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

Lecture - 19
Transduction – I

So, let us start. So, this week, we will discuss about that microphone and loudspeaker design. So, before we go for the microphone and loudspeaker design and specification let us start what is transduction, because what is required when I say the microphone and loudspeaker it is nothing but acoustical transducer. So, first we start from the transduction, and then go for the acoustical transduction. So, transduction, the meaning of the transduction is that converting of one form of energy to other form of energy maybe heat to mechanical rotation is one kind of transduction. Similarly, acoustical transduction means converting acoustics energy to electrical energy and from electrical energy to acoustical energy.

So, if you see in real life, when I speak or when the sound is generated or say that sound source is produce a sound it is nothing but an acoustic wave. Now, if you see that if you want to process that acoustics wave, suppose I want to amplify it, I want to filtered it or I want to do some sort of modification on it, then what is required because all of things will be done in a electrical circuits. So, that means I have to convert that acoustical energy to electrical energy, and or other either I can say I have to convert that acoustical signal if I say the acoustical signal to equivalent electrical signal and modify whatever I want on that signal modification, maybe equalization, maybe amplification whatever I want, and then convert back to acoustical signal.

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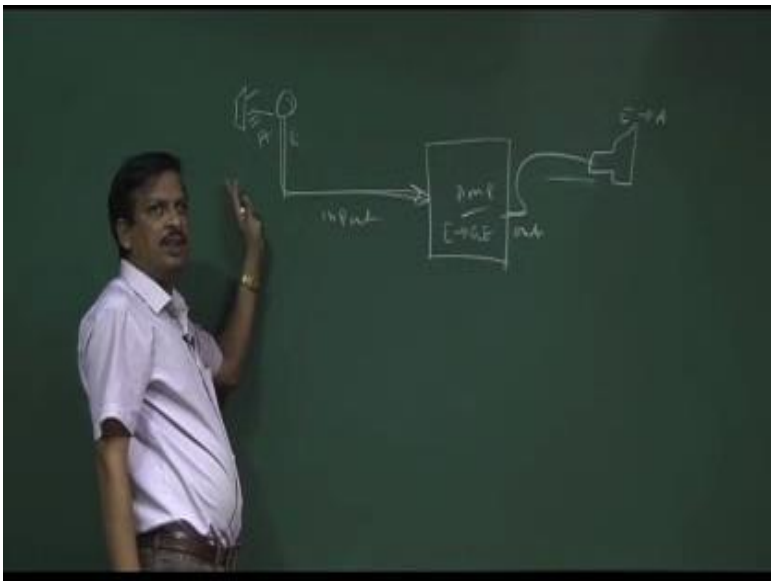

Suppose requirement, let us say that amplifier you see that audio amplifier you have seen why it is audio amplifier, because there is nothing audio that everything is electrical signal. So, in the audio amplifier if I say I want to amplify an acoustic wave, I say in a source let us this is an acoustic source produce an acoustic signal, let us say human being producing a speech. Then I have to convert that speech or I have to amplify that acoustic signal to spread it in this side. So, what I will do, I will connect a loudspeaker to an amplifier acoustical amplifier, and I connect a microphone to an acoustical amplifier. This is input and this is output, amplifier is electrical amplifier.

So, what I do, I convert acoustical signal to electrical signal then I modify that electrical signal by a gain lets G, so E G then E G will be delivered to a loudspeaker where it is convert from electrical signal to acoustical signal. So, I required a transduction in real life application from acoustical signal to electrical signal; similarly, electrical signal to acoustical signal.

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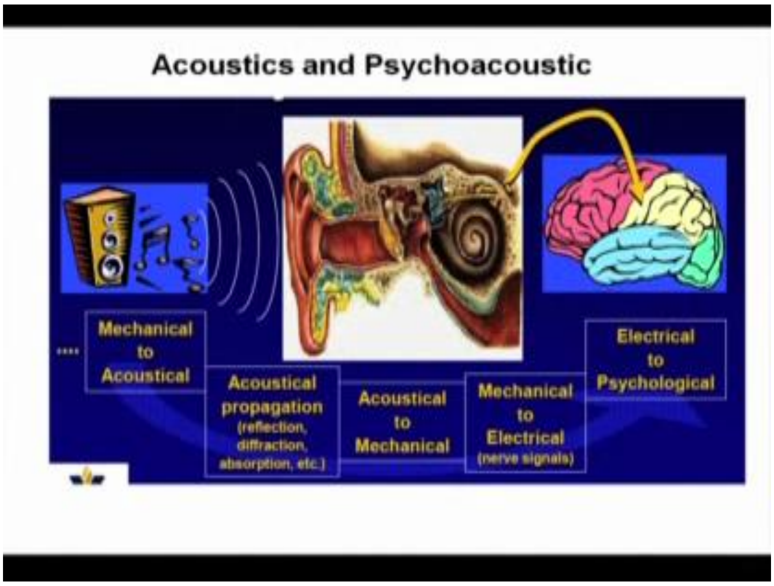

Similarly, if you see human being, if you seek the psychoacoustic transduction, let us this slides, this is the acoustic to psychoacoustic transduction. What is happening if you see there is a loudspeaker is produce a acoustical and mechanical energy or acoustical energy and that acoustical propagation will done here mechanical to so loudspeaker is a mechanical to acoustical then acoustical propagation has done then acoustical to mechanical because this acoustical signal is goes to the membrane, membrane will vibrate. So, acoustical to mechanical, then mechanical signal goes to the cochlea and cochlea convert in nerve is the psychological electrical signal or nerve signal on that create and perception, so that is electrical to psychological.

