Electrical Measurement And Electronic Instruments

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Lecture – 26

High Resistance Measurement

Hello and welcome, we are discussing about Measurement of Resistance. And we have said that measurement of low and high value resistance needs special care. For example, we have seen that if the value of a resistance is small then the contact resistance or the terminal resistance that becomes comparable or significant in comparison to the actual resistance itself therefore, we need to take care of how to avoid the contact resistance or any problem due to contact resistance or terminal resistance.

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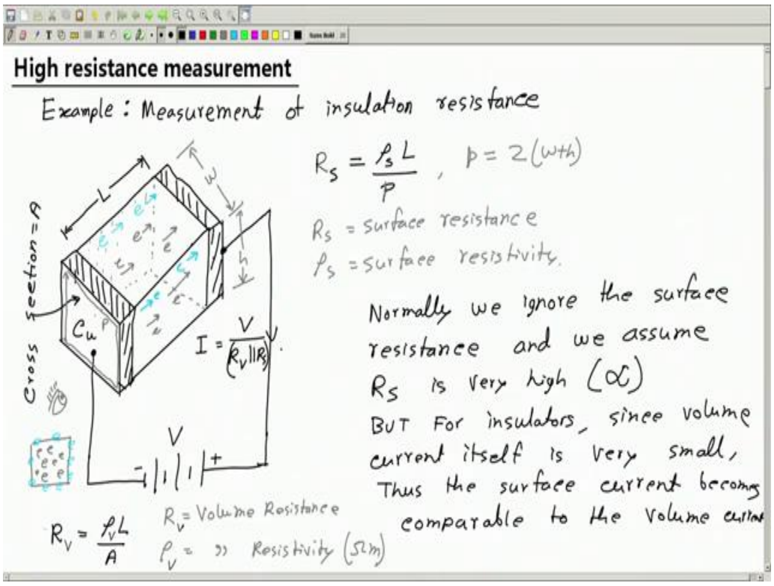

High resistance measurement

Example : Measurement of insulation resistance

$R_s = \frac{\rho_s L}{p}$, $p = 2(w+h)$

R_s = surface resistance

ρ_s = surface resistivity

Normally we ignore the surface resistance and we assume R_s is very high (∞)

BUT For insulators, since volume current itself is very small, Thus the surface current becomes comparable to the volume curren

$I = \frac{V}{(R_v \| R_s)}$

$R_v = \frac{\rho_v L}{A}$ R_v = Volume Resistance

ρ_v = " Resistivity (Ωm)

Today, in this video in this class we are going to see, what are the problems that we may encounter when we are measuring a high resistance, ok. So, high means, very high it could be several mega ohms or even higher. And particular example of this is measurement of insulation resistance, ok. So, insulators means non-conductors, so they ideally should have infinite resistivity or 0 conductivity, but nothing is an ideal. Insulator, so they have some conductance or they have a very high resistance, but that is not infinite; that is high, but not infinite.

Now, suppose I have a block of insulating material, ok; so, say I have a rectangular block of insulating material which is like this, ok. Now, what I will do? I will put two conducting plates on two sides of this block, maybe one conducting plate here. So, this is a conducting plate on this side, and similarly we will have another conducting plate on the other side which is here, ok. So, the let me erase this, ok. Now, so this is insulator and this is conductor, may be copper, ok. So, say this is copper and this is some insulator.

Now, what we will do? We will we can connect these two plates to a voltage source like this, a sufficiently high voltage source otherwise the current I mean almost no current will flow through this insulator because this is an insulator. But not a perfect insulator, so if you apply some voltage source through it then some current will leak through the insulator, ok. So, there will be some leakage current through this insulator.

Now, if say the cross section area of this insulator is A, so this area, cross section area, ok. And say this length through which current flows is L, and if the insulator has a resistivity of rho, so this is resistivity which should be very high for an insulator. Then we know the resistance offered by this block is given by R= $\frac{\rho L}{A}$, ok. And the current flows through the entire volume of this insulator, ok.

