Electromagnetic compatibility, EMC
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High-frequency behavior of electrical components - Mechanical switches and transformers

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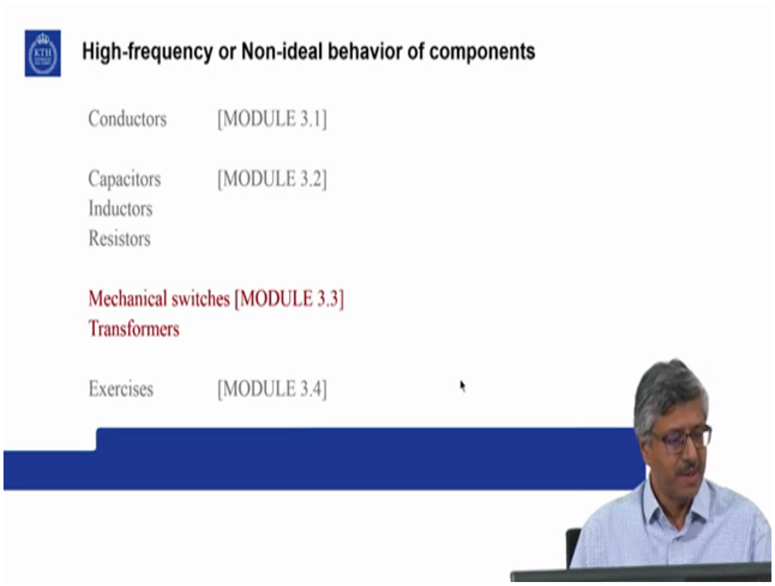

Welcome to module 3 of chapter 3 on high frequency behavior of electrical components. Now in this module we will look into the behavior of real mechanical switches, how they produce noise, what are the noise suppression techniques and about the transformers, real transformers. Here by transformers what is meant by is the instrument transformers. The kind of power supply transformers you can find for converting AC to DC. So these type of very small transformers.

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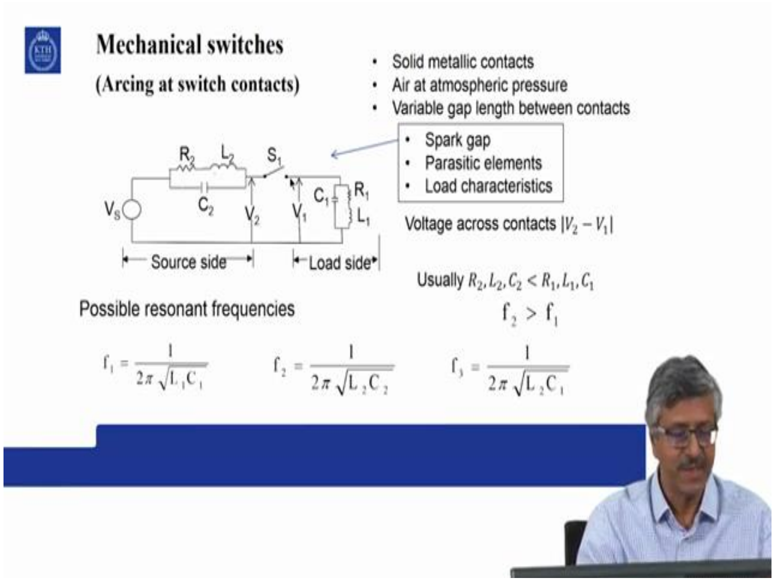

Now take the case of a mechanical switch. Normally you have a switch, switching element here. This is the switch element. Then feeding from this source you have some circuit and that circuit will have some resistance, inductance and capacitance value. And you have some loads that is controlled by switch that will have some resistance, inductance and capacitance value. So source side is 2 and load side is written as 1 here. Now these are resonant circuits. If you look at the possible resonant frequencies, you can find at least three frequencies here. One is resonance in the load side, C_1 and L_1.

And resonant frequency of $\frac{1}{2\pi\sqrt{L_1C_1}}$. Another is from the source side, $\frac{1}{2\pi\sqrt{L_2C_2}}$ that is f_2. And f_3, a combination of the load side and the, a combination of source side and the load side. So L_2 and C_1, so likewise you can find the several resonant frequencies. And usually R_2, L_2 and C_2, these are far less than these (load) values because these are load more intentional, whereas these (source) are mostly represented by the parasitic elements leading up to the switches.

