Analog Electronic Circuits
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Lecture No 01
Review of DC Models of Diodes & BJT's

Welcome to AA204 and the course name is Analog Electronic Circuits this is the first and the last class of 1995 isn't it right? 29th December 1995. So our next meeting will be one year later.

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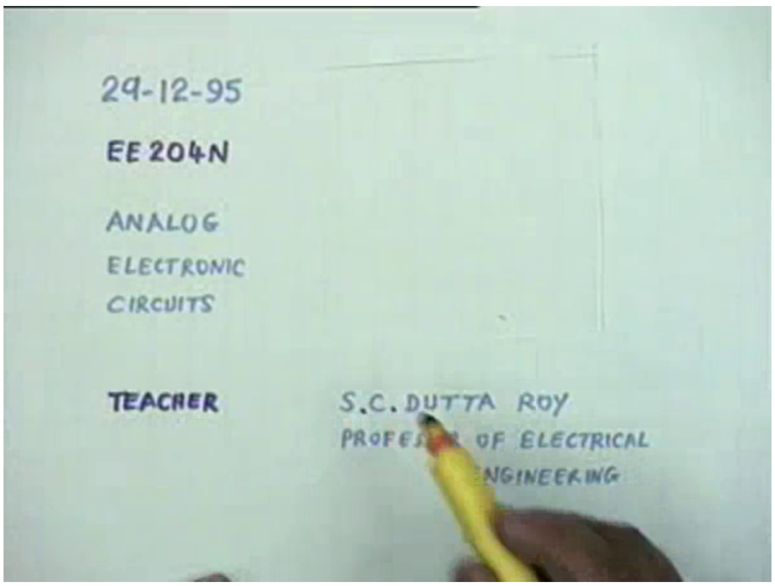

This is my name S C DUTTA ROY I am a professor of Electrical Engineering in this institute.

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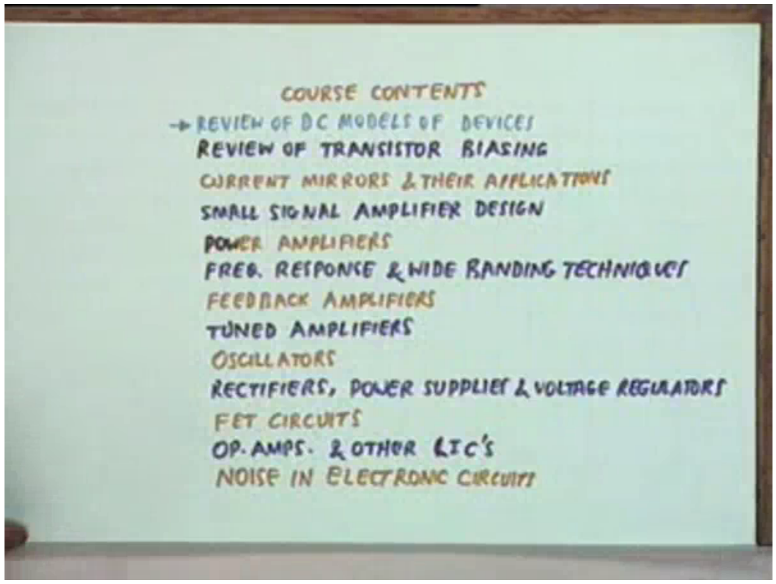

The course contents as listed as listed in the bulletin. This item is missing, this is what we will start with. Review of DC model of devices. And this device is basically are junction diodes, BJT's Bipolar Junction Transistors and FET Field Effect Transistors. You have been acquainted with them in EE110 that is introduction to electronics electronics circuit. Have I told the number number correctly 110? Yes. We will review knowledge basically from the surface not going into very deep then we shall Review of Transistor Biasing, this also we have done earlier but we will bring in quantitative measure of bias stability like yes stability is the term. Then we shall Current Mirrors and Their Applications, Small Signal Amplifier Design little bit of this we have done earlier RC Couple Amplifiers Frequency Response we will go into other kinds of Amplifiers in my more details. We shall discuss power amplifiers in details the Frequency Response and Wide Branding Techniques that is given an amplifier which is a certain bandwidth how can you increase the bandwidth.

