Analog Electronic Circuits
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Lecture - 03
Revisit to pre-requisite topics

So, welcome to the third module of this online program Analog Electronic Circuits, where primarily we will be going into prerequisites of this course. Most of the topics you may be knowing, but the purpose of revisiting this prerequisite is just to see what maybe the important electrical technology theories are required to understand this analog electronics better. So, let us see what are the topic we are going to cover.

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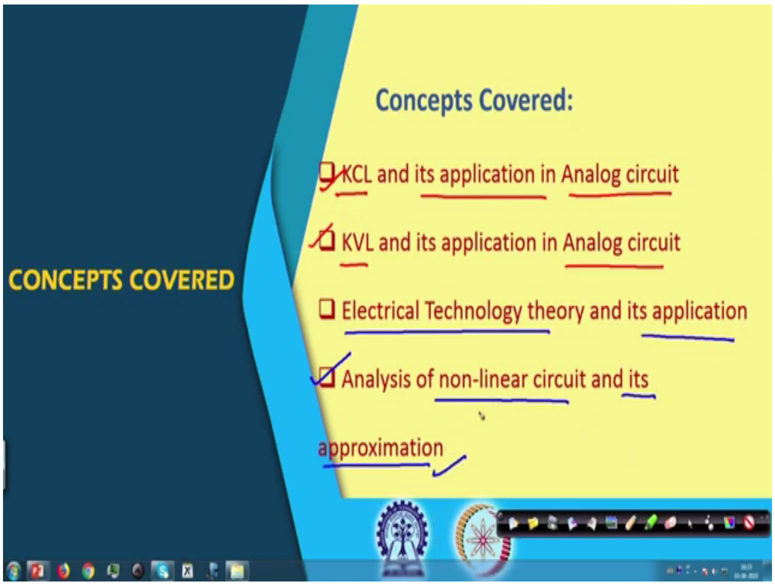

Primarily Kirchhoff's current law and its application specifically for the voltage; so, we will be moving to the Kirchhoff's law KCL and then KVL and specifically their application with an example in analog circuit.

So, these two things obviously, as you know from passive circuit we will see that this case KCL and KVL they are also applicable for a non-linear circuit as well which are very common for analog circuit. And, then our next one is Thevenin equivalent voltage source generation from a given circuit which is again commonly used in electrical technology. And, we will see that what is its application in analog circuit and then we will be moving towards the main topic analog electronic circuit, where circuit elements maybe non-linear in nature which is in contrast to typical electrical circuit ok.

Whenever we do have some non-linear a circuit we will find that there will always be a need of approximating non-linear circuit; sometimes approximating a actual non-linear circuit into another simplified non-linear circuit or it may be all together we can line linearize non-linear circuit with respect to a point called DC operating point. So, primarily these are the subtopics we do have in our target today.

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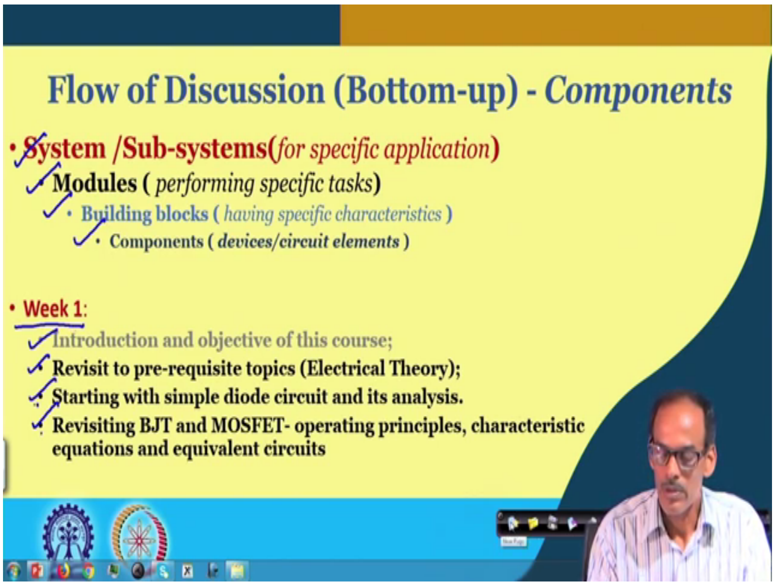

So, let us move to you may recall from the previous discussion. Whenever we talk about say analog system for that matter we do have different levels of abstractions namely system level, module level then building blocks and then we do have different components. Today we are going to start with these components and also as I said that we will revisit some of the prerequisite.