So I am talking of the switch and the connector circuitry that are required to mount the switch onto a bus bar or some other things. So since source side values are smaller than load side values, f_2 is greater than f_1. f_1 is the load side resonant frequency, so that will be smaller than the source side. Now the switches are in the form of solid metallic contacts, it can be air at atmospheric pressure.

There is a variable gap length between the contacts. Switch have certain operation speed controlled by the springs. So as a time is increasing, this opening of the contact also is changing. So it is a dynamic gap. So you have spark gap, parasitic elements and load characteristics. Then this creates an instantaneously varying voltage at the switch contacts, V_2 and V_1. So depending upon the V_2 and V_1, you may have arcing across the switch, there is an arc voltage being developed here. If this gap length is above certain value, you can produce an arc. So that will produce additional noise in the switch.

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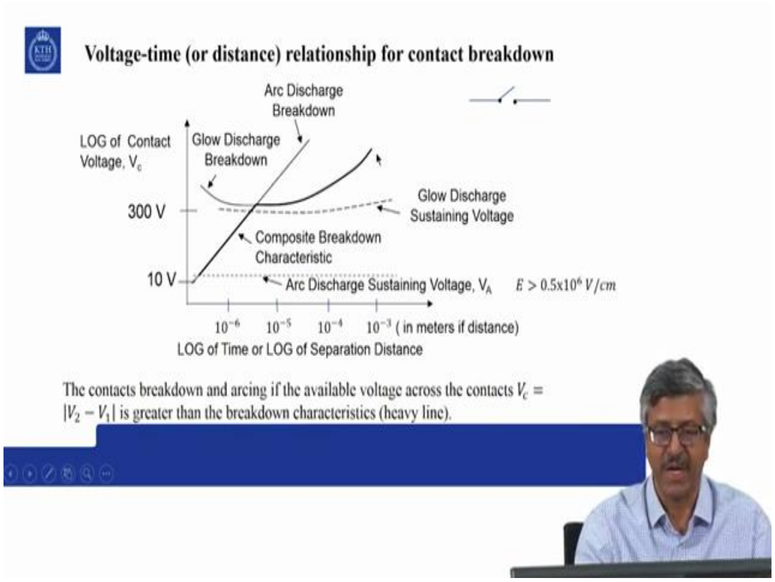

So let us look at the voltage-time relationship for contact breakdown. So this is a mechanical switch. So in small air gaps, you have certain voltage applied across this air gap of the switch. The air gap length is varying or you can express in terms of length. Say for example, this is 1 µm, this is 10 µm. This is 1 mm distance of gap or it can be if you have certain speed for operating of the switch, it can be in terms of time also, this axis.

So what is expressed here is a voltage-time relationship, a composite breakdown characteristic that is being expressed here. So it is a voltage-time relationship for contact breakdown. So we are not going into the theory high voltage specifics or anything like that. But there are phenomena like glow discharge breakdown and arc discharge breakdown. So it is enough to say that glow discharge breakdown happens at much higher voltage around 300 volts or so.

And above that you have glow discharge happening and if, you can have arc discharge breakdown if the voltage is going much higher. Then after the arc discharge breakdown, suddenly you establish a current across this switch contact and then to maintain that current you do not as much voltage. So that voltage, it is depending upon the arc resistance that is the arc discharge sustaining voltage, V_A. And that is shown here, so it is around little more than 10V for most materials.

So, above this value you have a sustained glow discharge and above this value you have, and once arc is formed, you have a sustained arc discharge voltage. So ideally you want to operate the switch below this curve, this is a composite breakdown curve. If you are below this curve, if you are, suppose you have a voltage versus time, instead of meters we write time here because it is at constant velocity contact is traveling. You can transfer it into time. So if you have a curve like this, say like that, it will never go into breakdown. So you only have this normal oscillation associated with resonant circuits and all. But if you go above this, then you will have a breakdown. Either glow discharge or arch discharge. So then you will have noises associated with switches. So the contact breakdown and arcing if the voltage across the contact, $V_C = V_2 - V_1$ is greater than the breakdown characteristic, this heavy line, below that you do not have that breakdown.