We shall discuss Feedback Amplifier, Tuned Amplifiers amplifiers which resonate at a particular frequency that is which responds to a particular frequency and a small band of frequencies around it. These are Tuned Amplifiers we will discuss oscillators that is signal generators circuits which generate single sided signals as soon as the power supply is put on. They don’t require any external input. Then we shall discuss Rectifiers some of which you have done diodes circuits you have done earlier, Rectifiers, Power Supplies and Voltage Regulators. Along with all these circuits we will discuss both BJT Bipolar Junction Transistor and Field Effect Transistors circuits. We shall discuss the most important analog integrated circuit viz. the Operational Amplifiers and other Linear Integrated Circuit LIC’s. And finally if time permits then we shall discuss Noise in Electronic Circuits.

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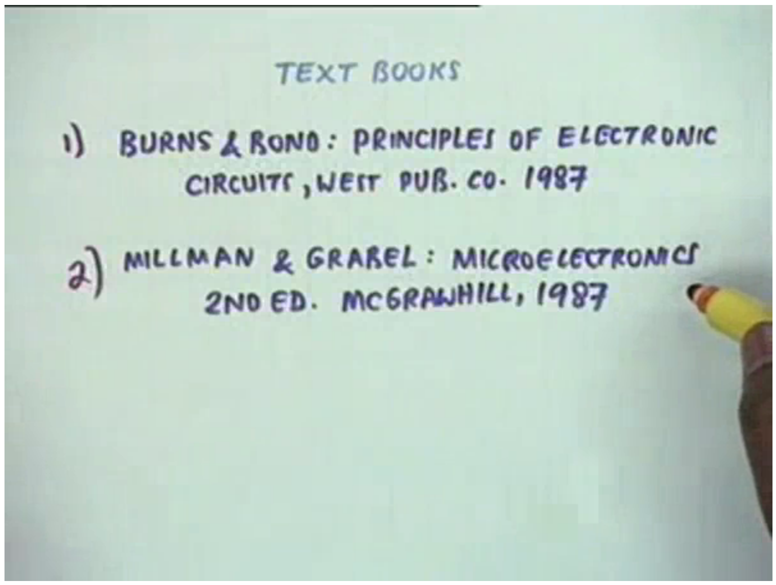

The 2 text books are Burns & Bond this is Principles of Electronics Circuit Published by West Publishing Company in the United States and it's 1987 book. And the second one is Millman & Grabel this book is Microelectronics Second Edition McGrawHill 1987. A large number of copies of this book is available in the library but this may not be available in plenty Burns & Bond. If certain portions are needed badly I may give you a handout I may Xerox that portion and give you a handout. But let me assure we will not generally require to read a text in great details unless you miss a class or absent in the class. Both are costly publication, this is not available in soft binding at all, the first one. This one is available in soft binding so I leave it to you whether to buy or not. But the library should be able to help you.

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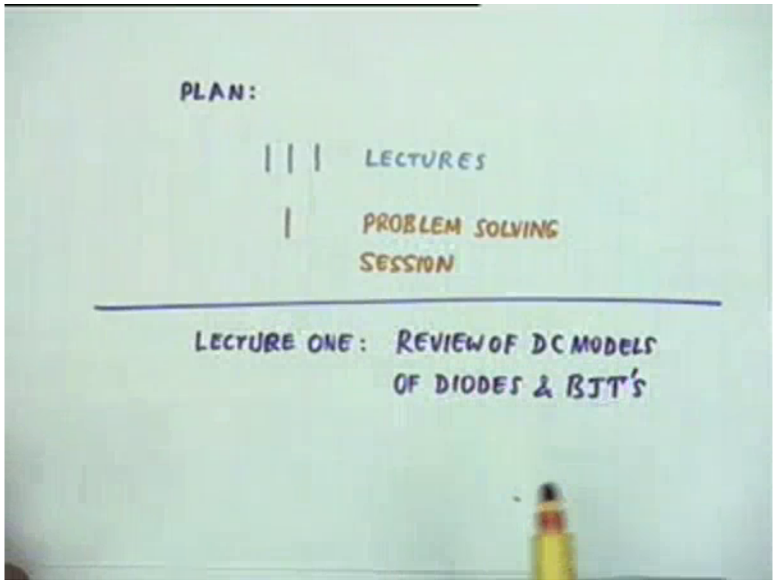

Now our course of plan is to have 1 2 3 lectures and then 1 problem solving session but as I said we will be flexible in this. And today is the first lecture. Lecture 1 and our topic is Review of DC Models of Diodes and BJT's Bipolar Junction Transistors.