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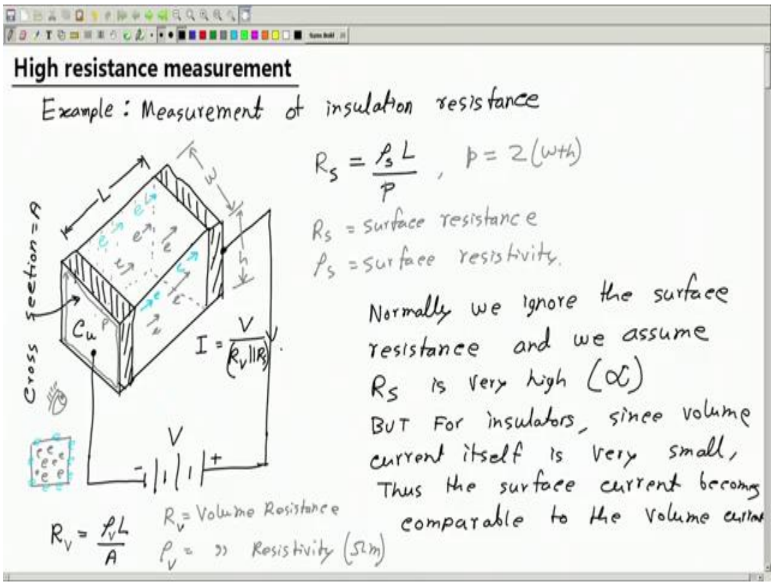

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So, the charge or the electrons, they flow through the entire volume means if this is the 3D volume of the insulator then the electrons will flow through it everywhere, everywhere through it, ok. So, sorry this is if it is electron then I should draw it in the other direction minus 2 plus and it flows everywhere inside, ok, inside the volume, ok.

And so, if you see from this side, from here if you see, from here you will see then this cross section as a square and you can see the electrons moving through the volume everywhere, ok. It will fill the entire volume. And this conductance of the current you can call the volume conductance. Similarly, this resistivity you we call it volume resistive volume, this is volume resistance and this we call the volume resistivity, ok. So, R is said the volume resistance and rho is said the volume resistivity, ok. So, the dimension of rho will be, so this dimension will be ohm into say meter square divided by meter, ok. So, its dimension will be ohm meter, ok.

Now, there is also some current which will flow only through the surface of this insulator, ok. So, there will be also some current or electrons which will flow only through this surface, ok. So, that means, only how do I draw it. So, just consider this surface, which is the periphery of this block. So, from there we will also have some electrons flowing only through the surface, ok. So, if you look from here you will see this electrons only at the surface, ok, only on this line, ok.

So, this particular type of conductance where current flows only through the surface and not through the volume is called surface conductance, and the associated resistance to that we call it surface resistance, ok. So, we let me use a v symbol this is for volume v, v, v. So, this is volume resistivity and this is surface resistivity, sorry, volume resistance and volume resistivity.

Similarly, we can define surface resistance which will be proportional to some constant which we call the surface resistivity multiplied by the same length, but divided by the periphery; a peripheral length of this block, ok. So, call that, call that. What can I call? Periphery say small p, ok, where this periphery is this length from here this up to this, then you go like this, then you go like this and like this. So, this is the periphery p, ok. And also if you call say this distance as w and this distance as h, ok, this is the height, this is the width of the block then this p periphery, then p periphery is equal to 2, w plus h, ok. This is what is called the surface resistivity; R s is surface resistivity, and rho s is sorry, this is surface resistance and this is surface resistivity, ok.

So, the important difference is that for this phenomena electron flows only through the boundary or the surface of this material and for this phenomena electron flows through the entire volume inside of the material. Now, the physics of these two conductance we are not going to talk about. So, that is beyond our scope. So, we will only stay happy here by knowing this fact that some current flows through the volume and the resistance offered to that current is called the volume resistance, and some current which flows only through the surface, only through the surface is associated with what is called the surface resistance and surface resistivity.