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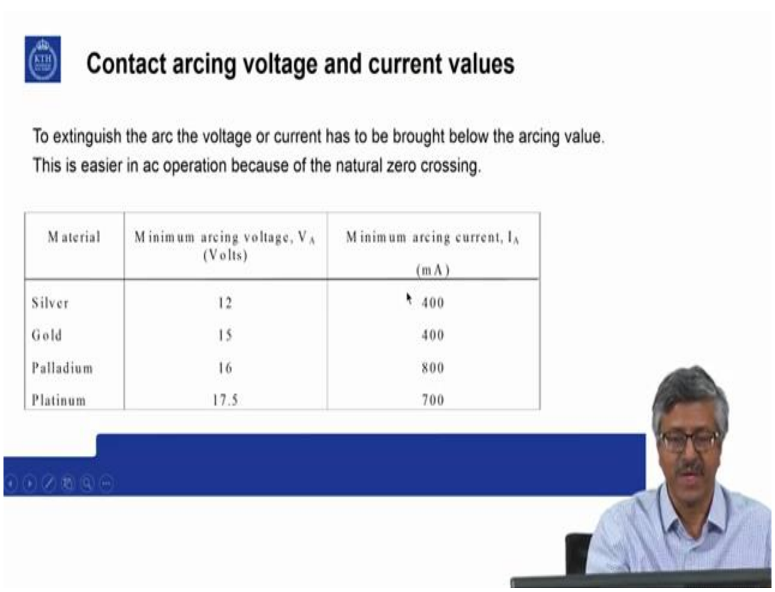

Material	Minimum arcing voltage, V_A (Volts)	Minimum arcing current, I_A (mA)
Silver	12	400
Gold	15	400
Palladium	16	800
Platinum	17.5	700

Now contact arching voltage and current values for common materials are shown. To extinguish the arc the voltage or current has to be brought below the arching value. This is easier in AC operation because of the natural zero crossing. So for silver it is around 12 V and minimum arching current I_A is around 400 mA. So for other material it is slightly higher. So you have to make sure, to extinguish the switch you have to make sure that the arching voltage is below this value, 12V and arching current is below this value for 100 mA. Then you can extinguish the arc.

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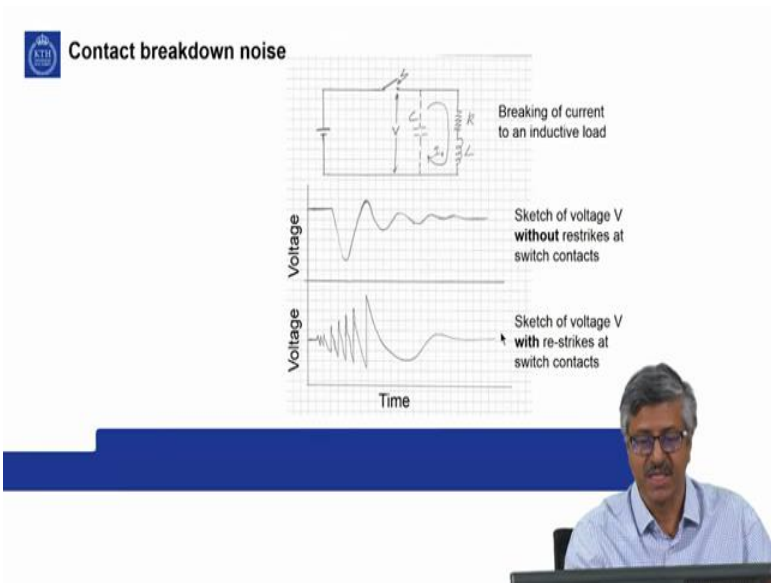

So this shows, we have seen this curve before. This is without breakdown of the contacts, just oscillation due to this resonant circuit, damped oscillation but this is with restrikes of the switch contacts because periodically there will be arching, extinguishing and then arching, extinguishing et cetera will be happening as V_2-V_1 is changing.

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Now avoiding contact breakdown. Keeping the contact voltage below the composite breakdown characteristic, below around 300 V to prevent the glow discharge, if the breakdown happens, force the current available always below that for sustaining the breakdown. That is keeping the initial rate of rise of voltage below the value necessary to produce an arc voltage. So the rate of rise of voltage is very important in forcing the current available below that value. Say a value of 1 V / μs is usually sufficient for most contact. So you keep it below that value, then you can prevent arcing.