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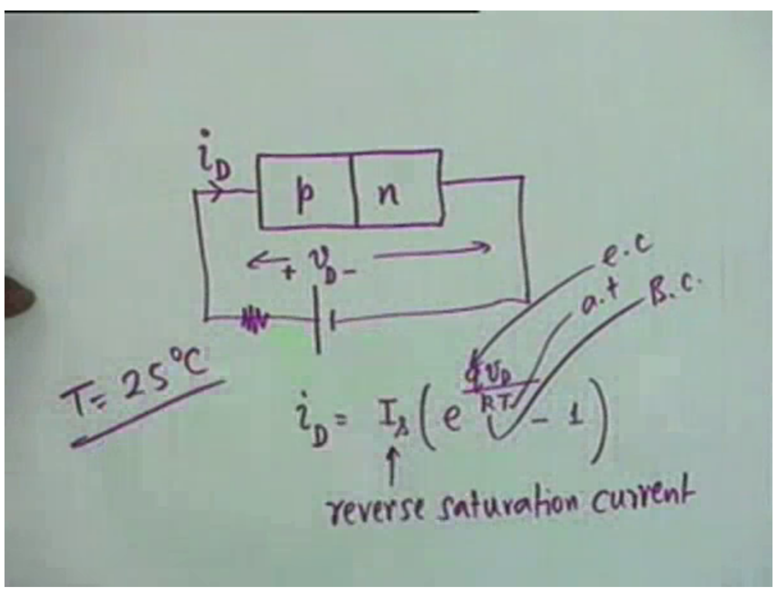

First we talk of a diode, as you know the semi-conductor diode contains basically, two types of semi-conducting materials brought in the neighbourhood of each other by metallurgical means okay. And 1 is a P type which is a preponderance of holes that is positive charged carriers. One is an N type which is a which is a preponderance of electrons which are the majority carriers. The P type material also has electrons but they are in the minority carriers whereas N type material also has holes but they are minority. And normally a diode if a battery is connected like this with positive connected to the P side and negative to the N side then it is said to be forward biased. This diode is forward biased. And if I denote the voltage across the diode I might have a resistance here, I might have a resistance here.

If the voltage across the diode is denoted like this and the current is denoted like this, the current naturally shall leave the positive terminals of the battery, enter the P type and then go out of the N type to the negative terminal of the battery. Then the i V characteristics of the diode to denote that it is a diode we use a subscript D. Is the writing clear enough on the, okay. V The to denote that it's a diode we say i D and V D and the mathematical equation connecting i D and V D as you have studied in 110 is i D equal to some I S E to the power q V D divided by K T minus 1 this is the equation basic equation of a diode where capital I S is a constant, it is called the reverse saturation current. Q is the electronics charge. K is the boltzmann constant and capital T is the absolute temperature q V D by K T. It is exponential in nature. Normally at room temperature, room temperature is usually taken as T equal to 25 degree C.

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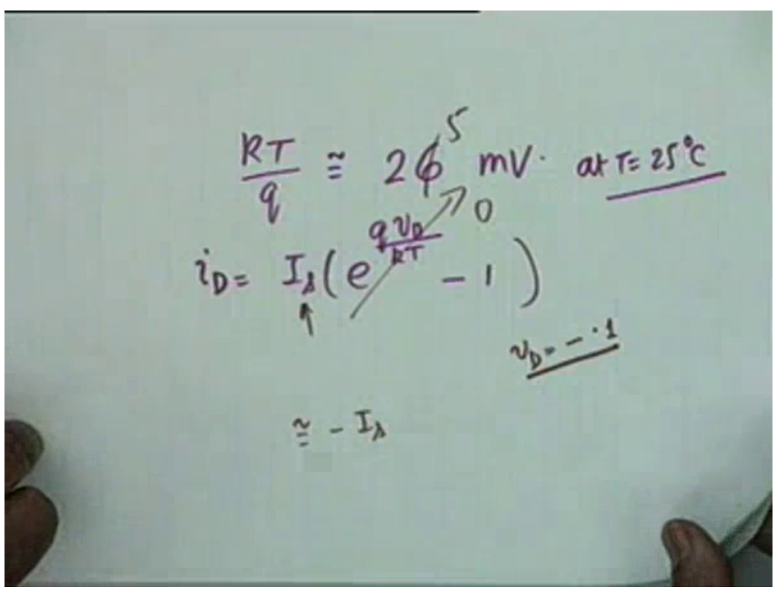