And the relationship is quite similar. Here we see that this resistance, volume resistance is proportional to the length of this block; that means, how far, how long the current should flow it is inversely proportional to how much area or how big, how wide the path of the this current is. The thicker, the bigger the path resistance will be smaller and the proportionality constant is called surface volume resistivity.

Similarly, here this resistance is again proportional to the length how long the current has to flow and is inversely proportional to how big the periphery is, how wide the path of the current is which is this periphery, peripheral length, ok and the proportionality constant, so this is a constant which is called surface resistivity, ok.

Now, the fact is that normally we ignore the surface conductivity or surface resistance, and we assume that this surface resistance is very high. Here I mean as high as infinite, ok. Nothing is in finite, so by this I mean it is very high, ok. And therefore, we generally ignore this, ok. So, if this block was a better conductor, then almost the entire current will flow through the volume and very little amount of current will flow through this surface, so therefore, we ignore this surface conductance. But when this itself is an insulator, so that only a small amount of current goes through the inside, through the volume of this block then this surface current is also comparable to the volume current, ok.

But for insulators since the volume current itself is very small thus the surface current which is also small, but now it becomes comparable; that means, no longer negligible comparable to the volume current, ok. So, if we want to find out the, so if this voltage is V and if we want to find out how much current will flow through this block, ok, now this conductors will have very little resistance, so that you can ignore. So, this current I will now be given by I is equal to, let me write it here. This I will be equal to V this voltage divided by the resistance offered to these current. But now there are two parallel paths, one path is through the volume another path is through the surface, ok.

$$I = \frac{V}{Rv\ ll\ Rs}$$

So, we have two paths for the current to flow. And the two phenomena is different, but the physical phenomena we will not discuss. We will stay happy with the fact that, ok, there are two types of current, one flows through the surface, one through the volume, ok.

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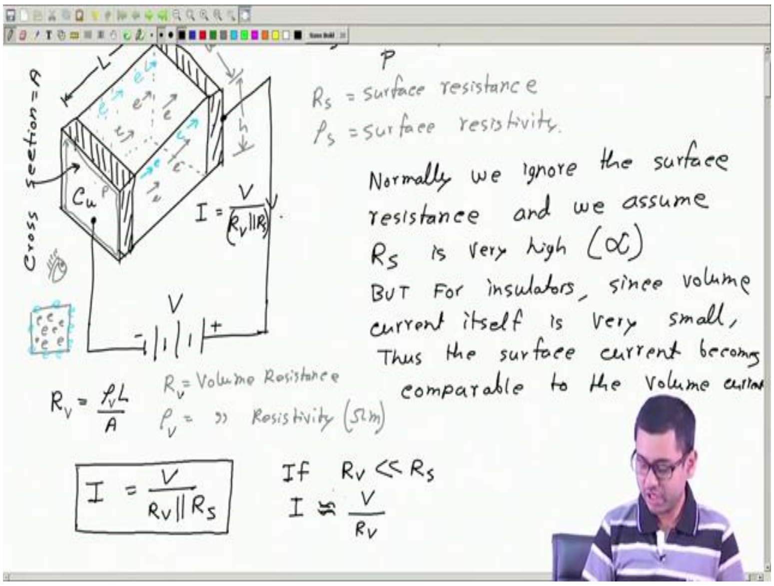

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$$\boxed{I = \frac{V}{R_v \| R_s}}$$

If $R_v << R_s$

$I \approx \frac{V}{R_v}$

So, this is what I will highlight, not plus they are not in series, sorry this is a mistake they are in parallel, ok. And, if say this R v is much smaller than R s, then this quantity will be equal to V by R v only because if R v is much smaller than R s then this parallel combination will be same as R v only. So, if this is true then we can write $I = \frac{V}{Rv}$

only and we can ignore R s. Ignore means we assume it to be very high or infinite, not 0, its very high, ok so, approximately. So, this is normally what we do we never talk about R s surface resistance, but here we have to talk about surface resistance because R v itself is very high, itself is very high.