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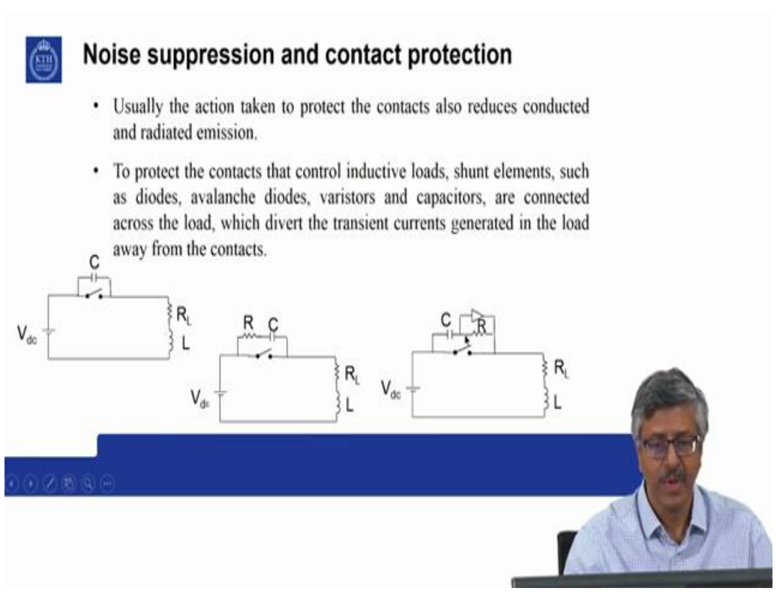

Now noise suppression and contact protection. Switching produces arcing and this arcing can create high frequency radio noise, say from an old-fashioned tube lights, the starters and the chokes will produce high frequency noise. And the noise can be suppressed by having a shunt capacitance. But then once the shunt is short-circuited, then it is a zero value. It kind of bypasses completely the switch. Then, this is a modified form of the circuit with the resistance R also. And this is with a diode connected across the resistor for better performance. So several variants, depending upon the cost you can find the several variants of the circuits in arc suppression for the contacts.

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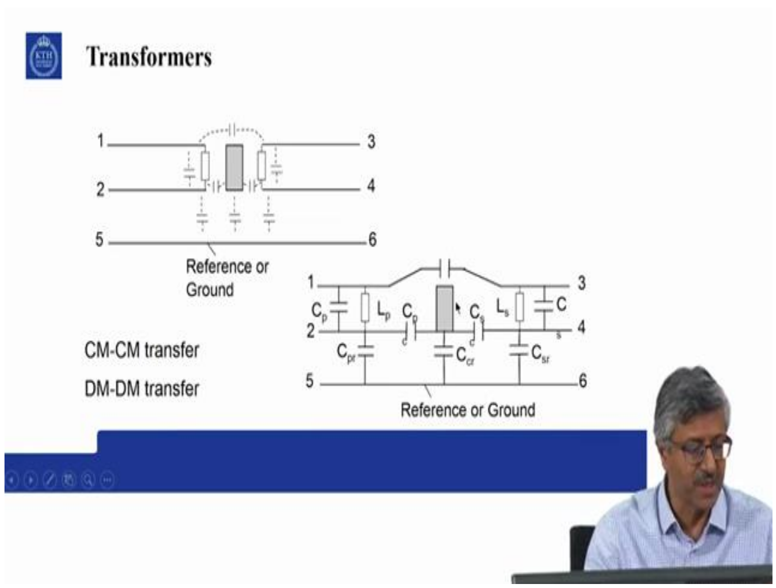

Now transformers, transformers have iron core and you can have a primary winding and secondary winding. And normally they are 4 terminal devices but for the purpose of noise transfer, you can consider it as a 6 terminal device because you have a reference or a ground. So transformers are 6 terminal device. Now you have several parasitic elements between primary and secondary, and across the primary and across the secondary, primary to the core, secondary to the core, core to reference, primary to reference, secondary to reference, et cetera. You can have common mode to common mode transfer. You have seen in the first class what is meant by common mode. They have the currents in the same direction. And differential mode to differential mode transfer. Differential mode is when currents are in the opposite direction. So this now, suppose the core is not connected to the reference, so this will be the capacitive network.

Now this is the model and you can simplify the model if the core is connected to the ground or not connected, or primary is only connected to the ground or secondary part is only connected to the ground, you can get different circuits. So let us do some analysis of the circuits.

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So our purpose is to avoid surge transfer across windings. So there are two ways, one is connect the core to the ground and use the conducing foil.