At room temperature K T by q is equal to 26 millivolt approximately at capital T equal to 25. Let me recall the relation, i D equal to I S e to the power q V D divided by K T minus 1. K T by q is nearly 26 millivolt. Now is it clear that K T by q should have the dimension of voltage, because the power of exponential cannot have a dimension. That must be dimensionless and V D is in volts therefore K T by q must also be in volts. Numerical value is 26 times 10 to the minus 3 volt 26 millivolt at 25 degree C. This is conventionally and universally used as the room temperature as the temperature at which all calculations are made. 25 is very sacred figure. We see later on that in order to make calculation simple we might take this instead of 26 we might take this as 25. There is nothing sacred about it we have changed the temperature slightly we reduced the temperature slightly. To make life simple to make numerical calculation simple. Which means that 1 by 25 we will require V D by 26, 1 by 26 is not a very nice figure. But 1 by 25 is 0.04 it's a very nice figure. So sometimes we will take many of the time, most of the time number 1.

Number 2 why is I S called reverse saturation current. This is because if V D is negative let's say V D is equal to minus let's say 0.1 volt. 0.1 volt is how many millivolts 100 millivolts. So it would be E to the power minus 4 agreed? 100 divided by 25 E to the minus 4. Now the value of E lies between 2 and 3 and therefore E to the minus 4 is a very small quantity compared to 1. Even when V D goes to minus 0.1 this term goes to 0. Compared to unity, it's a very small quantity and therefore the current goes to minus I S. The current cannot decrease further alright because the minimum value of this is 0, therefore the current gets saturated when the diode is reverse biased. Even at a very small voltage even at a small reverse bias the diode current gets saturated and therefore I S is called the reverse saturation current okay.

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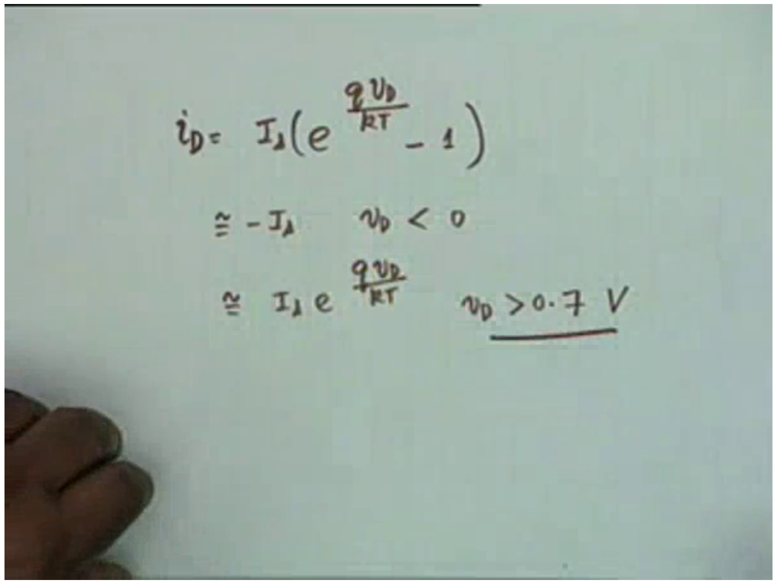

In the reverse biasing under reverse biasing I S E to the power q V D divided by K T minus one. So this is approximately equal to minus I s, if V D is negative alright. On the other hand, if it is positive if V D is positive suppose V D is 0.1 volt then you see it E to the plus 4 is a very large quantity compared to unity. What is 3 to the power 4 81 and 2 to 4 is 16. 16 is not very large but 81 is between 16 and 81, so under forward bias you can write this as I S E to the power q V D divided by K T for forward bias okay. Not very negligible forward bias but sufficiently large and you will see sufficiently large means that V D must exceed about 0.7 volt. You will see in a minute okay. So under forward bias this is the relationship, under reverse bias it is approximately a constant.

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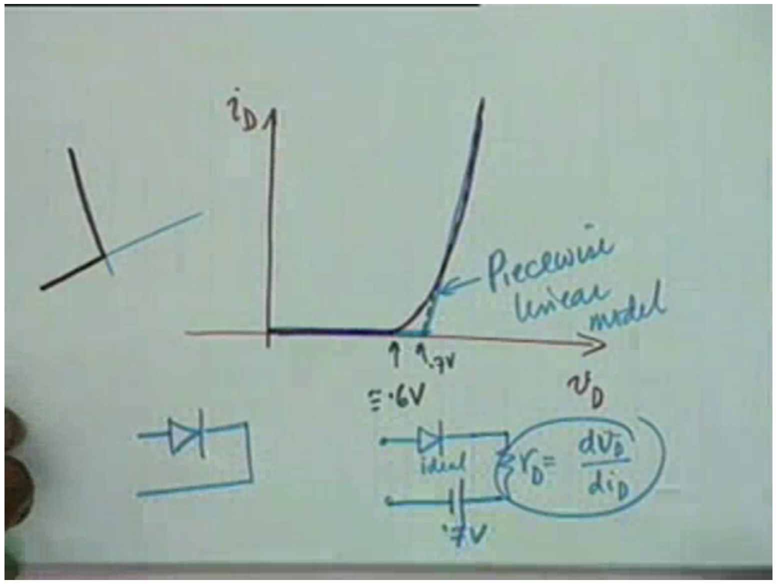