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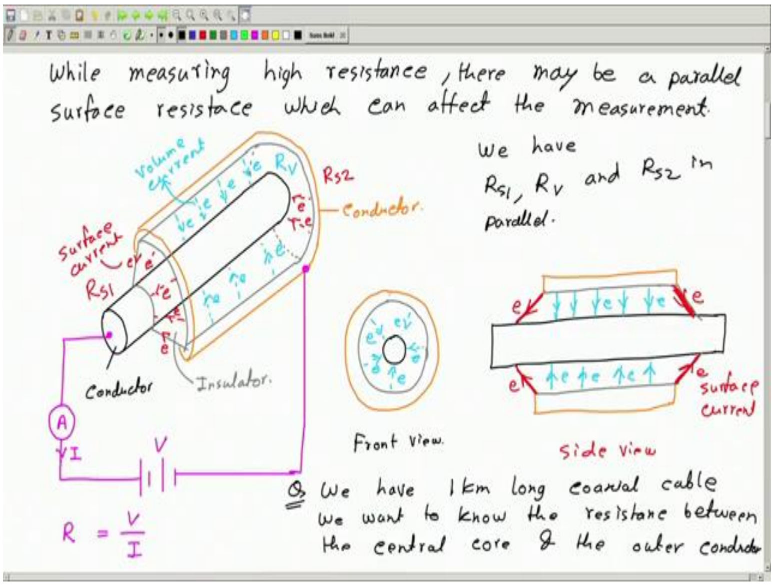

While measuring high resistance, there may be a parallel surface resistace which can affect the measurement.

We have R_{S1}, R_V and R_{S2} in parallel.

Q We have 1 km long coaxial cable we want to know the resistance between the central core & the outer conductor

$R = \frac{V}{I}$

So, what we have seen is that while measuring high resistance, like insulation resistance there may be a parallel surface resistance which may if affect the, which can affect the measurement, ok. So, this is what we have seen, ok.

Now, let us see a practical scenario or let us take a practical example where this will be more clear. Suppose, we have a coaxial cable. What is the coaxial cable? A coaxial cable looks like this. So, it has central core a cylindrical, cylindrical core which is of course some metal, maybe copper, ok. So, it has a core and surrounding this we have a layer of insulator, ok. So, surrounding this we will have a layer of insulator, like this, and then surrounding this insulator we will have another layer which is again a metal, copper, aluminum or something, ok.

So, after that we will have another layer on top of it which is again a conductor, ok. So, this is a conductor, the outer one is a conductor, the inner one this is also conductor, and the middle one is insulator; this is insulator, ok. Although, I have drawn a small or very short coaxial cable, but this cable in principle can be very very long and this is the cable which is often used for power supply, underground power supply in many of our houses often, ok. So, maybe it is possible that this inner core acts like the life phase or say the positive terminal you can think of the positive terminal of a power supply and the outer one is the ground terminal or the neutral phase. So, this way we can have a long, very long power carrying coaxial cable.

You may have seen some similar coaxial cable in your; if you have a cable line or a DTH line or anything your television. So, when your television, the cable that carry signal also is a coaxial cable, which has a central core and the outer metal sheath and there is some insulator between this.

Now, the insulation between this should be able to separate these two conductors perfectly. There should be no leakage current between the inner core and the outer sheath. But no insulator is perfect, so we may be interested in finding out how good this insulator is; that means, we would like to find out the resistance offered by this insulator. So, for that what we will do? We will once again connect say these two conductors, so this one and this one. So, these two are conductors the core and the outer sheath. We will connect this to a battery and we would like to measure the current that flows in this circuit, ok. So, we will put say an ammeter, ok.

So, let us put an ammeter, ok; so, now, if we know this voltage if we get some reading I, then we may like to find out the R = $\frac{V}{I}$. So, this is the resistance between this conduct with this central core and this outer sheath, ok. But, if we do in this way we will have a small problem. What is that? Let us see.

Before that let us first find out the path of the current that flows, ok. so, path of the current. So, current comes from or say electron comes from here it comes here and then it gets distributed all over this orange color in conductor, ok. So, electrons come here and then these electrons go through the insulator to the central core, ok. So, the electrons flow like this, from this side as well as from this side everywhere, ok.