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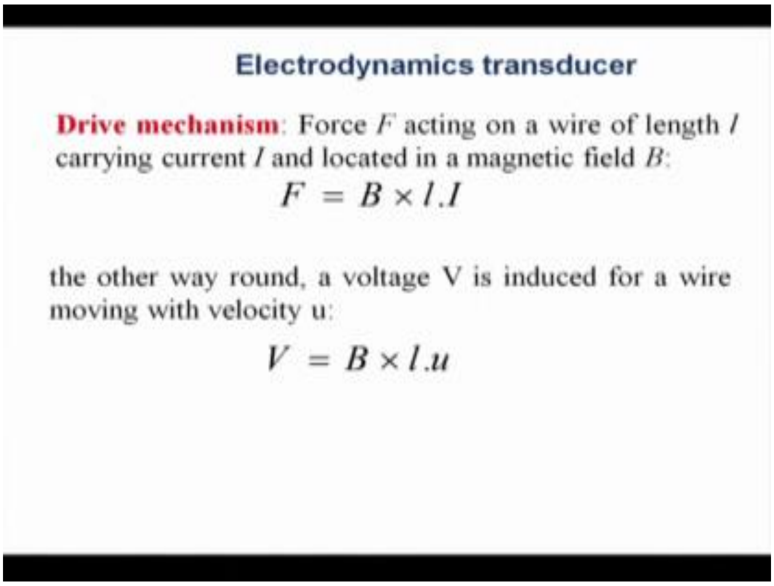

So, similarly, it give some amplifier I required an electrical signal. So, what I do acoustical to electrical then electrical, I have put some operation and then again electrical to acoustical. So, how do you do it, how do you do it, you want to transform that let us electrical to acoustical and acoustical to electrical. Now, if you see, there is a call electrodynamics transducer, the device which transducer acoustic to electrical is called transducer. So, it may be a microphone or it may be a loudspeaker. So, it is a nothing but acoustical transducer. So, let us one form of the acoustical transducer is called electro dynamic transducer.

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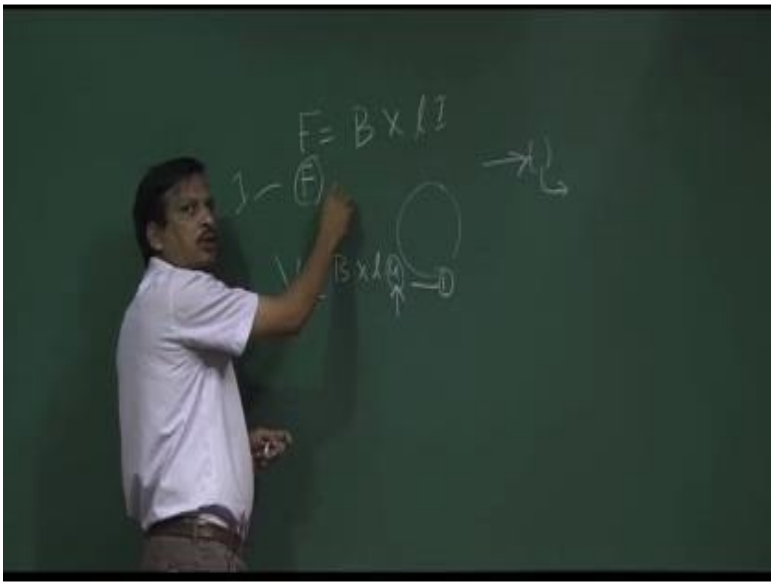

What I said here the force - mechanical force is nothing but a B into l into I you know that B into l into I; l in the length of the wire. I is the current B is the magnetic field strength then the applied force will be B into this cross product of B into l into I. Then similarly, if in a magnetic field is something in rotate then what will be happen that will be a electrical current will be produces. So, I can say V is equal to B into l into u, u is the mechanical velocity or moving velocity; l is the length of the wire, B is the magnetic field strength. So, l cross l into u is produces a mechanical voltage.

So, why I electro dynamic principle, I can convert this is the acoustic velocity I can convert that mechanical velocity to electrical voltage or mechanical force to electrical current, sorry, electrical current to mechanical force. So, in a loudspeaker, I can say a microphone I want mechanical force must be converted into electrical signal. So, I use this equation. If I want loudspeaker, there will be electrical signal I will be flow and I have to create by which the diaphragm will vibrate, the vibration is nothing but mechanical oscillation. So, this force creates the mechanical oscillation which produces the sound.