So, the first week of the main program we already have started with introduction to this course and today we are going to revisit as I said electrical technology and theories. And, then slowly we will be moving towards this actual circuit namely diode based circuit and its analysis and then we will be moving to BJT and moss circuit, but of course, this it will be done in the next class today we will be covering only these two. So, that is aligned with our first week plan. Now, let us move to KCL and KVL.

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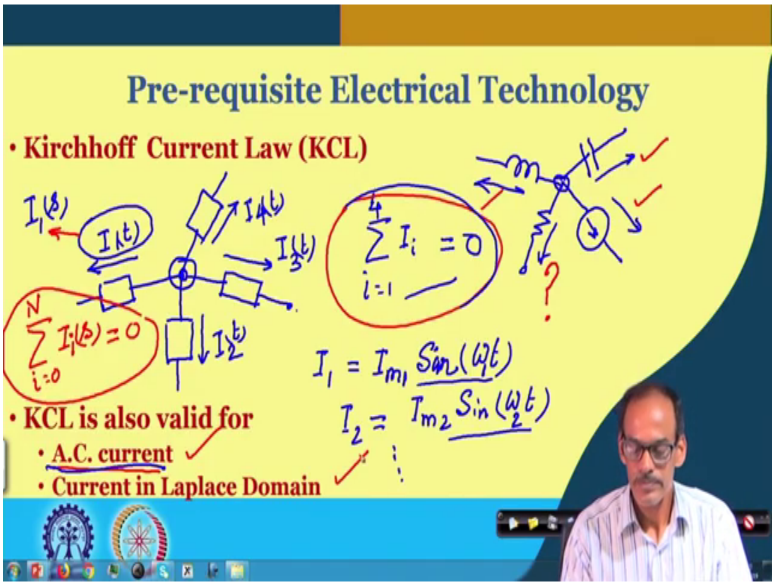

So, as you may be aware already whenever we talk about Kirchhoff's current law what we consider there it is a circuit. So, there we consider one circuit node and we assume that to this circuit node there may be different elements are circuit elements are connected. Those elements maybe active or passive or whatever it is, in electrical technology most of the time we consider with the elements which are resistive or maybe inductive or capacity and so and so.

So, let you consider this is one circuit node and then we do have say different 4 different elements. They are connected to another node and so and so, but when you consider say this node and whatever the elements are connected to this node. And, then if you consider the current flow corresponding to each of this elements say a element 1 is having a current of say

I 1 element 2 is having a current of say I 2 and so and so. So, what this KCL says that all this currents departing this node is actually it is 0.

So, all summation of I I's where I in this case it is 1 to 4. So, this is equal to 0. So, we frequently use this you know this equation to find some unknown quantity from some of the other known quantities. Now, this equation as I said it will be frequently used and say for example, this elements maybe say resistive and then one element maybe having a say constant current and the other element may be having capacitive in nature and so and so, it may be in the inductive kind of element and so and so connected to this node.

So, we can consider each of these currents and then we can add all of them those currents and then we can find what maybe the expression of say some unknown element in terms of some other known elements. Say for example, if you would like to know what maybe this current from the expression of known current say this one this one and this one. So, using this KCL we can find this the unknown quantity.

Now, what definitely as I say that you are already knowing it, but you must also be aware this KCL is valid for AC current as well. What does it mean is that suppose whatever the currents are flowing through each of these elements say I 1; it may be having a signal having a frequency say I m1 and the signal frequency it is a omega. So, we can see that this is I m1 sin omega t and I 2 equals to say I m 2 sin omega t same omega we are talking about and so and so.

And, then again we can use the same KCL to find some unknown quantity from the known quantities. So, we can say that whenever we will be dealing with a circuit which involves a signals. So, each of the signals or each of these currents are having signals maybe time varying sinusoidal signal or it maybe something else there also we can use KCL. In fact, it can be said that even if we have different currents are having different frequencies say this may be omega one this may be omega 2 and so and so then also you can apply this KCL.