So, if we see from the front, ok; so, the front view, in the front view we shall see that this is my insulator, then we have this central core and outside we have this sheath, ok. So, this is the front view so, we shall see electrons flowing like this radially everywhere from the outer sheath to the inner core, ok. So, this is how the electrons flows this is one path for the electron to flow from here minus terminal to the plus terminal.

But there is another path which is which is only through these surface or boundary of this insulator. So, electrons can flow only like this, only through this surface, not through the volume, ok. So, this is only through this conical part of this insulator, ok and these electrons do not flow through the volume of the insulator. So, this is the surface current and this blue one this is the volume current, and these two currents are flowing in two parallel paths, right. So, both are starting from this outer sheath and ending at this central core. So, these two currents are parallel, ok and the these two resistances offer to these two currents we can call them as R v, volume resistance and here any resistance offered to this we call it as R s, ok.

Now, we may have actually another surface area open area on the backside of this long cable, ok. We can see only the front side from this drawing, but there is definitely some the back side will also have this open or exposed area of the insulator. So, there we will also have some surface current there, ok. So, this is the back side of this insulator, ok.

So, basically, we have like R s here and we can think, there is another R s, call these R s 1 and the call this as R s 2, ok. So, we have R s 1 then R v and R s 2 in parallel, ok so, if we draw a side view. So, let me try to draw a side view; so, this is the central core, then we have this insulator. So, this is very long I am drawing it small, but this is actually a very long and then another metal, ok. And then we have the surface current flowing only here, here, here and here.

So, this is the surface current so, this is side view as we are seeing from this and the volume current flows here, ok. So, this is the volume current or current is in the opposite direction this is the direction of the electrons, ok. So, volume currents flows everywhere, surface current flows only through the surface, ok. So, this, so this three are in parallel.

Now, say we want to know, so we have say 1 kilometer long coaxial cable, ok. So, question so, we have a 1 kilometer long coaxial cable and we want to know the resistance between the central core and the outer sheath; outer conductor for this long cable, for this 1 kilo meter long cable.

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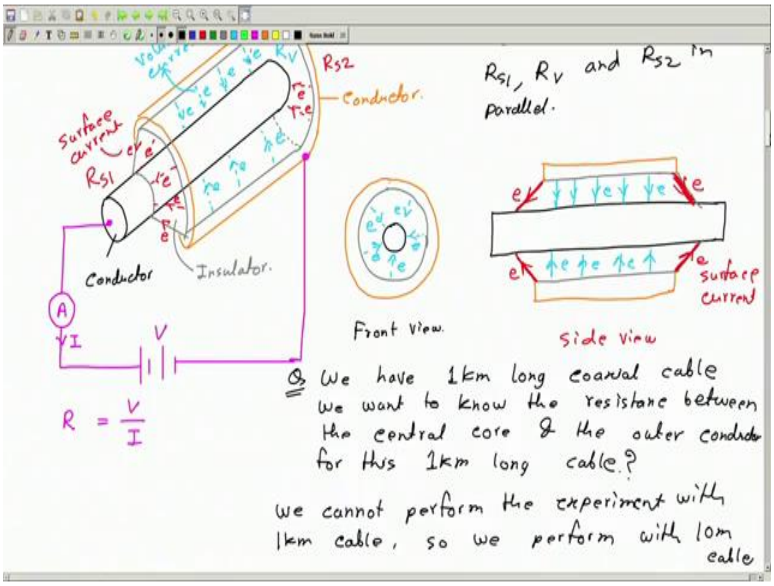

$R = \frac{V}{I}$

R_{S1}, R_V and R_{S2} in parallel.

Q We have 1 km long coaxial cable we want to know the resistance between the central core & the outer conductor for this 1 km long cable?

we cannot perform the experiment with 1 km cable, so we perform with 10 m cable

But suppose we cannot; so, what we have to do to find this answer? We have to perform this experiment. We have to apply some voltage and measure this current. But we cannot do this experiment suppose with a 1 kilometer long cable because that will be a huge arrangement. So, maybe we are doing this experiment with say 10 meter long cable or maybe 1 meter long cable, ok. So, we cannot perform the experiment with 1 kilometer long cable, so we perform with say 10 meter cable, ok.