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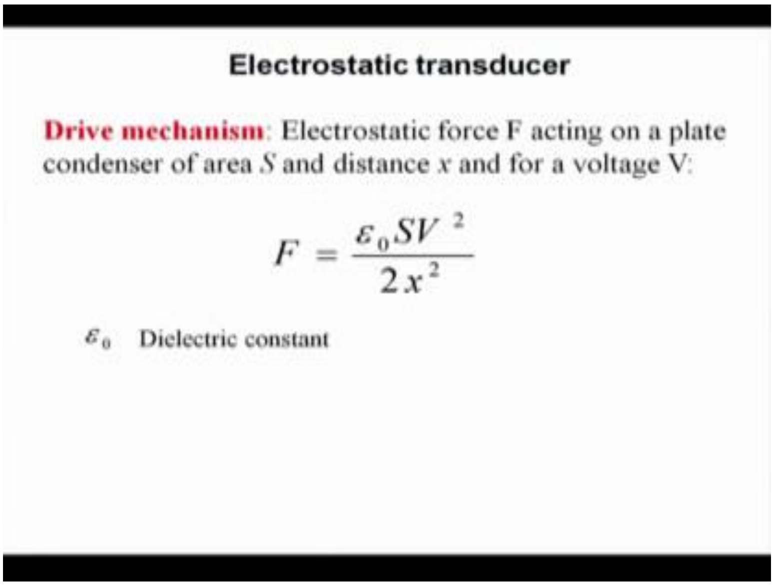

Similarly, another kind of example is that electrostatic transducer where I use capacitance - variable capacitance as a transducer.

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What it means, suppose, I have a two plate of capacitance and gap between the two plates is x 0, and dielectric constant is epsilon 0. Then force acting between the two plate is nothing but a dielectric constant multiply the surface area of the plate multiply by the voltage applied voltage square divided by 2 x square; x is the or x is the distance between the plate.

So, if the x is the distance between the plates and if the V voltage applied across the plate where I apply a voltage V applied then the mechanical force which is acting between the two plates is nothing but epsilon dielectric constant multiply by the surface area of the plate into voltage square divided by 2 x square. So, this creates electrical energy converted to the mechanical energy. Similarly, if I apply a force in one of the plates, so distance will be change and the voltage will be induced then I can say the mechanical force converted to equivalent electrical voltage. So, these two kinds of transduction I have discussed.

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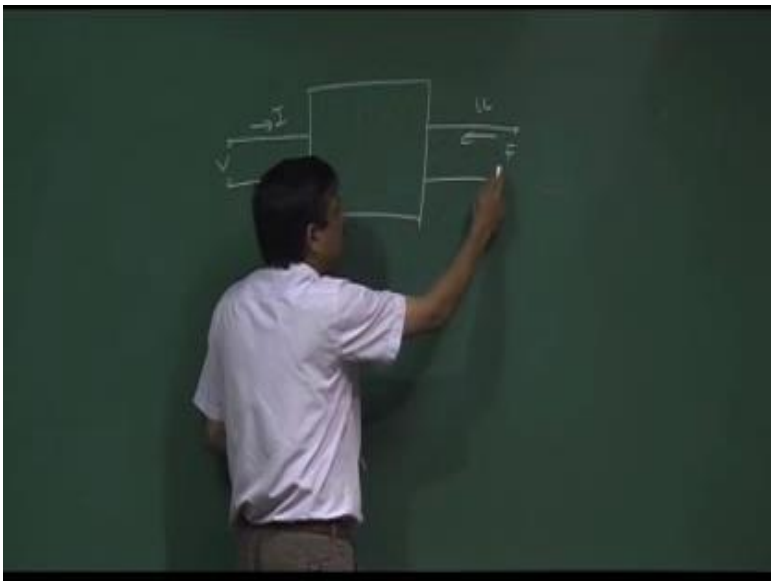

Let us discuss about the theory of transduction part and then we will go for the practical application. So, let us what is theory. So, I already said that list I required a transduction. So, let us this black box is by transducer, this is the black box is my transducer. I have a two port electrical networking here this side. So, this is electrical side I can apply a voltage V here a current can flow I here. And this is called mechanical side. So, again there is a mechanical force on here and the particular velocity will be u will be acting on here mechanical side. So, this is a transducer that has an electrical side, and has a mechanical side. So, electrical side V voltage applied I current induce, and here mechanical side F force is applied, u is the vertical velocity.

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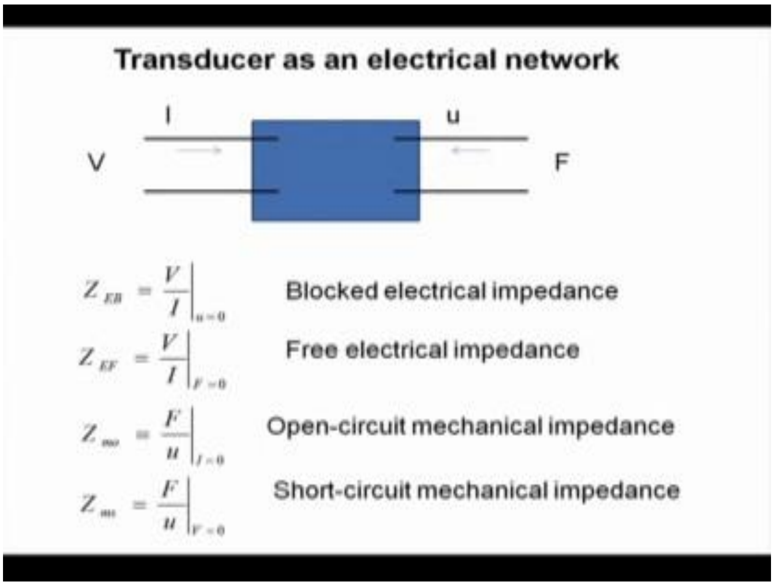