So, that sort will be frequently using and in case in general say each of this currents are in time domain. So, in time domain definitely this KCL is valid and what next we will be considering is that each of this time domain signals if you convert into their corresponding Laplace domain signal say I 1 s then I 4 s, I 2 s and so and so and there also you can use this KCL. So, once you are representing each of this individual current from time domain to Laplace domain then you can add up all of these currents in a Laplace domain and then you can add them together and then you say that the summation is equal to 0.

So, that is what it is very important for us we are using this KCL which you are already knowing it, but we are also going to extend that in the AC signal domain as well as in Laplace domain based on our requirement.

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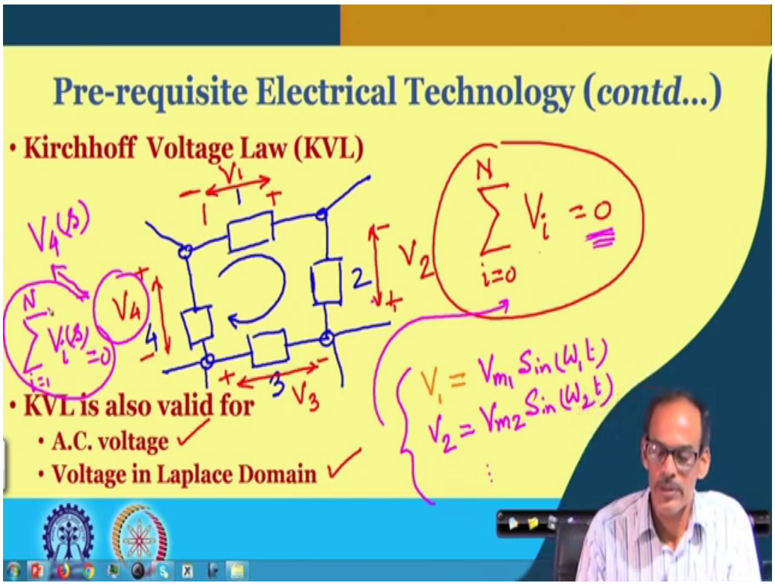

So, this is what we like to say. Similarly for KVL also; so, for KVL also we can deploy the this KVL for AC signal in that case of course, the signal it will be voltage and also the signal may be even in Laplace domain. So, there also we can use KVL. So, quickly just to complete that in a KVL what you do suppose you do have a circuit where you do have multiple elements are connected together and then if they are forming a closed loop.

Say let you consider we do have 3 elements or maybe 4 elements in a circuit and then we do have different nodes here different circuit nodes are there. And, each of this node may be having some other elements connected multiple elements they are in here and so and so. And, then let you call this is element 1 and element 2, element 3, element 4 and so and so forming a loop like this. And then through this loop what you can do? You can capture or you can count each of the potential drop across each of this elements say starting from say this node.

And, then if I say that from here to here the potential difference is node 1 to 2 or we can say simply you can say that this is V1 drop here it is V1 from negative to positive. So, likewise if you consider this drop and if I say that this is positive and this is negative and let you call this is potential drop of V2. So, likewise you consider V3 which is having positive side here and negative side here and so and so and then KVL suggests that the summation of all these potential drop across each of these elements forming this loop namely all this V i's together equal 0. So, this is what we know the KVL and this signals each of the signals as I say that they may be in presently in time domain, but they are this KVL is valid for even in.

So, if we consider V1, V1 may be say V m1 sin omega 1 t V 2 maybe it is having own amplitude and then maybe having it is own signal frequency and so and so. So, likewise you may have all of them maybe having their own signal and again you can add all of them and then you can say that according to the KVL this is equal to 0.

So, whenever we will be dealing with the circuit which is having signals flowing through each of these elements and if the signals are represented in the form of potential drop or potential the voltage signal voltage. And, then we can add all of these signals together to get equal to 0 and this equation maybe a fundamental equation to find expression of one of these signals in terms of the remaining unknown signals. And, this is also valid as I said that in general if we do have each of the signals are general in nature and if you convert those time domain signals into Laplace domain signals.

So, instead of V4 t if we are representing that signal in Laplace domain then also you can deploy this KVL; in that case of course, we have to add up all the signals in Laplace domain and then they add up to 0. So, again this KVL will be frequently using while will be dealing with the analog circuit.