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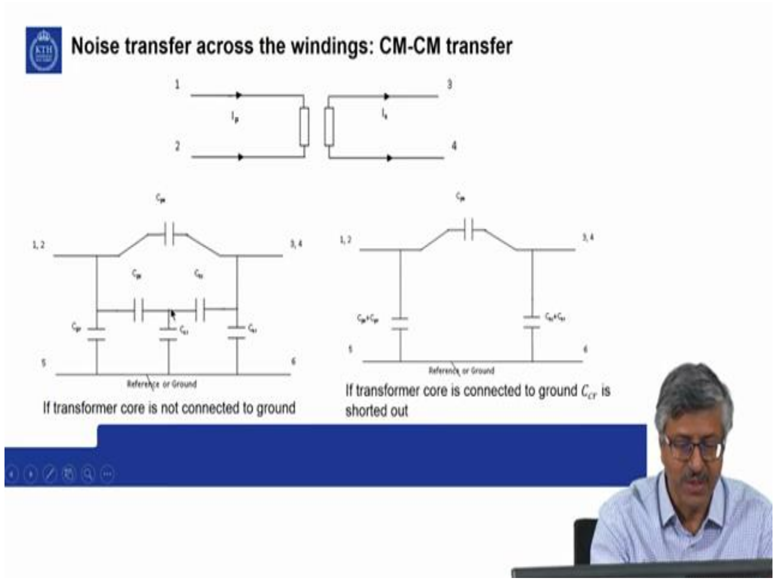

So we take common mode to common mode transfer. So what happens is that if the core is not connected to the ground, this is the capacitance across the windings, primary to the core, PC, secondary to the core, SC and core to the ground. So this will be the kind of network for capacitances for common mode to common mode transfer. So 1 and 2 are the same terminal here, then if the core is connected to the ground, it shorts out this capacitance and it shorts out this capacitance also.

So you have kind of, these two capacitance are in parallel now C_{PC}. So you just add up those capacitance, C_{PC} + C_{PR}. These two capacitance are in parallel, so you add up those capacitance. So you get a network like this. And now you can have analyze how much transfer of noise will happen from primary to secondary or secondary to primary in the case of common mode. So this would be the circuit to be used.

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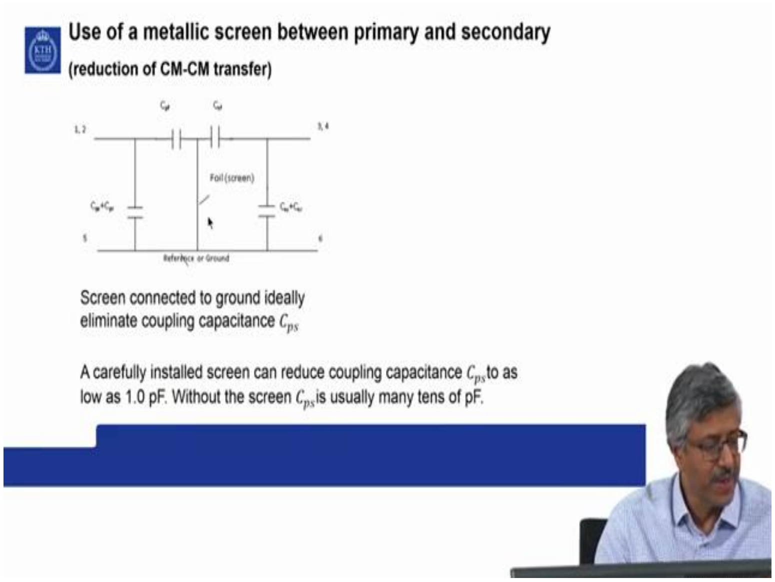

Now use of metallic screen between primary and secondary reduction of common mode to common mode transfer.

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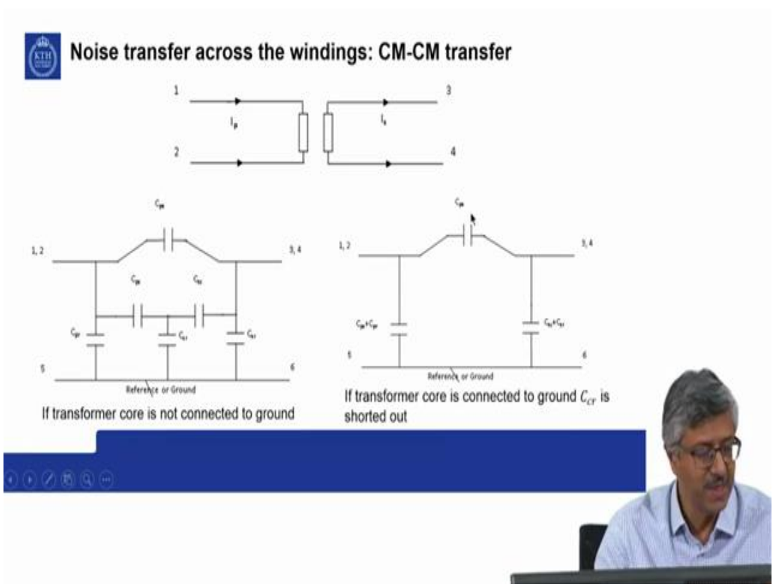