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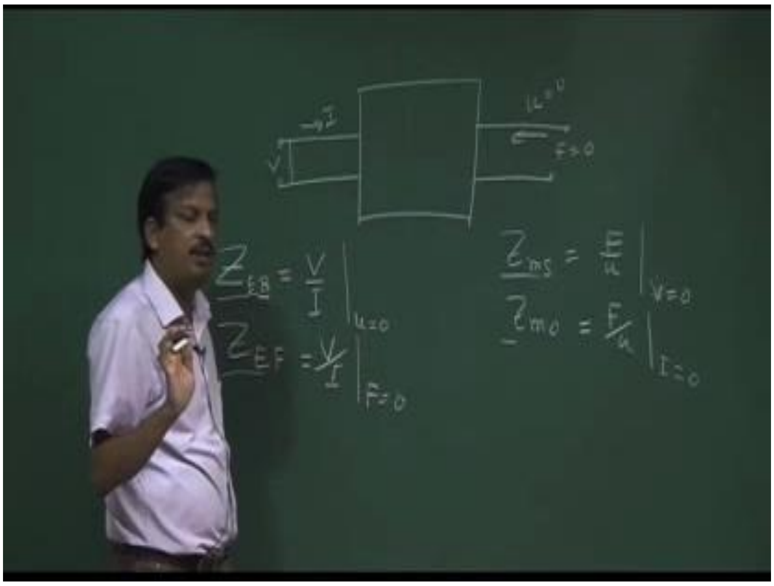

Then what will happen let us electrical impedance Z has two conditions, either this F equal to 0 or either u equal to 0. So, Z E B let us, so I write E B is nothing but a V by I find E B blocked electrical impedance when u is equal to 0. Why, because this is called block electrical impedance suppose I have a mechanical transducer, and if I apply electrical voltage, the diaphragm of the transducer will vibrate. Now, if I block that vibration I say there is a no motion of the mechanical force, so there is a no motion of the diaphragm so that means, u is equal to 0, then that electrical impedance will be Z E B electrical impedance when the mechanical side is blocked means no motion is allowed.

Then there will be a Z E F, when the motion is allowed free motion, there is no mechanical force resist it to stop the motion. So, it is free in motion so that means, V by I find F equal to 0. So, it is called mechanical electrical impedance Z E is the electrical impedance when it is mechanical side is free means there is a nothing acting on the diaphragm nobody stop the diaphragm, diaphragm is vibrating. So, it is free from applied force this force is not there. So, F is equal to 0.

Similarly, in mechanical side, I can say Z m s short circuit mechanical impedance is nothing but force by vertical velocity when short circuit, if it is short circuit then it is nothing but a voltage is equal to 0. Then Z m o open circuit mechanical impedance, it is F by u when I equal to 0. Short circuit, if I make it short circuit then the voltage acting on this two plates will be 0, two lines will be 0. So, the voltage is 0 means short circuit mechanical impedance, open circuit mechanical impedance. So, when open circuit means there is a no current is flowing, so I equal to 0; short circuit means current is flowing, but voltage equal to 0. So, short circuit mechanical impedance, open circuit mechanical impedance, this terminology will be used later on. So, I think this is the clear understanding has done.

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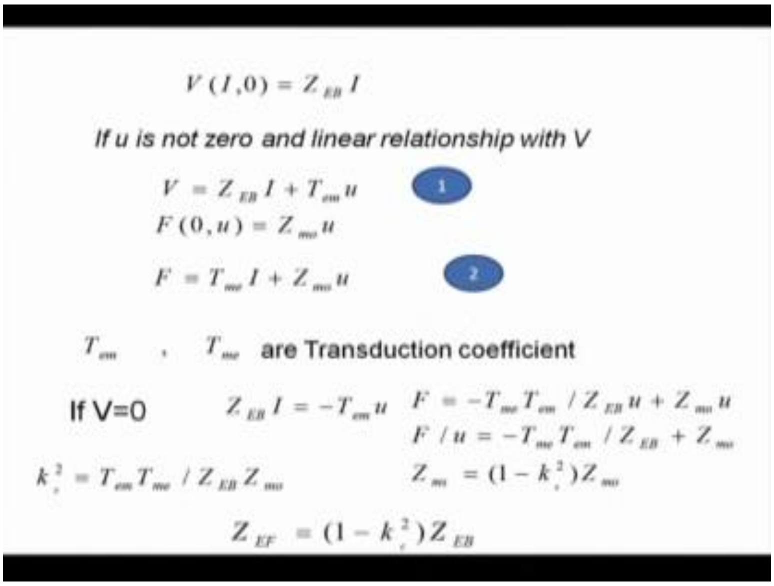

Now, let us if it is that then what is the equation, let us start that derive the equation.