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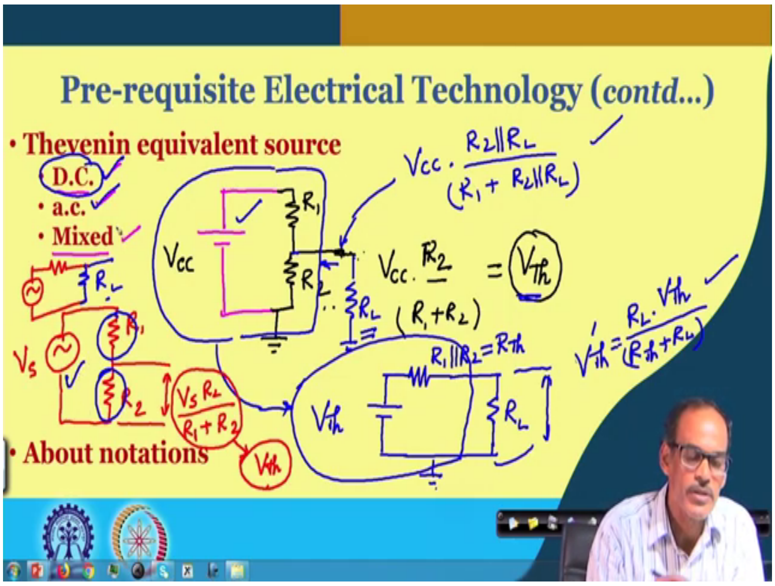

Now, let us move to another important theory in electrical technology what is called Thevenin equivalent circuit. And, we will be frequently using and interestingly we can see that how it can be used for not only DC, but also for AC and mixed kind of situation. So, we will see that mixed kind of situation shown, but let we revisit what we mean by this Thevenin equivalent voltage source. Suppose we do have a DC source, we do have a DC source and it is connected across 2 elements say R 1 and R 2.

So, we do have R1 and then R2 and suppose this is our output node, this may be say common node ground and then suppose this is the supply voltage Vcc. So, what is the voltage here you will be getting? It is Vcc into R2 divided by R1 plus R2 and we may use a different notation for this call V Thevenin equivalent voltage. So, before you connect any load here whatever the voltage you will be getting that is called the unloaded voltage coming here which is Thevenin equivalent voltage.

Now, the moment you connect one load here of course the voltage it will not remain same as the Thevenin equivalent voltage. Depending on the I should say the load here say RL and depending on the strength of these two registers who are trying to maintain this voltage close to Vth you may you will be getting a voltage which will be in between threshold voltage and of course, this ground.

So, we can say that by connecting this register the voltage here somehow it will drop. So, in case if you are having a simple circuit like this probably after connecting this RL you can directly analyze the circuit saying that the voltage now here it will be Vcc multiplied by R2 in parallel with the load resistance divided by R1 plus R2 in parallel with RL. But in general in case this circuit maybe fairly complex it may be non-linear and so and so. So, if this portion it is not really visible to you then how will you analyze?

So, of course, without knowing any information it will be difficult, but in case if we characterize the circuit looking into this port from outside as the load is seeing this circuit probably along with this Thevenin equivalent voltage and something called Thevenin equivalent resistance; you can model this circuit and you can handle the situation even with a fairly complex situation.

So, suppose this is a voltage source called the Thevenin equivalent voltage and the Thevenin equivalent resistance which is basically looking into this circuit and you can find what will be the corresponding equivalent resistance. In this case it is R1 coming in parallel with R2. Now, if I connect the load say RL and if I know that Thevenin equivalent resistance here and let you call for simplicity say Rth. Then by analyzing this circuit we can say that by connecting this

RL the voltage coming and across this one it is Vth equals to it will be RL multiplied by sorry.

I should say now it will be different voltage. So, let me call this is V th dash or V out whatever you say. So, this RL multiplied by the current and the current it is V th divided by R th plus RL. In fact, it can be shown that this expression and this expression they are same. So, I will be not be going in detail of that, but you yourself can do it. So, we know that if we are having a complex situation like this need not be having 2 resistor it maybe having many more elements, that can be equivalently represented by these two elements called Thevenin equivalent voltage source this we know.