And if I plot the diode current voltage characteristics. V D versus well i D versus V D the characteristics is something like this the current is approximately 0 for a certain range then it rises. And the rise is obviously it would be exponential okay and this is this region where the current can be approximated I S times E to the power q V D by K T. This point at which the current rises, starts rising is approximately this voltage is approximately 0.6 volts. Approximately 0.6 now for reasons to be clear right now we take the cut-in voltage that is the voltage after which it come that is 0.7 and the reason is this. That this exponential rise we don't like non-linearity. Electrical engineers in fact all engineers they will try to avoid non-linearity as far as possible.

Now a diode even though the characteristics is exponential we usually try to approximate this by means of a straight line a linear rise and this straight line a linear rise. And this straight line usually cuts the axis at 0.7 and therefore what we do is instead of taking the usual model of the diode usual non-linear characteristic we make it piece wise linear that is we take this as a straight line up to this and then a straight line going up this blue line is the Piecewise Linear Model of the diode okay. Which means that in the forward direction when the diode is forward biased I can model the actual diode the actual diode by means of by means of an ideal diode what is an ideal diode? In ideal diode the current is infinity when the voltage is 0. For and ideal diode the characteristic is something like this, for an ideal diode the characteristic is this. That is ideal diode is an ideal switch. As soon as you apply voltage it becomes short circuit, short circuit means it can pass indefinite amount of current. No ideal diode by virtue of the adjective itself can be made in the laboratory. Idealness cannot be absorbed cannot be seen okay.

So what we can do is we can approximate by and ideal diode and then what else do we need. We need a battery because it starts conducting at 0.7 and therefore we will make this a battery of 0.7 volt and this piece wise linear characteristic can be approximated by a resistance. If I take the slope of this, that is d i D d V D that would be the resistance and this resistance we will call this as R D which is which is d V D d i D that is the reciprocal of the slope of this curve alright. Reciprocal of the slope of this curve. So this is a model you see if you apply a voltage between these 2 point there will be no current in the circuit till the voltage exceeds 0.7 volts because the cathode of the diode the N is maintained a plus 0.7 this must exceed 0.7 in order to made the diode conduct and this is an ideal diode. Now the ideal diode the total circuit is a model of non-ideal diode because we have included resistance r D okay. In actual practice, well this will be the DC Model of a diode that we shall be using in our discussion of electronic circuits.

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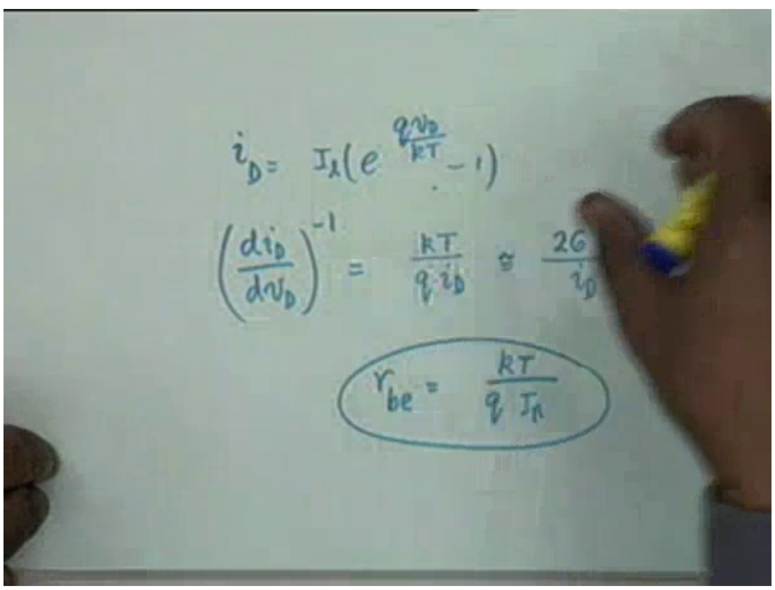