If you take this capacitance now between primary and secondary, this capacitance you can break into two halves if you use a foil.

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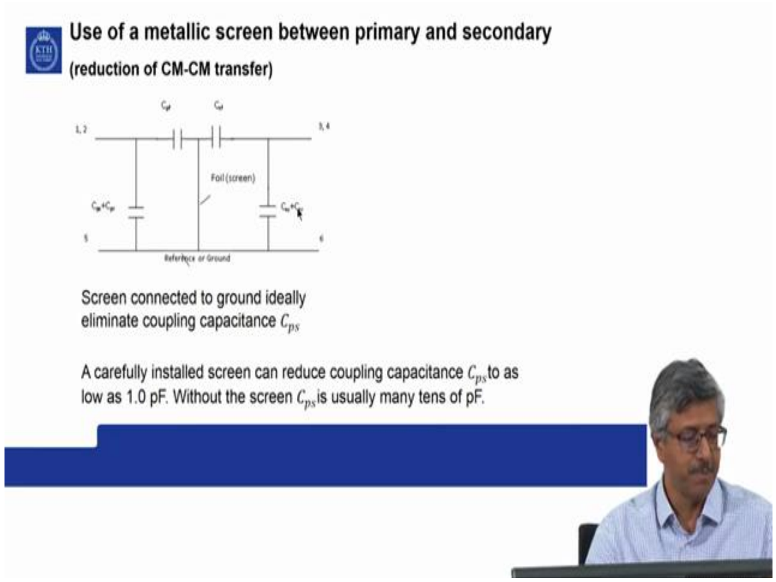

So one part is primary to foil and other part secondary to foil, so these are connected together, so you can see that there is no direct transfer between primary to secondary the transfer is to the ground. And these two becomes parallel, so just standard to this. So screen connected to ground ideally eliminate the coupling capacitance C_{PS}. So if you have a carefully installed screen, it can reduce coupling capacitance to as low as 1 pF. Without the screen, C_{PS} is usually many tens of pF. So screens can be quite effective in eliminating common mode to common mode transfer.

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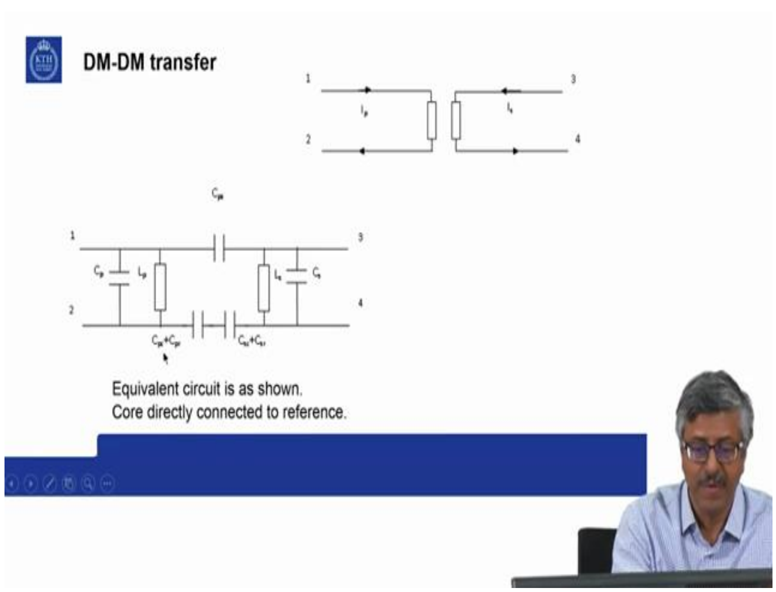

Now differential mode to differential mode transfer, so there you have to consider this winding also, C_{PS}, primary to secondary capacitance. Now core is directly connected to the reference, so if you take this one.