Now, this analysis we have done for a situation where the supply voltage is DC. In fact, it can be extended for a signal also. Namely, instead of having a DC voltage here suppose you do have a signal source and say this signal source it is applied across say R1 and R2 similar situation. And, then you like to know what maybe the voltage coming here. So, let me call this is signal voltage Vs.

So, the signal coming here across this R2 again it will it is a if you analyze this circuit you will be finding this is Vs multiplied by R2 divided by R1 plus R2. Now, in this situation of course, again you can say that this is nothing, but Thevenin equivalent voltage in this situation. So, whatever the under DC condition whatever the Thevenin equivalent analysis you know Thevenin equivalent circuit analysis you know. So, here also you can do the same thing or similar thing.

So, instead of seeing this entire circuit probably the circuit can be represented by two element one of them is this Vth and of course, the Thevenin equivalent resistance. So, now, this circuit it can be replaced by Thevenin equivalent signal source in series with Thevenin equivalent resistance and then of course, if we do have some unknown load is getting connected here then you can find what maybe the theory or what maybe the analysis approach to find the corresponding output voltage here. It will be the same way as we have done here.

So, what I will like to say here it is whatever you know Thevenin equivalent representation of a complex circuit it is applicable for AC situation also. But of course, here we have assume that the circuit is linear, the situation it may be different in case if the circuit elements are non-linear in nature. So, those things we will see it later, but in case if you have a circuit let you consider that everything is linear and in case if you have a situation where you do have DC source as well as signal. So, in that case what may be the situation? So, we call this is mixed situation. So, let me explain the mixed situation.

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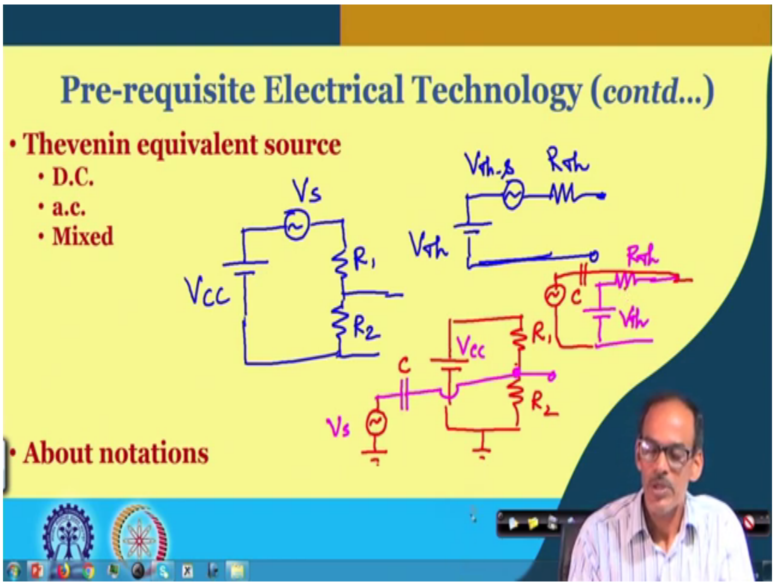

To start with we do have a say DC source and then we do have AC signal and then you do have the potential divider and then you can find what maybe the corresponding Thevenin equivalent voltage source and so and so. Note that this situation it is fairly simple and straightforward. So, whatever Vcc we do have and then signal source you do have a both of them are seeing the same circuit. This analysis it will be simpler you may say that I do have a

Thevenin equivalent voltage source and Thevenin equivalent signal source and then I do have the same Thevenin equivalent resistance.

So, the whole circuit can be represented by this equivalent circuit. So, we can call this is Vth and we can we may call this is Vth for signal and so and so. Now, this situation you may not be seeing always the situation may be even different. So, let us see what other possible situation you may have. Suppose you do have a voltage source and then you do have R1 and R2 and then you are feeding a signal at this node through different circuit. So, probably you do have a signal source. This may be the same common node, but then the signal is coming through different element.

Suppose you do have some capacitor and let us assume that this capacitor it is directly connected here to this node. So, then what may be the situation. So, we may call this is Vs we do have Vcc. So, now, by analyzing this circuit I may be having a DC voltage. I may be having a Thevenin equivalent resistance ok. So, this is DC Thevenin equivalent voltage and then we do have Rth and then directly at this node we do have the signal coming there.