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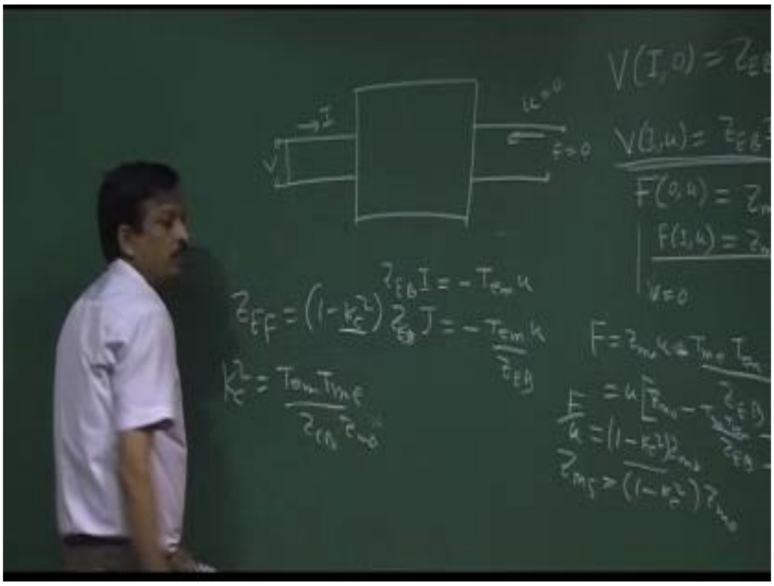

What is the equation if I say I applied V voltage when u is equal to 0. Let say the V electrical voltage is a function of current and to u is equal to 0. So, there is no mechanical velocity, so only voltage is there with u is 0. Then it is nothing but u e 0 means Z E B. So, it is nothing but Z E B impedance multiplies by the current I. Now, if I said no, u is not equal to 0, lets u is varying linearly with relationship with V then I can said V when I and u both are there is nothing but it Z E B into I plus lets there is a curve coefficient curve T e m - electrical to mechanical; coefficient into u. So, u is not there. So, some component of the u contributes to the mechanical electrical voltage. So, I said like u is there and this is called electrical to mechanical coupling coefficient. So, coupling coefficient electrical to mechanical is T e m coupling coefficient, and u is not zero, so it is nothing but V I u is nothing but Z E B into I plus T e m into u.

Similarly, if I say force, similarly I can derive the force. So, if I say force is only function of I 0 and u and it is nothing but I is 0. So, it is nothing but a Z m e into u impedance into vertical velocity. Now, if I say it is not I equal to 0, so F is the function of electrical current and mechanical velocity, then it is nothing Z m o into u plus T m e mechanical to electrical coupling, and then I ok or understand, you understand. So, I have a V equation and I have a force equation and T m e is the transduction coefficient. So, those are the coupling or transduction coefficient.

Now, if they are transduction coefficient, this is the equation number one and this is the equation number two. Then if V is equal to 0 then in equation number what will happen Z E B into I is equal to minus T e m into u if I put the Z E B into I Z E B into I. So, I is nothing but a minus t e m into u by Z E B I put that I value in F equation. Then what will happen, let us write F equal to Z m o into u plus T m e into t e m into u divided by Z E B or minus this will be minus there is a minus sign into Z E B. So, if I take u outside, so it is nothing but a Z m o minus t m e t e m divided by Z E B lets I write that K c square is nothing but a t e m t m e divided by Z E B into Z m o.

So, I can write F by u F by u is equal to what is F by u F by u is equal to I can write one minus K c square into Z m o, this K c square is nothing but T m e Z E B minus Z m o. So, I can write one minus K c square Z m o will be multiply here Z m o come on one minus K c square into this what is F by u is nothing but a Z m S Z m S is nothing but a one minus K c square into Z m o. So, this is the in relation between hard circuit mechanical impedance to open circuit mechanical impedance similarly I can derive the relation between Z E B and Z E B similarly Z E F will be one minus K c square into Z E B blocked electrical impedance and free electrical impedance and K c is called coupling coefficient. So, K c square is nothing but a t e m t m e divided by Z E B into Z m o. So, I can write, so this is the relationship between Z m S Z m o Z E F Z e F into Z E B. So, this relation I have discussed I just said.

Now, generally two condition possible in this equation this two equation two condition is possible either T e m may be equal to T m e electrical to mechanical and mechanical to electrical those transaction coefficient may be equal if it is equal to t then equal reciprocal transduction then I call equal reciprocal transduction.

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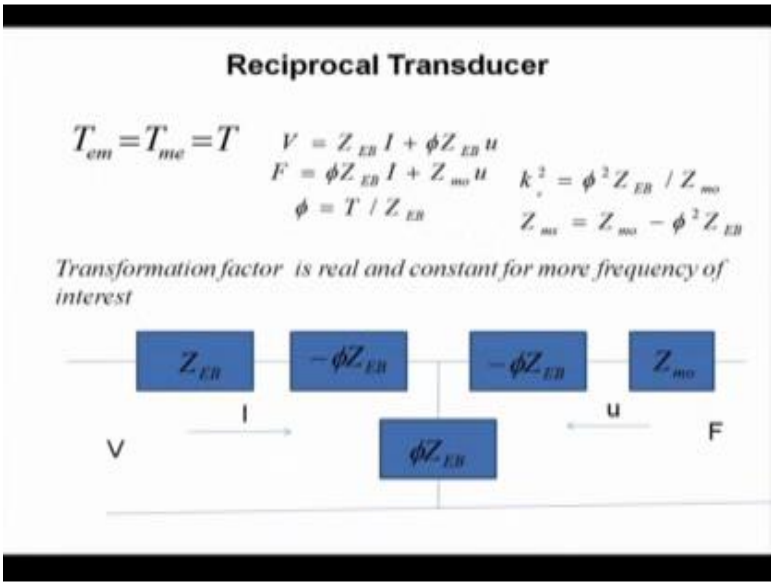

