Analog Electronic Circuits
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Lecture – 04
Revisit to Pre-Requisite Topics (Contd.)

So, welcome to again the second part of this topic namely Revisit of this some of the Prerequisite. In fact, prerequisite part we already have completed, but under this one we are about to start some topic called non-linear; analysis of non-linear circuit. So, let us move to that and then we start with the corresponding circuit yeah.

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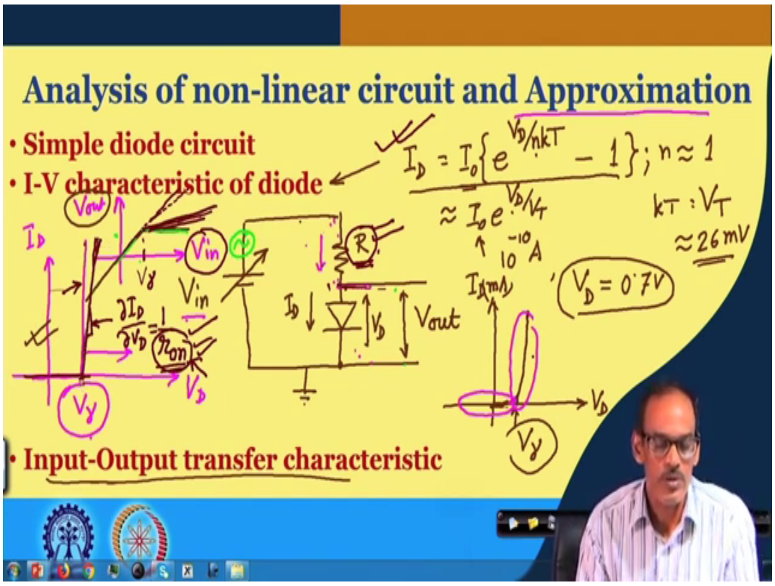

So, here you go. We do have say to consider simple circuit, diode circuit. So, it containing one register and then diode and then let you consider, we are applying a voltage across this. Series connection of this register and diode let you consider this is the common node and let you call this is V in. This is almost like a dc, but changing with time do very slowly and then we are observing the voltage across this diode and let you call this is the observation point, the corresponding observation is the voltage across this diode.

Now, depending on, of course the value of the resistance then the characteristic of the diode and of course, the voltage here will be getting different voltage. And whatever the input to output characteristic we will be seeing that is fairly non-linear, but before that it is important to express the diode current in terms of diode voltage or it may be vice versa. So, let me call the diode current is I D equals to I naught e to the power V D voltage drop across the diode divided by n into Boltzmann constant k and temperature in degree Kelvin minus 1 whole thing it is multiplied by I naught.

So, as you know that this I naught it is referred as device the diode reverse saturation current, you can find this value of this one it will be very small from any practical diode. It may be 10 to the power minus 10 ampere level. The non-ideality factor k it is typically considered for in this situation 1 and k into T of course, it depends on the temperature, but typically this k into T it is again denoted by capital V capital T thermal equivalent voltage close to 25 to 26 millivolt at room temperature ok.

And then V D is the drop across this diode, V D and I D is the current flow through this diode ok. This, though this equation it is it involves some approximation, but it is fairly practical and that may be sufficient for many analysis. So, we will use this equation, diode equation like this. Now, we are asked to find what may be the voltage across this diode V D for different value of this input.

Now, if you see this exponential relationship indicates that if this diode voltage it is much higher than thermal equivalent voltage namely 26 millivolt, this part it will be quite large compared to 1 and this part it will be almost I naught into e to the power V D divided by say V T. So, let you consider n is equal to 1, in this situation. And so that is the equation we will be finding, but of course, here we assume that is V D is much higher than V D.

Now, even though we say that this current it is quite small maybe 10 to the power minus 10 ampere level, but then this voltage because of this exponential nature, if this voltage it is in the order of say or maybe around 0.6 or 0.7 volt this ratio to be so large the current here it will be coming in the ampere range or at least milliampere range. So, if the voltage here it is around 0.6 or 0.7 depending on the value of this current we may say that this current it will be in milli ampere range, that may be in our range of our observation.

So, if we plot this exponential relationship ID versus V D curve, if the current the voltage it is small may be comparable with 26 milli volt and so the current is very small, but then it just suits up like this exponentially. So, we can say that this current is in the scale of milli ampere. So, suppose this scale it is in milli ampere level. So, we can say that this curve it is away from this x axis V D axis particularly at a point called V gamma, this is commonly known as cutting voltage of the diode.

So, depending on the voltage across this diode, whether it is less than this cutting voltage or if it is more than you know this cutting voltage we may approximate this characteristic by either this part or this part. Now, here it is very important whenever we are dealing with non-linear circuit we need to have appropriate approximation to simplify our analysis. Otherwise if you are dealing with this exponential equation it may be sometimes it will be difficult to handle the situation.