But in an actual diode as you can see i D is equal to I S e to the power q V D by K T minus 1 as you can see d i D, d V D okay reciprocal of this is a function of V D, isn’t it right, is a function of V D. Now you can show by actual differentiation. That this is equal to K T by q i D that's it. You can show by actual differentiation (())(19:29) because we're considering the forward direction. We have to ignore this term. Then we will see that this is equal to K T by q i D so this is approximately equal to 25 or 26 whatever you take let's take 26 millivolt divided i D alright. Typically if the diode if a diode comes back let's say 26 milli-ampere then the resistance would be 1 ohm, just 1 ohm is that clear.

Now the reason why I am discussion this diode in details is that the emitter based junction of a transistor or the collector based junction of a transistor they are both diodes. And therefore if you take the emitter based junction of a transistor for example the resistance would be equal to K T by q the base color I p will we come to this later but the reason why I am discussing is that the same relation applies in junction transistors also in the 2 junction that we talk of.

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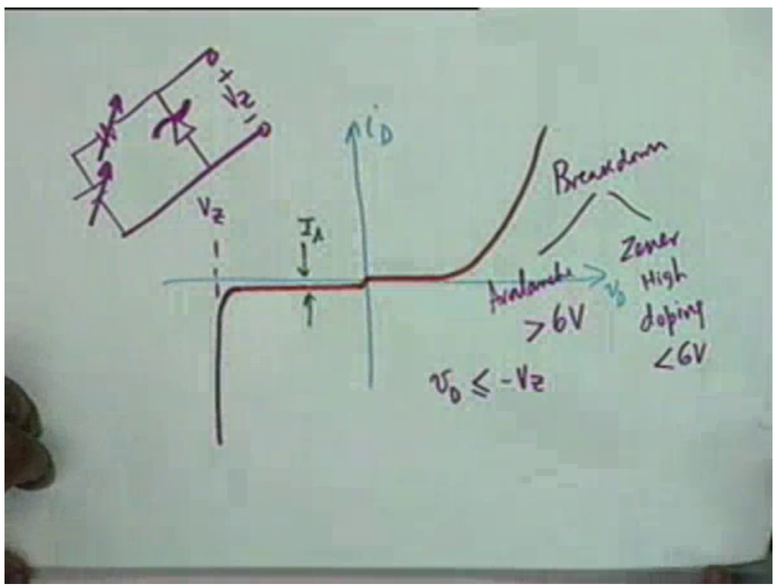

Now let's go back to this characteristic. What I what we did was we plotted the forward characteristics like this for the reverse characteristics naturally when V D is reversed the current shall also reversed. Reverse characteristics is something like this. And you know that even for a small reverse V D the current remains almost constant at I S that is the reverse saturation current. So this current is I S is the point clear? However it is found that if you if you continue to increase the reverse bias then ultimately ultimately the junction breaks down that is at a particular voltage that we denote by V Z at a particular reverse voltage, the current suddenly goes very high. And the voltage does not change, voltage remains almost constant.

Now this can occur due to one of the two phenomena. Obviously in this range if V D is less than equal to minus V Z then this equation of the that is i D equal to I S exponential Q V by K T minus 1 is not valid. This is valid only for the red portion of the characteristics. I have shown this exaggerated; this is actually a very small quantity. I S is of the order of micro-ampere some 10s of micro-ampere that's about all. It cannot exceed more than this. But if you exceed a particular voltage V Z minus V Z reverse direction then the the diode breaks down. In other words the current goes on multiplying itself the current increases substantially without an increase in the voltage so it's almost almost a vertical line.

This breakdown can occur due to one of two phenomena, one is called avalanche breakdown are you acquainted with this term Avalanche and Zener? Zener of course you do Zener diode for voltage regulation you must have used okay. The difference between the two is the characteristics is more or less similar. The difference between the two is that the avalanche breakdown, well the avalanche breakdown occurs under high field condition, high electric field condition okay. And avalanche breakdown any breakdown which occur above let say 6 volt a rule of thumb it may be 7 I mean it may be 8, but rule of thumb based approximately if the breakdown occurs at high voltage then it must be due to a high electric field. If you increase the reverse voltage the electric field created in the space charged region also increases and that might cause a rupture or a tunnel in-through. So that the majority of the carriers can tunnel through very quickly.