So, we do have the signal, the signal same signal it is directly coming here ok. So, of course, this is a fairly complex, but this signal it is going through a capacitor. It is very important thing. So, the capacitor of course, we do have this capacity element and this capacitor of course, it will be seeing this register which is Rth ok. So, let me redraw the circuit and probably you may appreciate that this situation we will be frequently using and hence better we understand it in our intuition through our intuition.

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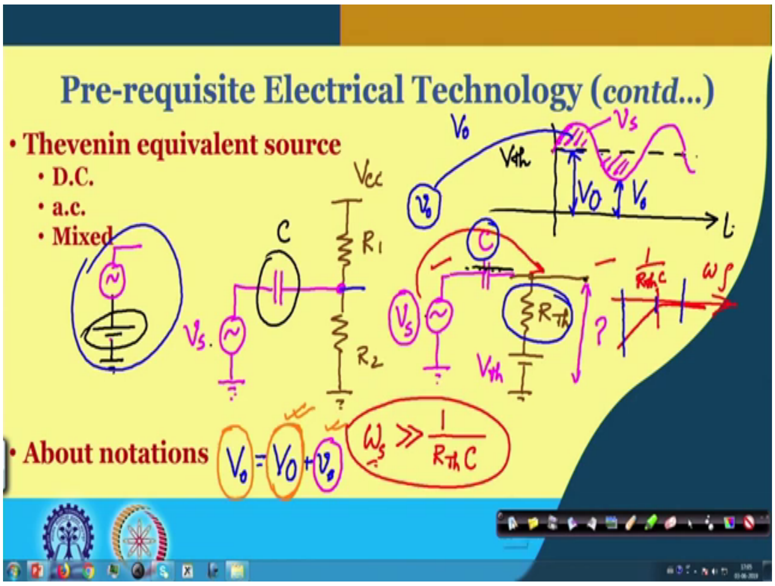

So, suppose we do have R1 and R2 connected to ground. This node it is connected to a DC source and then we do have a signal source connected to this node; simplistically I am ignoring the resistance here. And, what you will be getting here it is of course, we do have this circuit and then in addition to that we do have the DC part we do have the Thevenin equivalent resistance and Thevenin equivalent voltage source. So, at this point; so, we do have Rth we do have the capacitor and then we do have the signal.

So, what kind of situation will you find here at this node? Of course, we do have the Vth now let us try to see what maybe the situation at this point. So, whenever you are talking about a signal and we are feeding the signal through a capacitor. So, we are assuming this is changing with time. So, let us plot the voltage coming at this node with respect to time. So, this Vth it defines the DC voltage level. So, we can say that this is Vth this Vth. On top of that this signal it is getting almost like super imposed. So, suppose it is sinusoidal signal then you are getting the signal coming here.

So, whatever the signal you are seeing here this signal it is coming from this Vs. So, we can say that this signal is Vs. So, it looks like by arranging this circuit we made a good useful circuit where we do have a DC source. If I ignore say this resistance for the time being in series with a signal. So, many a times we will see that this DC source it is used to bias active device, whereas we do have completely independent signal source coming from another element and we do de couple the two sources DC source and the AC signal source through this capacitor C.

But of course, you may be wondering that what is the role of this C or what maybe the suitable value of the C and where shall we get this condition. The assumption here it is of course, we assume that this signal it will be nicely coming where the this capacitor it is really allowing the signal to coming to this point which means that very very important point is that we assume that the signal frequency whatever the signal frequency we do have it is much higher than the C time constant or 1 by Rth C time constant ok.

So, if you see we are where do I get this condition. Interestingly we do have CR circuit. So, this signal if I consider this is input and this is the output we are having CR circuit which means that in frequency domain we are getting some hypes circuit and the cutoff frequency this cutoff frequency if it is the frequency in omega then this cutoff frequency it is 1 by this R C time constant; so, Rth and C.

So, if I assume that these signal frequencies will above this cutoff frequency then only you can say that this signal it is practically entire amount it is coming there. So, that is how we are doing. On the other hand if you violate this condition say for example, if you have a signal component somewhere here which is less than this one; obviously, it will be having huge attenuation. So, you may not be getting this nice signal there.