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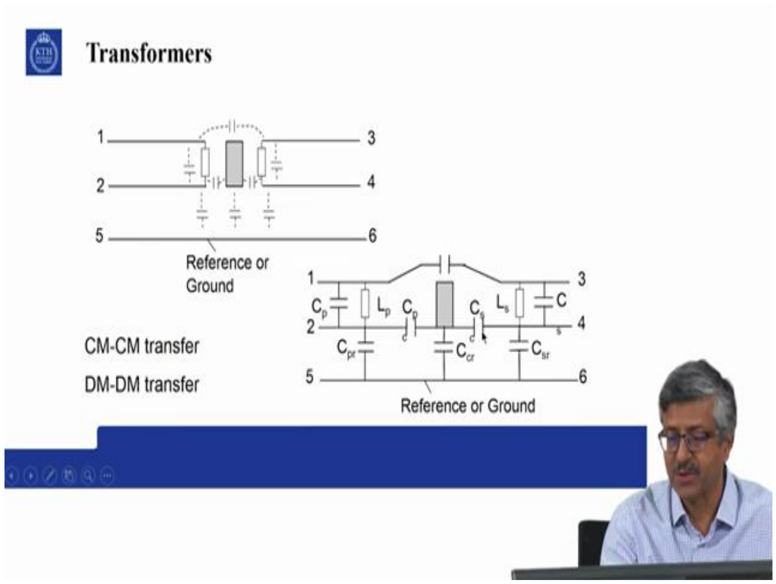

Then core is connected to the reference, these two becomes parallel, these two becomes parallel, so you just add it up.

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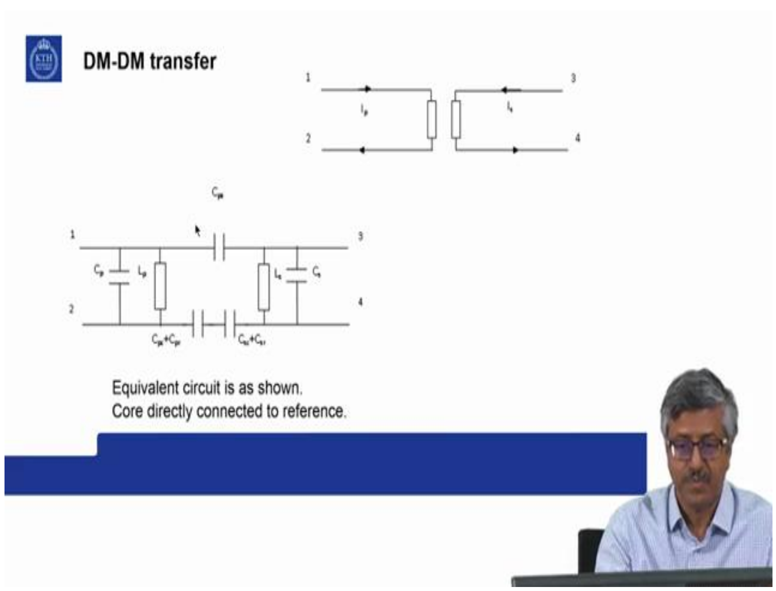

And those two are connected in series, it comes like that. So this would be the circuit.

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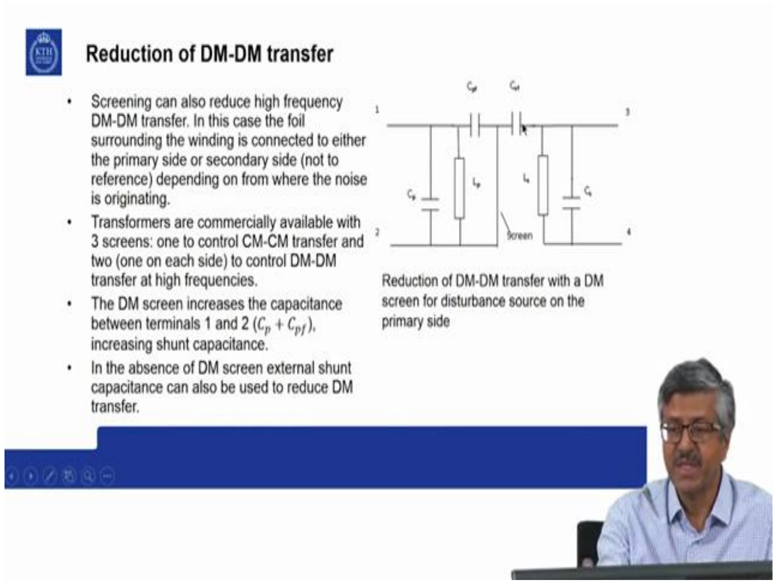

So how do you reduce DM to DM transfer? See C_{PF} and C_{SF} in the previous.