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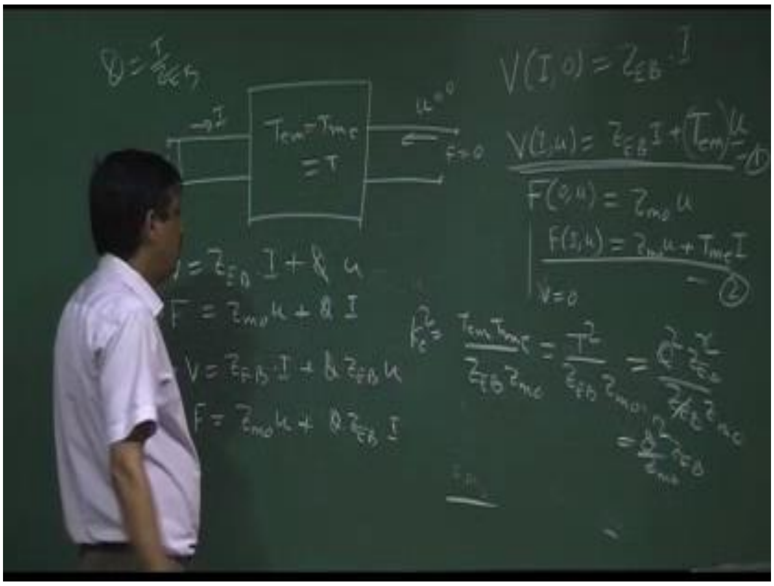

So, if it is reciprocal transduction then what will happen lets this transduction is reciprocal transduction in that case T m equal to T m e is equal to T, same, mechanical side to electrical side, electrical side to mechanical side both are same. In that case, so V will be Z E B into I plus T into u, and F will be Z m o into u plus T into I. Now, K c square is nothing but T e m T m e divided by Z E B into Z m o, say it is nothing but a T square by Z E B into Z m o. Let us replace this T by a transduction factor phi, where phi is equal to T by Z E B.

So, I can write this equation phi is equal to I take T by Z E B. Then this equation I can write V is equal to Z E B into I plus phi into Z E B into u, and F is equal to Z m o into u plus phi into Z E B into I. Now, if it is K c square this one, so this is nothing but T square by Z E B into Z m o. And this is nothing but it phi is nothing but this phi into phi square Z E B square divided by Z E B Z m o. So, it is nothing but square will be cancelled. So, it is phi square by Z m o sorry phi square into Z E B square is cancel phi square into Z E B by Z m o.

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So, what is the relation between Z m s and Z m o? So, I said Z m S is nothing but it 1 minus K c square into Z m o. So, now K c square is nothing but a phi square Z E B. So, it is one minus phi square Z E B divided by Z m o into Z m o. So, it is nothing but Z m o minus phi square Z E B. So, this playing of the relationship mathematics we can do it well later on also.

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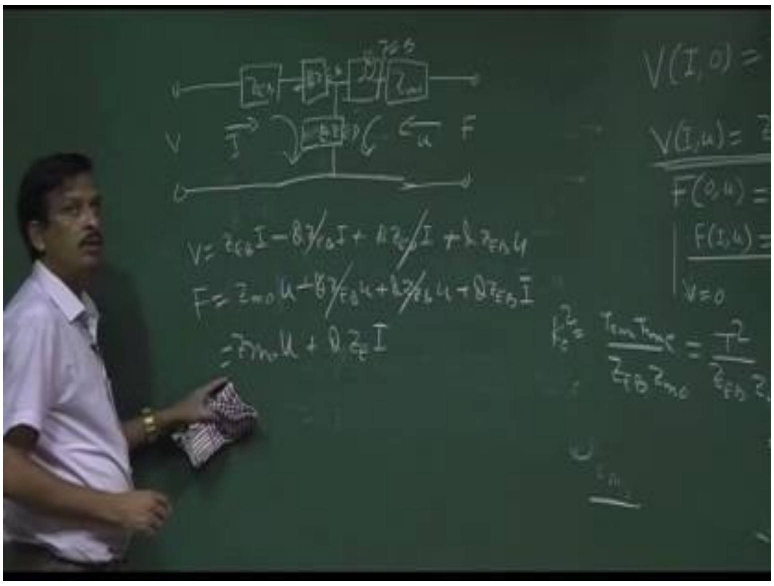

Now, if it is this is your equation, this is equation number one and this is equation number again two, then can you draw the equivalent electrical circuit? What is electrical equivalent circuit? Now, if it is V let us try to draw it from that equation. I have any electrical side where I am applied voltage is v. So, there is a impedance which is Z E B, the current is I flowing. Next, Z E B into lets there is another, so Z E B if Z E B into I. And now this side I have a mechanical force. And I have an impedance Z m o and current particle velocity u is flowing.

