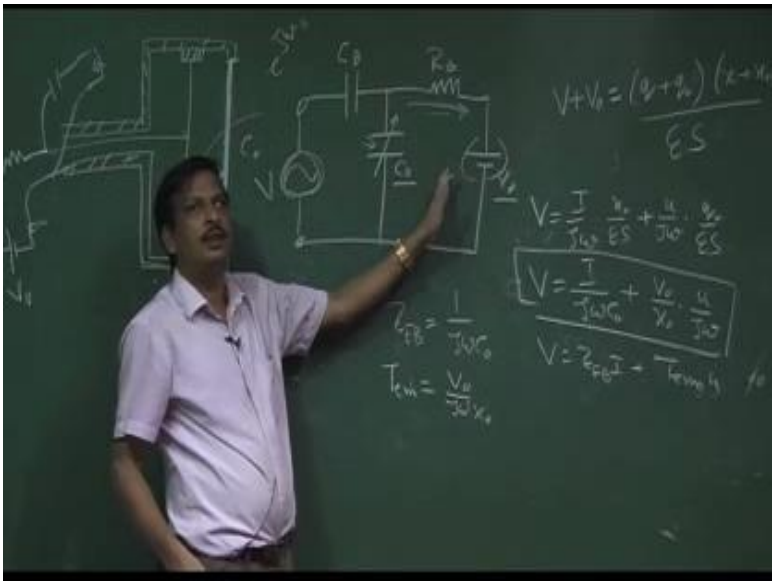

Now, I put this in this equation. So, what it will be done, x 0 is constant, epsilon is constant, s is constant, I cannot change. So, I replace q by I. So, it is nothing but a I by J omega into x 0 by sorry I should write V is nothing but a I by J omega into x 0 by epsilon s plus what is x, it is nothing but u by J omega I write u by J omega into q 0 by epsilon s. Now, what is x 0 by epsilon S? So, it is nothing but c 0, 1 by c 0. So, I can write V is nothing but a I by J omega c 0, where c 0 is equal to epsilon s by x 0 plus q 0 by epsilon s is nothing but a V 0. So, I can write V 0 by x 0 into u by J omega. Why I write V 0 by x 0, q 0 by epsilon s what is V 0, V 0 is nothing, but a q 0 by c 0. So, it is nothing but a q 0 by epsilon by x 0. So, I can write q 0 x 0 by epsilon s is nothing but a V 0. So, I already have q 0 epsilon s. So, I have to divide by x 0. So, I do the x 0.

Now, if you see this is the canonical equation of a reciprocal transducer one. So, what is Z E B, Z E B is nothing but a 1 by J omega c 0. And what is phi? Phi is nothing but a V 0 by J omega x 0 Z E B. So, V is nothing but a Z E B into I plus phi into Z E B into u or I can write not phi it is a T e m sorry T e m not phi, I write T e m. So, the canonical equation is one. Now, I derive the second equation. So, here what I said if I apply a voltage then q additional q charge will be deposited and that is why the capacitor plate

will be displaced by x amount and that create displace x amount and to create the mechanical oscillation. So, electrical to mechanical I said.

Similarly, if I apply a mechanical force on the plate, it should create an induce voltage v. So, if I apply a mechanical force, the electrical voltage will resist that force to change it. So, I can say the electrical voltage will resist. So, what is that at force, force F is nothing but minus q into q 0 divided by epsilon into s.

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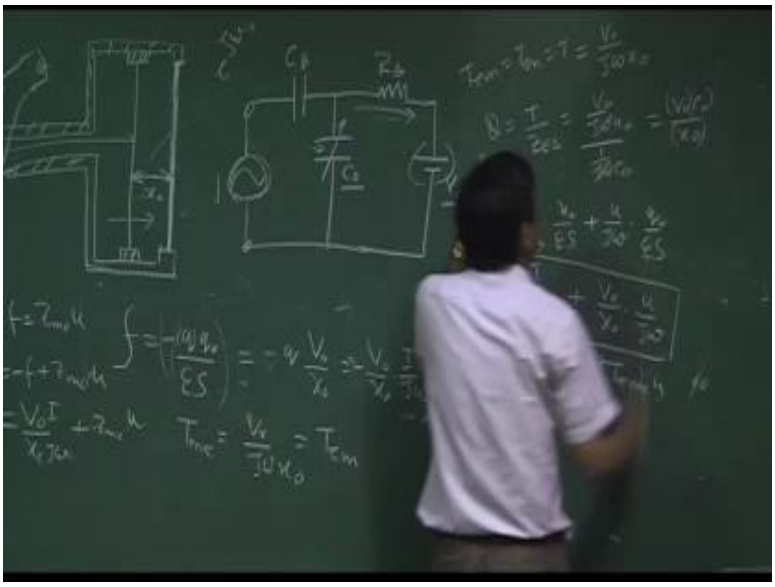

So, the force acting on the diaphragm, so this mechanical force want to change the diaphragm and these amount if the q amount of charge is due the mechanical force is induced here the charge will be changed q if the q amount of charge required to resist that force. Then I can say F equal to equal to that force produced by the q amount of force and it is negative because mechanical force is this direction and electrical force illustrate. So, it is the opposite direction or I can write F is equal to q 0 by epsilon into s.