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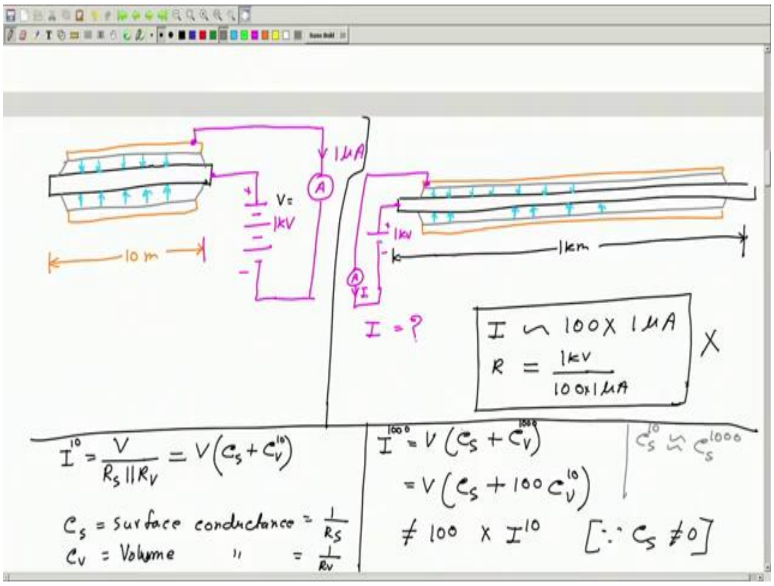

I = ?

$I \sim 100 \times 1\,\mu A$

$R = \frac{1\,kV}{100 \times 1\,\mu A}$ X

$I^{10} = \frac{V}{R_S \parallel R_V} = V(C_S + C_V^{10})$

C_S = surface conductance = $\frac{1}{R_S}$

C_V = Volume " = $\frac{1}{R_V}$

$I^{1000} = V(C_S + C_V^{1000})$

$= V(C_S + 100\, C_V^{10})$

$\neq 100 \times I^{10}$ $[\because C_S \neq 0]$

$C_S^{10} \sim C_S^{1000}$

So, we have this cable 10 meter long; so, you have this 10 meter long cable with this insulator and this sheath. So, this is 10 meter and we are applying a voltage between this and this, ok say, we have a voltage applied like this and we are measuring this current with an ammeter. Say this voltage is form to be we know this voltages or you can measure this voltage, so this is 1 kilo volt and say this current is found to be 1 micro ampere. The length of this conductor is 10 meter, ok.

Now, if we do the same experiment with had we done the same experiment with 1 kilo meter long cable, ok, so this is 1 kilometer. If we had done the same experiment with this, same voltage one k v we apply and we measure the current, ok. So, this current I, so how do you think this current I will be? How much will this current be? Roughly speaking this I should be, so this is 10 meter, this is 1000 meter, so this is 100 times longer, ok; so, we have 100 times more path for the electrons to flow. Here this is the path for the electrons mainly and here we have 100 times longer path. So, definitely I, this current I will be expected to be around 100 times this current, which is 1 micro ampere right because now we have more current.

So, for this cable therefore, we could have estimated the resistance like as this voltage 1 KV divided by 100 times 1 micro ampere, for this experiment, ok. So, with this experiment is not performed, this experiment is performed and from this we are trying to guess what would have been the value of this current, if we actually had 1 kilometer long cable. But this result is not correct; this result is not correct, why it is not correct? Let us see in detail.

So, in this experiment, ok so, this with 10 meter cable we the current that we have I this is given by the voltage V.

$$I = \frac{V}{Rs \; ll \; Rv} = V\,(Cs - Cv)$$

Cs = surface conductance = $\frac{1}{Rs}$

Cv= volume conductance = $\frac{1}{Rv}$

$$I^{1000} = V(Cs + Cv^{1000}) = V\,(Cs + 100\,Cv^{10}) \neq 1000\,I^{10} \qquad (Cs \neq 0)$$

So, now, therefore, if we perform the experiment with a smaller cable, we cannot multiply the current with a factor of 100 and predict the current in this experiment because of this surface conductance or surface current. So, this is the problem, ok. So, this is the problem due to surface conductance. Now, let us see this solution, ok. So, that was the problem, why surface conductance is so crucial to take care.