So, what is transduction coefficient transduction is phi into Z E B, phi into Z E B u. So, here another impedance phi into Z E B u will be multiply. So, it is V is equal to Z E B into I plus phi into Z E B into I. So, have to neglect that thing. So, I have negative impedance phi into Z E B. So, if I compute this circuits this two equation stands, V is equal to Z E B into I plus phi into Z E B into I minus Z E B into I and u into minus sorry this will be minus and I put it plus. So, this will be if I write this what I writing V is equal to Z E B into I minus phi into Z E B I plus phi into Z E B I plus, u is there phi into Z E B u. So, this, this cancel, I got the equation Z E B into I plus phi into Z E B u.

Similarly, if you look at the force F is nothing but a Z m o into I plus, so I have to put on impedance here which is minus phi Z E B. So, minus phi Z E B into u plus phi Z E B into u plus phi Z E B into I, I-current will flowing here. So, I can write this, this cancel Z m o into I plus phi into Z E B Z m o into u sorry Z m o into u plus phi into Z E B I, so that is this term.

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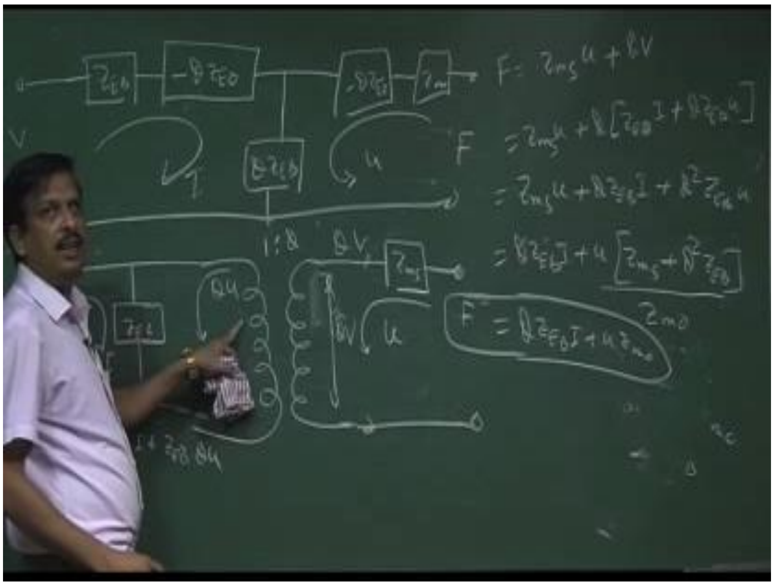

So, the equivalent electrical circuits, let us I draw in cleanly it will be V, there will be a Z E B, there will be negative impedance minus phi Z E B, then there will be a here minus phi Z E B, Z m o and terminal here I put on impedance phi Z E B. Then I apply a voltage here V, current I will be flowing, and I apply a force here F, particle velocity u will be flowing equivalent electrical circuits.

Now, can I reduce it? So, mechanical reciprocal transducer equivalent electrical circuits is this, now, I cannot realize phi minus phi in negative resistance can I realize it negative resistance I cannot. So, how do you realize this negative part in form up coupling coefficient? So, let us say I put a voltage transducer meter transformer here I put a voltage transformer here transformer here, whose has a Trans ratio is 1 is to phi.

So, if I apply a V voltage here, it will induces phi into V voltage in here, because Trans ration is 1 is to phi, is OK. And if a current u is flowing in here it induces phi into u current in here. Now, the voltage V lets I put it impedance here, which is Z E B. So, voltage V is nothing but if the current I is flowing here, so Z E B into I plus Z E B into phi u which is turn by first equation done. Next, this side come. So, this side here I induce here is the current I have taken, and this side I taken the phi V voltage. So, phi V voltage is inducing in here that point phi V will be there.

Now, if I apply a force in here, and a resistance which is Z m S in here, and u is flowing then can I drive the F equation then I say the force F is nothing but Z m S into u plus phi into V phi into V. Now, what are Z m S and Z m o relationship, and what is phi and V relationship, I can find out. So, I can say then it is nothing but Z m S into u plus phi into what is V, Z E B into I plus phi Z E B into u I put the voltage V there. Now, once I put the V here, then what will I get, I get Z m S, Z m S into u plus phi Z E B I plus phi square Z E B u. So, I can write out phi Z E B I plus u into Z m S plus phi square Z E B phi square Z E B.