So, explanation is that if I apply a mechanical force on the diaphragm, the electrical energy try to reduce that force or oppose that force. So, as per Newton second law of motion, if I applied to a force F, then if the electrical opposite force is same then it will be remain equilibrium. Next, that I applied a force F in this direction then the electrical force will be produce this, why this force will be produced because it induce some charges, so that charge is the electrical force, so that since the two force is opposite direction I can write in negative side. So, if it is negative then what I can do, I can write

it is nothing but what is q 0 by epsilon s nothing but a minus q into V 0 by x 0 or I can write this is nothing but it q is nothing but Y by J omega. So, V 0 by x 0 into I by J omega minus.

So, total force acting on the plate is nothing but a force is nothing but a force which is oppose that force. So, total force is nothing but a F plus F is equal to Z m o into u particular velocity into impedance while open circuit electrical circuit there is nothing is there. So, I can write F is equal to F minus F plus Z m o into u. What is F is nothing but a V 0 I by x 0 into J omega plus Z m o into what is Z m o into u. Now what is this, T if it is T e m then it is nothing but T m e mechanical to electrical V 0 by J omega x 0, here it is T e m V 0 by J omega x 0. So, the T m e is equal to T e m. So, it is reciprocal transducers are proved.

Then what it is phi. So, T reciprocal transducer is T m e is equal to T e m equal to T is equal to V 0 by J omega x 0. Now, what is phi is equal to T by Z E B. So, T is V 0 by J omega x 0 divided by what is Z E B, Z E B is nothing but a 1 by J omega c 0 1 by J omega c 0 is equal to J omega J omega cancel. So, it is nothing but a V 0 c 0 divided by x 0. Now, see phi is V 0 is real, c 0 is real, and x 0 is real and it is constant. So, phi is real constant because of reciprocal transducer we have to prove that phi is nothing but a real constant, so phi is there.

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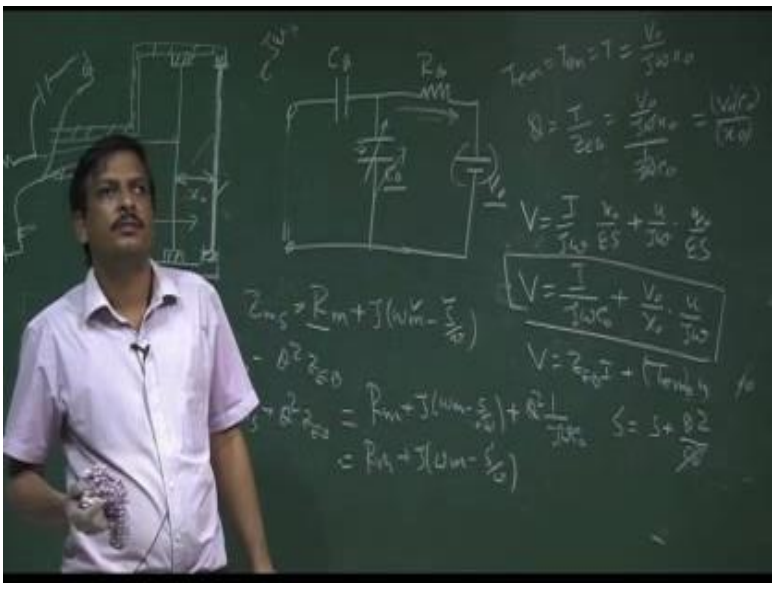

Now, can I do what is the relation between the Z m o and Z m s? So, by construction what is Z m s of this transducer? Short circuit mechanical impedance, so short circuit mechanical impedance means nothing is there no voltage is there no voltage is applied. Electrical circuit is short there is nothing but a spring mass system. So, I can say this is nothing but a R m plus J omega m minus s by omega spring mass system because this is a diaphragm as a stiffness and has an mass and it is hosted on a mechanical there will be mechanical resistance for hosting, stiffness and mass of the diaphragm which is nothing but Z m s. What is Z m o? Z m o is when the electrical voltage is applied then as soon as short circuit is open the voltage is applied. So, and the Z m o when it is open circuit then when it is open circuit then Z m o is equal to you know that what the relation Z m s, Z m s is equal to Z m o minus phi square Z E B. So, I can write Z m o is nothing but it Z m s plus phi square Z E B.

If I write that what is Z m s r m plus J omega m minus s by omega plus phi square Z E B; what is phi square? Phi square is nothing but V 0 c 0 square by x 0 square. So, I can write phi square and what is Z E B, Z E B is lets phi square and Z E B is nothing but a 1 by J omega c 0. If I add this, so this is nothing but I can say R m plus j. So, it is J omega c 0. So, it will be the change only the stiffness. So, I can say omega m minus s dash by omega where S dash is nothing but S plus phi square by c 0.

So, if we say mathematic shows that the as soon as I open that short circuit condition then the stiffness of the diaphragm has change to S dash. As soon as I open that short circuit condition stiffness of diaphragm will change to phi square by c 0. So, it could be now if the c 0 is a variable capacitance, so if the c 0 is change if the stiffness of the diaphragm will be change. So, if capacitance is change then the voltage will be the stiffness will be change phi square by c 0. So, I can say voltage change is equivalent to create a vibration equivalent to capacitance change.

So, next class, I will discuss about the coupling coefficient how it is work in that case of applied voltage.