So, if I am allowed to approximate this characteristic curve say something like this suppose this is the I D versus V D characteristic curve and if I call this is approximated characteristic curve. We can simply say that this is a vertical line particularly when V D it is beyond or at say V gamma. On the other hand when it is less than this it is almost aligned with V D axis, which means that depending on the voltage here or to be more precise if the current is 0 drop across this resistance is also 0 right.

So, in this region as long as V in it is less than this cutting voltage this current here it will be very small and drop across this one it is also small. So, the voltage here it will be essentially you can say whatever the input voltage you are applying same voltage it will be coming. On the other hand if the V D it is beyond this point, then this diode it is getting on the current it will be non-zero.

So, then there will be a drop and the voltage across this one whatever the level of current it is required to generate this drop the voltage across this diode you may say practically remains close to this cutting voltage. So, if this approximation it is valid you may create two situations, one is V in it is less than this cutting voltage and V in it is more than this cutting voltage. So, let me use this small space, please bear with me.

So, suppose this is V in and this is a V out. So, what we are expecting here it is the two as I say is there two cases, V in it is a say less than this V gamma. So, here this portion it is open, drop across this one is 0. So, we can say that the voltage here it will be same as whatever the input voltage you are applying. So, you may say that the input to output transfer characteristic it will be like this, on the other hand if the input voltage is beyond this cutting voltage. So, we are in this region.

So, what you are expecting there it is the diode can support practically any current, but then drop across this one it will be it will be prominent and then voltage here it will be retain practically it will be same as the V gamma. So, you can say that this will be the situation. In fact, you can make this voltage even negative and you may get this kind of characteristic.

So, with this simplified approximation what we can get that input to output transfer characteristic is like this. On the other hand in case if we want to have a better approximation, by the way this is referred as input to output transfer characteristic. So, frequently we will be using this input to output transfer characteristic while we will be dealing with non-linear circuit. And this may be helping us to understand that how input to output signal it is getting propagated to the output.

Say for example, say if you are having a small signal; if I am having a small signal here, and then if I am observing the corresponding output. So, if the DC voltage it is somewhere here; obviously, this part of this transfer characteristic indicates that input signal it will be directly coming there almost as is. On the other hand if this voltage it is say beyond this cutting point and then you are in this part of the transfer characteristic. So, the signal hardly it will be coming here ok.

So, that is the importance of this input to output transfer territory characteristic, we will see that frequently. Now, let us consider as I say that this is this may be too simplistic approximation. Many a times it may not be you know acceptable in case if you want to know more detail about the variation of the current, instead of call I am drawing a vertical line we may prefer to have you may prefer to have a line which is having a finite slope.

So, instead of having exponential characteristic curve we may be having a characteristic curve which is finite, but this part it may be again it remains a horizontal. Now, if I consider this characteristic of the diode having a finite you know slope. Slope here it may be considered as change in this current with respect to change in the voltage across this one and you can see that this is the ratio of current divided by voltage.

So, in fact, it is unit it will be 1 by ohm more and you may say that this is the resistance. In fact, this is on resistance of the diode, one by on resistance of the diode. Once the this diode is on whatever the equivalent resistance you know offered by this diode for the current or for that matter signal that may be represented by element called R on.

In fact, whatever the slope if you see here, in this case it is an approximation it is a linear line and if you assume this slope it is remaining constant. So, again it is an approximation you may say that r on instead of assuming this curve where r on it is 0 and that is why this slope here it is infinite you may say that it is having some practical value, it may be 10, ohms 20 ohms and so on. And so now, this slope and the value of this resistance or I should say on resistance and this resistance they do have important role to play to define this whatever this voltage is there.

In fact, to understand that you consider this R on it is very small compared to this R, then what may be the change here in this characteristic curve. So, if I am using this finite slope then it is expected that instead of being this is horizontal this will be having a finite slope, because the voltage across this diode it is no more remaining at this cutting voltage V gamma based on this current level actually it is slowly moving. So, that part it is getting represented here.

Now, if this value of this resistance it is comparable with this one then of course, this part this characteristic curve it may be again it will be moving like this and finally, it may be going like this. So; obviously, this on resistance and this resistance and their relative value it is important to define the slope of these transfer characteristics slope alright. So, depending on the value of this resistance you may not be able to ignore this on resistance you may have to consider practical value of this resistance.

So, that is about how do we you know manage with non-linear circuit, suppose we do have this is fairly complex kind of non-linear relationship. But, that situation that non-linear behavior may be well approximated by just a vertical line and this horizontal line or it may be a horizontal line with a almost vertical line having a finite slope depending on the situation we may use one of them.