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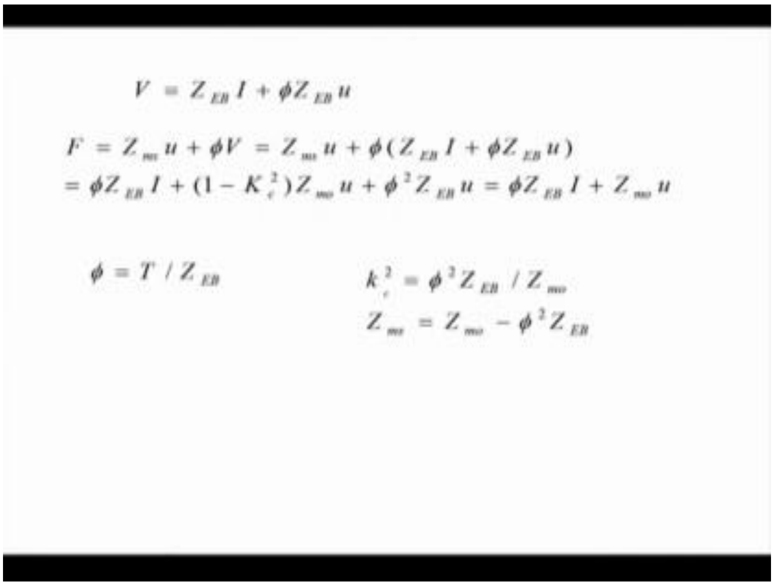

So, from there relation from the relationship between the Z m S and Z E B, you will find this is nothing but a Z m o. So, if you see this slide, I have derive that phi into this is nothing but phi square I phi square Z E B 1 minus K c square Z m o into u plus phi square Z E B I have taken and then. So, Z m S is nothing but a 1 minus K c square Z m o into u, I put the Z m S value. And then if you seen this is cancel it is nothing but a Z m o u. So, if I put the Z m S value in here, Z m S is nothing but a Z m s is equal to Z m o minus phi square Z E B. So, if I put the Z m S value, it only Z m o will be stand. So, it is nothing but Z m o. So, I can write phi Z E B into I plus u Z m o. So, this is the electrical this is F this is equation F stand. So, this is the electrical equivalent circuits for my first circuits.

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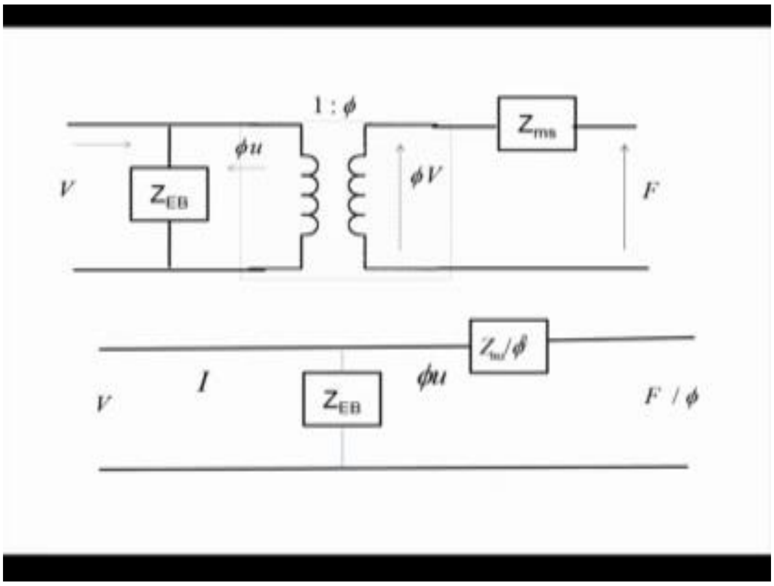

So, further I can say this phi is resuming. So, I can say this circuit can be simply transduction ratio if I divided by.

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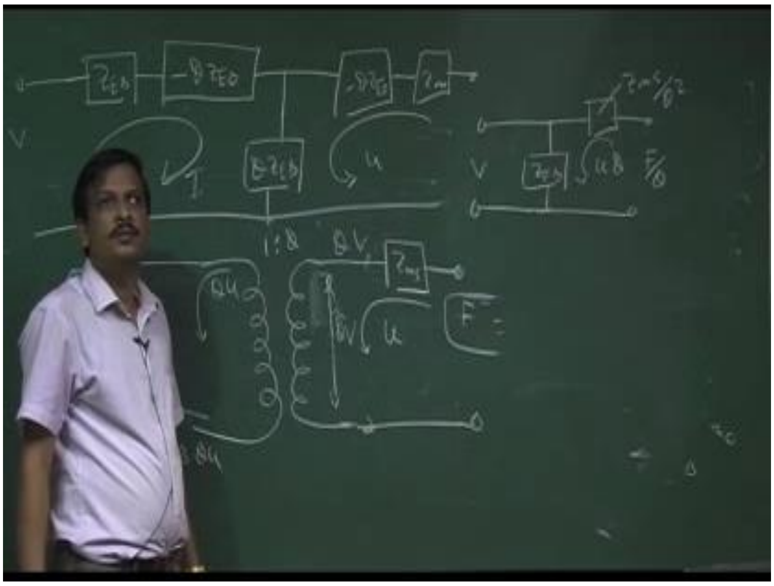

So, it is simply I can say apply the voltage V and if I say this is Z E B resistance electrical side and this phi V is induces. So, I can say lets the voltage is reduces by this mechanical force by phi. So, it is nothing but Z m S will be nothing but this impedance will be Z m S by phi square, and the current will be u into I, so that can be equivalent circuits. So, this is the equivalent circuit for a reciprocal transducer. So, when I said the reciprocal transducer I can derive its equivalence circuits like this way.

So, next class, I will discuss about the anti reciprocal transducer.