And increase of current means that carriers there are more carriers to carry the current okay. So avalanche breakdown is a high-field phenomena, on the other hand Zener breakdown is a high doping phenomenon, that is both P and N materials if they are very heavily doped then even a majority carrier with a small energy when it enter into the minority carrier, into the let say when an electron from the N type material enters the P type material it encounters minority carriers that is electrons in the P type region right. Electron in N type is majority carrier. If it enters with a small velocity into the P type material it encounters other minority carriers majority carriers which are holes and also atoms which are not ionized.

This energy because it is heavily doped it gets so many particles to collide with that it sets out electrons free from atoms which are not ionized. And therefore it creates by collision more carriers of current and therefore the current increases. This is the zenering effect Zener Effect okay. Zener effect occurs usually for less than 6 volt. If this breakdown occurs for less than 6 volts value are more or less certain that it's a Zener effect. If it occurs for higher values then more or less it is sure that it's an avalanche effect. Whatever the effect is if you're a circuit engineer, if your job is not is not to understand but to use them you don't care. What you care is whether the manufacturer has list this as an avalanche diode or a Zener diode.

The Zener diode as you know is used in voltage regulation. That is the current can take any value depending on the external circuit but the voltage remains a constant. For example if you have let's say a circuit like this a resistant and then a Zener diode like this Zener diode is usually indicated by a curve line here. You see this diode is reversed biased right. This is the positive supply but the diode is reversed biased. Then if Zener breakdown occurs here then this voltage will be V Z irrespective of what the external resistance is, is the point clear. Whatever the resistance is this voltage remains constant and this principle is used in voltage regulation that is in making a power supply whose voltage shall remain a constant irrespective of fluctuation of, even this battery may fluctuate it doesn't matter, even this resistance may fluctuate but this voltage shall remain a constant. So getting a constant voltage supply a Zener diode is used.

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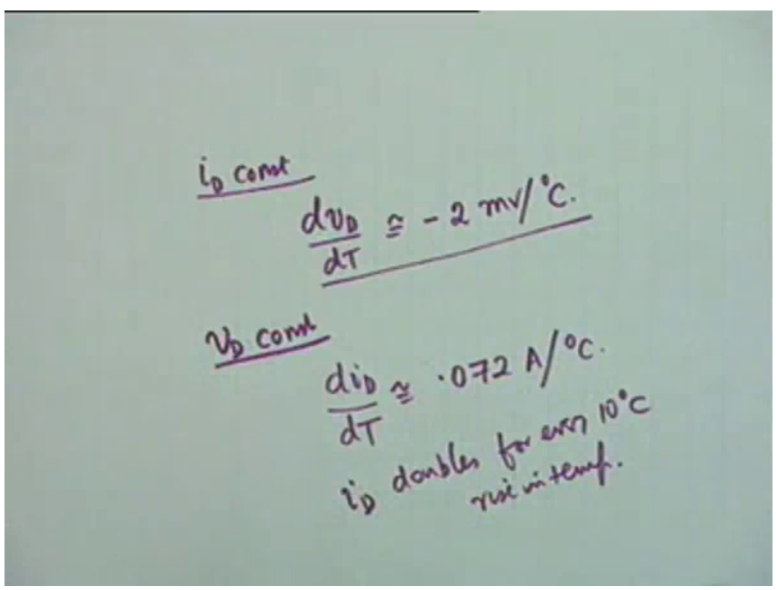

The characteristics of a diode are temperature dependent. Okay, this is one of the disadvantages of a diode. But it's also an advantage if you want make temperature compensation it's also an advantage. It is found that if i D constant that is if you drive the diode by current source a constant current source you inject a current i D then V D changes with temperature at the rate of minus 2 millivolt per degree centigrade. This figure is important. d V D by d T is approximately minus 2 millivolt per degree centigrade on the other hand if V D is constant then i D, V D is constant that means you drive the diode with a constant voltage supply then d i D d T is approximately 0.072 ampere per degree centigrade 0.072.And the rule of thumb is this figure should also be remembered, the rule of thumb is that if the current doubles for 10 degree centigrade rise in temperature. i D doubles for every 10 degree centigrade rise in temperature. Okay, these two figures are important and one should remember this.