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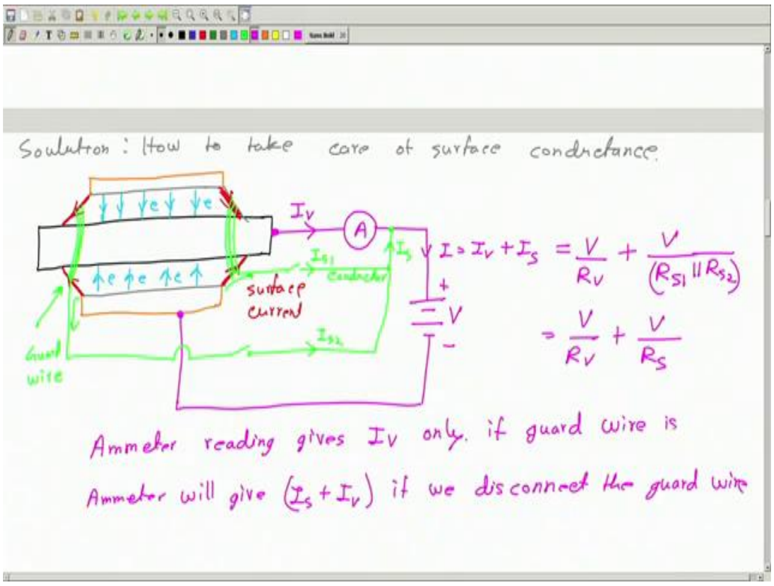
Soulution : How to take care of surface condrctance.

$I = I_V + I_S = \frac{V}{R_V} + \frac{V}{(R_{S1} \parallel R_{S2})}$

$= \frac{V}{R_V} + \frac{V}{R_S}$

Ammeter reading gives I_V only. if guard wire is

Ammeter will give $(I_S + I_V)$ if we disconnect the guard wire

Now, let us see this solution how to take care of surface resistance solution; how to take care of surface conductance, ok. So, what we will do? We will connect a voltage source between this and we have to measure the current, the solution is very simple actually. So, we have an ammeter.

Now, what we will do is this, ok. So, let us take some copper or conductor ok, what we will do? We will wrap some turns of a conductor touching this insulator, so some turns like this, ok. So, and then we will take this turns and connect it like this. So, now, what happens? Say this electrons or current which is flowing from here it comes up to this and then it has two paths, one through the volume another through the surface. So, the part that goes through this volume will come to the central core and has to then go through this violet color conductor through this ammeter and return, ok.

But the electrons that flow through the surface after reaching halfway through this surface they will find, this conductor which is of much lower resistance than the surface and therefore, this electrons will bypass like this, ok. So, then they will come through this conductor so, this is a conductor, somewhere. So, these electrons will then bypass through this conductor, they will not go through the ammeter they will go directly like this and will return the battery, ok.

Similarly, if you have another exposed surface here then we need another cable not cable conductor, which is twisted surrounding this insulator, touching this insulator, in contact with this insulator, but it is not in contact with this core, ok. This should not touch the core. It is touching the insulator, but it is not touching the core, ok. And then also we can have another bypass path from here, like this. So, this electrons also which we are going like this, they will get bypassed and they will come directly like this. So, this current will not flow through the ammeter.