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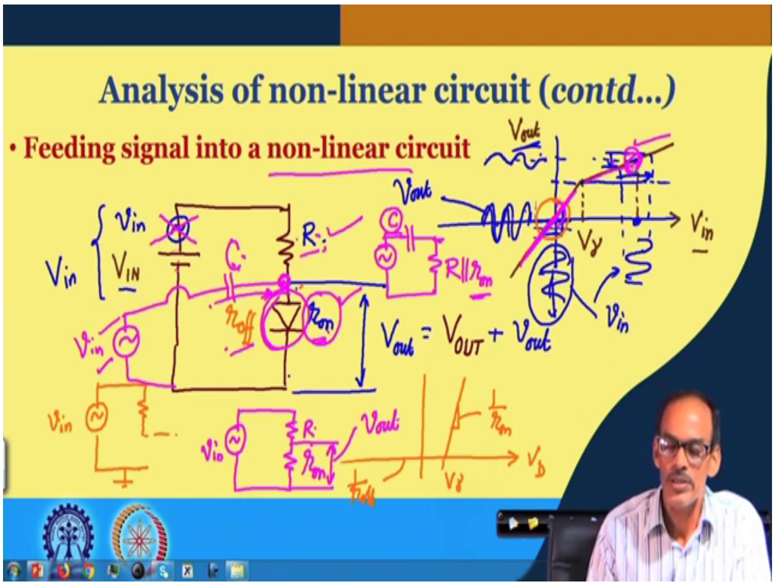

Now, let me move on about this diode circuit again. So, whenever in a non-linear circuit we are feeding the signal then what may be the situation? So, let me redraw the circuit again. So, we do have the register, we do have the diode and then we do have DC, maybe this is a DC and then in case if you have a signal coming in series with this DC as I said that depending on this resistance and if we are observing this is the V out. Now, note that the input we do have a DC so we may call this is capital V IN, capital IN and then we do have small v small in, these two together you may say that we do have capital V small in.

So, this part this is having two parts one is the DC part and the small signal part. So, likewise at the output we may be having V small out having two parts, namely capital V DC; that means, capital OUT in series with small v small out. Now, as I said that depending on the value of this resistance either in the transfer characteristic curve; either we are in you know in this linear part or we may be this is approximation or we may be in this part and this is where the voltage across this diode it is V gamma right.

So, this is of course, V in capital V small in capital V small out. Note that the previous input to output transfer characteristic we are dealing with DC voltage slowly varying with time. Now, we do have a situation some flexibility we do have a DC part remaining constant and then it is having a time varying signal. Now, if we are having this voltage say 0; that means, we are here and if you change this input voltage with respect to time.

So; that means, if you are applying a signal like this, the corresponding output you will be getting here. So, if this is how it is changing with time the corresponding signal you will be getting it is it will be like this. So, slope of this line is basically reflecting this input signal to this output signal. Please do not get confused that this axis is for V out and. So in fact, this is time varying signal. So, the input voltage it is going up and down with respect to this point. So, that has been represented here.

So, likewise whenever we are drawing this signal what we are drawing it is the voltage here with respect to this DC level how it is going up and down. So, you may say that this is representing signal at the output port and this is representing signal at the input port. Now, if I say that if the DC voltage it is somewhere here and we do have the same kind, same levels of signal which means the signal it is having the same amplitude as we do have here ok.

Now, here of course, this is the DC level. So, here the voltage if you see here it will be changing with a small amplitude, because if you see that if the input voltage is changing over this range the corresponding output change it is only over a small range. So, depending on the DC level here either here or here we may be you know getting the same signal as is from input to output or we may be having at the output and attenuated version signal.

In fact, if I consider the this idealistic situation where the drop across this diode it is almost this cut in voltage, then hardly you will be seeing any signal ok. Now, let you consider the other situation, probably we understand this part. In fact, whenever we are here if you see the signal it is seeing r and then R on, particularly if the circuit is then side circuit is here. On the other hand if it is the transistor it is off then the corresponding resistance here I have to consider R off.

So, this R on we said that the diode on resistance in the this situation where V D it is more than the cut in voltage. And, so this is the slope is 1 by R on and here the slope it is 1 by R off. So, here it is resistance it is you can say infinite or slope is 0. So, why in this case you are getting the same signal here because if this the DC voltage it is such that we are here then the diode it is off. So, whatever the signal you will be getting here, if I draw the only the signal part we do have this resistance and then we do have the output and here we do have open circuit like this.

So, this is the situation when V IN equal to 0; that means, in this situation. On the other hand whenever we consider say the situation at this point which means that we need to consider this on and in that case the same input signal we are applying across this R and then we do have small r on. And, as I said that depending on the value of this R on and this r we will be getting this voltage called small signal output voltage v out, from this whatever the v inl it is it will be defined by this ratio.