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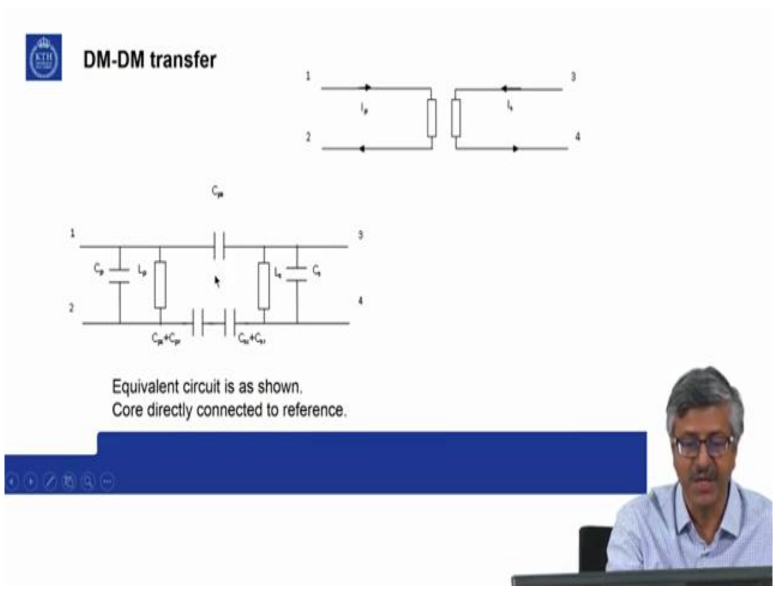

C_{PS} is the one, so if you can split it into two part.

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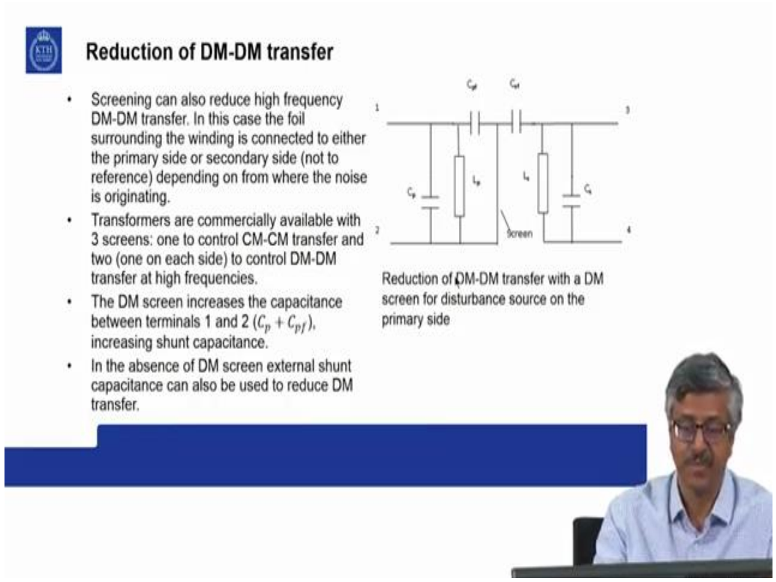

Say if you have a screen connecting the primary to the ground, then you split this capacitance into two part and one part is connected directly to the ground and this also is connected to the ground. So you are eliminating the transfer from the source side. Still from the secondary side there can be some transfer. Screening can also reduce high frequency DM-DM transfer. In this case the foil surrounding the winding is connected to either the primary side or secondary side and not to the reference depending on from where the noise is originating.

The transformers are commercially available with three screens usually one to control CM-CM transfer and two, one on each side to control DM-DM transfer at high frequency so one to primary and one to secondary and one for common mode transfer between primary and secondary. So that can be up to three screens in a transformer. The DM screen increases the capacitance between terminal 1 and 2. Usually that is not any big problem. The absence of DM screen external shunt capacitance also be used to reduce DM transfer. That is just by shunting the noise like a noise filter. So that will be more cheaper solution than providing screens.