So, the assumption here it is of course, the value of the C it is large enough in combination with Thevenin equivalent resistance whatever, the cutoff frequency we are getting here the signal frequency is will above this cutoff frequency. So, this is again we will be frequently using. So, whenever we do have a at any node we do have signal or voltage we do have one DC part and then we do have the signal part. So, the DC part typically suppose we call this is the voltage at the output node V small o then we call this is V capital O the DC part and then this part signal part will be using small v small o.

In other words the instantaneous value, instantaneous value it is having DC part as well as the small signal part. This DC level it is represented by a capital V capital O and then small signal part it is with respect to this DC level which is having average of 0 which is on top of this DC level. So, this is the signal part. So, in general we can say that if we consider some node voltage capital V small o equals to the DC part plus small signal part.

So, whenever we will be dealing with analog circuit both of them the signal part; the signal part is important, but at the same time the DC operating point is equally important to make sure that circuit is in good condition. So, whenever we will be dealing with analog circuit ultimately we have to see some signal which contains the DC part and also the signal part. And, many a times this DC voltage it plays very important role to give some active device in proper condition ok. So, that is probably we do have yeah.

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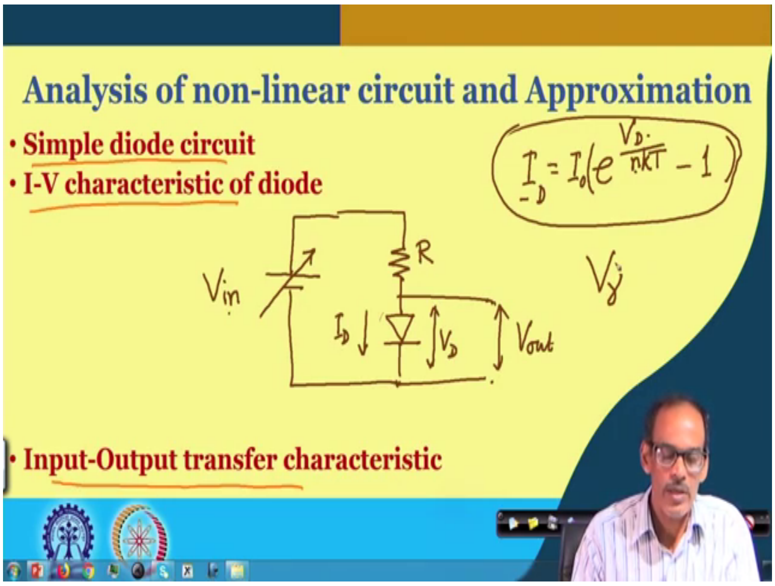

So, let me see what are the things are there, we will see whether it can be fine. Now, we will be moving to another topic the non-linear circuit and its corresponding approximation. So, we may start with simple DC diode circuit and the corresponding I-V characteristic and then we can see that what maybe the input to output transfer characteristic. So, just to give you as an example let you consider one simple circuit containing one register and one diode and then we do have a voltage applied across this one. And, then if you are observing this is the corresponding output for the time being let you consider this is DC voltage, but it is changing with time slowly.

Or you can say we are slowly changing this DC voltage and then we are observing the corresponding output. And, then what you may say about the voltage; the obvious answer probably you may be knowing the diode characteristic and the diode characteristic which is I equals to diode current equals to reverse saturation current e to the power the voltage across this diode divided by n Boltzmann constant k and then temperature in Kelvin; typically this non ideality factor n we consider 1. So, of course, we do have another part minus one. Particularly this minus 1 part is very important if the diode is in reverse bias condition.

So, this is the relationship between the current flowing through the diode and whatever the voltage we do have across this diode. So, this is the voltage across this diode and then this is the current flow through this diode.

Now, if I change this one of course, the voltage here it may be changing and you maybe you may anticipate that if this input voltage it is sufficiently high this diode it will be on, the drop across this one it will be approximately 0.7 or 0.3 depending on whether it is silicone or germanium diode or you may in general you may say that it is some voltage call cut in voltage denoted by V gamma. So, we will see that more detail about this circuit probably we will take a small break and then we will come back to this point.

Thank you.