Now, if this intuitively if this resistance is very small compared to this one you will see hardly anything coming here. And if it is comparable then you will be getting some attenuated version on this one. So, that is what you are observing here. So, this is a situation where both the DC as well as the signal both of them are going through the same equivalent circuit. The situation it will be even more tricky if say this signal instead of connecting here if it is getting a different path altogether.

So, we may be having a situation where the signal it is here and then the signal may be connected to this output node through some alternate path and then if the V in we you do have here then we have to see that how much the capacitor successfully feeding this signal to this node while this r on it is present. Now, if again this and this DC voltage it is such that if we are here then this capacitor it has to it has to overcome these two resistances namely this resistance and this resistance coming in Thevenin equivalent form right.

So, in that case the cutoff frequency of the C R circuit it will be constructed by this C and R in parallel with r off. On the other hand if we are here you have to consider now this and this and the corresponding cutoff frequency it will be defined by the same C, but then this R coming in parallel with r on this is very interesting thing. So, in that case in this situation I do have a signal, I do have this capacitor and then I do have the Thevenin equivalent resistance and in this situation you have to consider this R and then small r on coming in parallel.

Obviously, this small resistance it may create a difficult situation for this C to feed the input signal to the output. In other words say the cutoff frequency of the high pass CR circuit it will be primarily defined by this C and then this r on. So, that gives you some fair idea about the importance of this DC voltage while we will be dealing with the signal. Most of the cases we may ignore, we may keep the focus only on signal we may ignore this DC part. But here with this example I am trying to explain that you should not be completely ignoring this DC part because that really defines the input out to output transfer characteristic and also it defines the input to output.

Whatever you say gain or attenuation based on the condition of the non-linear device. So, in analog circuit which it will be having frequent non-linear circuit. So, there you need to understand that keeping this non-linear device in appropriate region of operation is very crucial.

Of course, appropriate it is relative term it depends on actually where you want to place either it is here or here based on that the same circuit it may create different situations.

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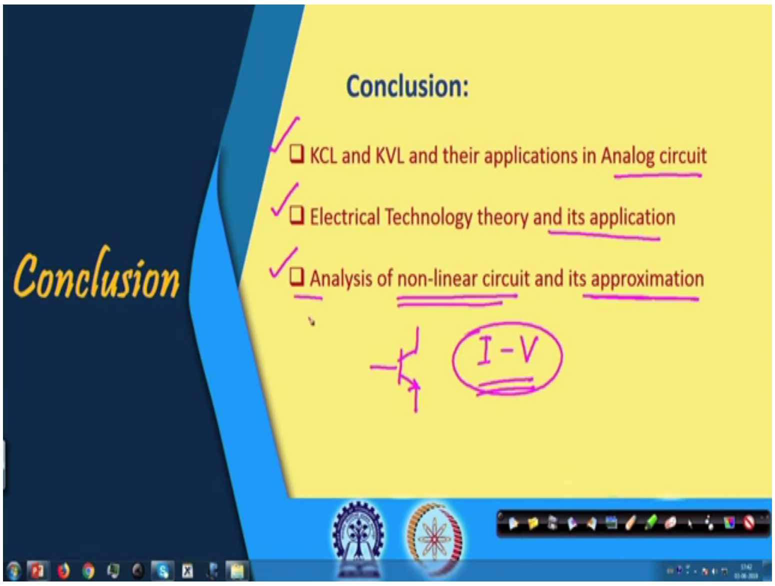

I think mostly that is what I like to cover. So, what we have covered today it is considering this module and the other model. We have revisited the important theory KVL and their applications specifically in analog circuit and then the Thevenin equivalent circuit.

In our context when we involve not only DC, but also the signals and their application in analog circuit and gradually have moved into non-linear circuit which is of course, this may be frequently used. We have considered in today's class a fairly, simple circuit consisting a one diode and register of course, one coupling capacitor. But, that gives you some idea that quite an extent electrical technology can be extended and used. But, once we do have non-linear circuit we may required additional in a tricks what it is called approximation.

So, this approximation again it comes from the experience, what kind of approximation is valid to represent non-linear circuit in the form of linear. So, we have, we got some test of a what kind of complexity it will be involved in to. Probably in the next class we will be moving towards some more non-linear circuit involving BJT and MOS circuit and their corresponding IV characteristic.

So, whenever we will be dealing with non-linear circuit say may be BJT or say MOS there the IV characteristic it is very important. So, whatever the IV characteristic they will be having in the form of equation, in the form of equivalent circuit those things are very important. And whenever you say equivalent circuit it is nothing, but it is an approximation. So, this topic again and again frequently we will be revisiting. So, today we have basically just started to get into analog circuit, I think that is all to share and yeah.

Thank you.