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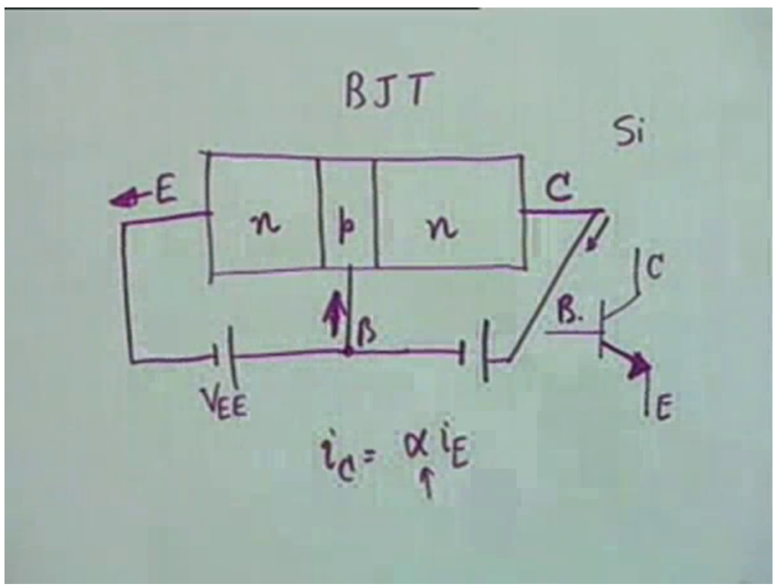

In a few minute that is left let me remind you of the physical phenomenon that occurs in a BJT very briefly. As you know a BJT's Bipolar Junction Transistors has two junctions and to be specific an npn transistors two junctions that is it is just opposition of two diode, np and pn alright. However these are metallurgical junction, these are not simply that a material is brought and placed close to each other. One is, the P type material is diffused in another words N type material. The details of fabrication shall be dealt with in another course. Which you will get in 3 year or 4 year, this is IC technology. And also the details of devices will be available in another course an (())(30:44) physical electronics. So we will not go into those, what we are interested in is in discussing electronics circuit analog electronics circuit.

We have to understand a little bit of the physics to be able to get a circuit model and that's where we shall leave it. For example in diode we got the circuit model the DC circuit model along with the incremental resistance piecewise linear. Now here we are taking an npn because npn is more commonly used than pnp. And also the material that is used is silicon okay. So we take a silicon npn transistor and we denote the terminals as E B and C Emitter Base and Collector. There are 3 terminals and as you know the symbol for this transistors is this. Now do you know the significance of this arrow? This is the actual direction of current into the emitter.

For example the emitter base junction will have to be forward biased that is we shall have a negative here and a positive here, we call this a V E E a battery has be connected a power supply has to be connected so that the emitter base junction is forward bias forward bias mean P should be connected to plus supply and N should be connected to the negative supply. Then what happens to the current, the current naturally comes like this. Okay, it comes like this and then goes from the battery. I am sorry it goes like this, it goes up from the base. The current the current is the conventionally the direction of motion of positive charges okay, electrons move in the opposite direction. So current goes like this through the p it goes to n and to the emitter terminal it comes out and this is what is indicated by this arrow.

If it's a pnp then the arrow should be pointed inwards okay. This is a popular question that one asks in interviews for example. Why is a symbol for a transistors like this? What is the significance of the arrow? Why in an NPN it points outwards wherein in PNP it points inwards okay. And then the collector junction is usually reversed bias, that is N shall be positive and P shall be negative okay. This is the connection of a Bipolar Junction Transistor. And what actually happens is that the minority carriers over here. I am sorry the majority carriers they are electrons okay, electrons since the current flows in this direction the electrons go in the opposite direction. So electrons are injected into the P type region through the base.

What happens is these electrons then meet some holes here, so some of them recombine. And this recombination comes as a base current. We will see a little later in the next time. But some of electrons recombine, the base region is so thin that there is very little time to recombine. The electrons are in a hurry to cross the base. After they cross they come into the collector region. And in the collector region they are majority carriers, isn’t it right because this is also n and because there is a positive potential here, they are attracted by the collector. Even though the collector base junction is reverse biased because of injection because of the flood coming in, it cannot obstruct the flood, it let's the flood in. The flood of electrons. So the electrons are collected by the collector and that constitutes the collector current.

And therefore the total emitter current total emitter current is there was no recombination here and if all electrons were injected, all electrons emitted by the emitter. If they are all collected by the collector the two currents would have been identical isn’t it right? i E and i C would have been identical but it is not so because of recombination and because the total emitter current is not just electron current, it is electron current plus hole current. And therefore the i C is usually less than i E and the proportionality constant is denoted by Alpha i E and Alpha is very nearly equal to unity but not quite, it is not exactly unity. We are at the end of our time so we will continue this next time.