So, the current that will flow through the ammeter is only the volume current which I am calling as I v and the current that will by get bypassed is this is this I s surface current, ok. So, this is I s 1 this is called this I s 2 so, this is the total surface current I s and this current is I which is

$$I = Iv + Is = \frac{V}{Rv} + \frac{V}{(Rs1\ ll\ Rs2)} = \frac{V}{Rv} + \frac{V}{Rs}$$

And now, this current; surface current gets bypassed. This wire we call as a guard wire which leads this surface current by passed through a conduct I mean easier path than this surface. So, they will not flow the through the ammeter. So, the ammeter reading now will give, so the ammeter reading gives I v only, ok. Now, if we disconnect these guard wires, ok suppose we have we can disconnect it say, suppose there are switches so that we can disconnect this. Here also we can have a switch, so that this is we can disconnect it; so, if we disconnect it then the ammeter will give both I s and I v, if we disconnect the guard wire, ok. And ammeter reading gives I v only if guard wire is present.

So, therefore, now what we can do; suppose, so we will go back to the previous question we need to estimate the resistance for a 1 kilometer long cable, but we are doing the experiment with 10 meter cable. So, how can we estimate the result for 1 kilometer cable.

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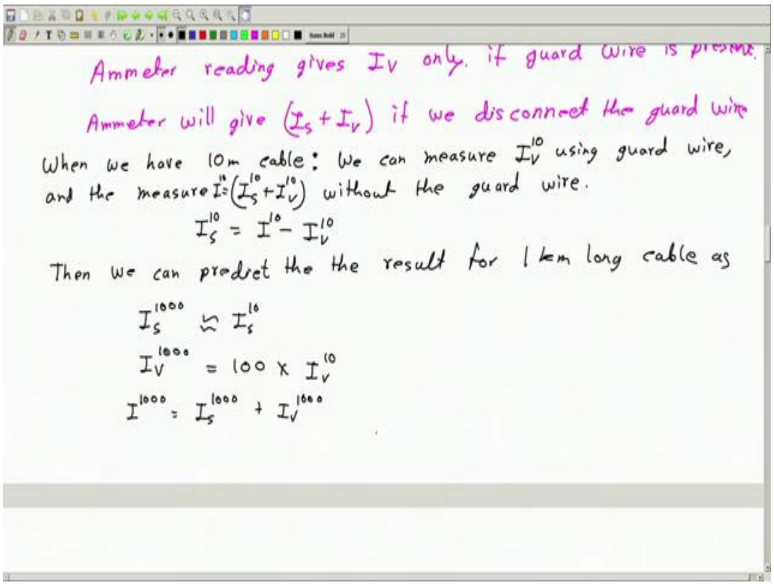

Ammeter reading gives I_V only. if guard wire is present.

Ammeter will give $(I_s + I_v)$ if we disconnect the guard wire

When we have 10m cable: We can measure I_V^{10} using guard wire, and the measure $I^{10} = (I_s^{10} + I_V^{10})$ without the guard wire.

$$I_s^{10} = I^{10} - I_V^{10}$$

Then we can predict the the result for 1 km long cable as

$$I_s^{1000} \approx I_s^{10}$$

$$I_V^{1000} = 100 \times I_V^{10}$$

$$I^{1000} = I_s^{1000} + I_V^{1000}$$

So, now say when we have 10 meter cable, we can measure I v using guard wire and then measure I s + I v with after removing the guard wire, so without the guard wire, ok. Call this I and then we can find the value of I s like this so, I is known this, I v is known as given by this ammeter, ok, we are with the when the guard wire is present or not present. So, from this we can find the I s.

Then, we can predict the result for 1 kilometer long cable as; so, this is I s 10 meter, I s 10, I v 10, 10 meter, 10 meter and this is I 10, experiment for 10 meter, ok. So, then we can predict the result for 1 kilometer cable as

$Is^{1000} \approx Is^{10}$

$Iv^{1000} = 100\ Iv^{10}$

$$I^{1000} = Iv^{1000} + Is^{1000}$$

So, we can predict the current that would have been flown in an 1 kilometer long cable, more accurately considering these surface resistance or surface conductances conductance, if we did not do that our result would have been erroneous, ok.

So, this is the important thing I wanted to convey to you is the fact that very while measuring a high resistance the parallel path; that means, the surface resistance comes in picture and if we do not consider that, if we do not take care of that our estimations can be wrong, ok.

So, thank you.