Analog Circuits
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Lecture – 03
BJT Small Signal Model

So, if you are here we will start so this is the book as I keep repeating I am one of the co-authors they are now okay we have been discussing yesterday about the bipolar transistors, we shall continue with that I think something we started with a typical BJT.

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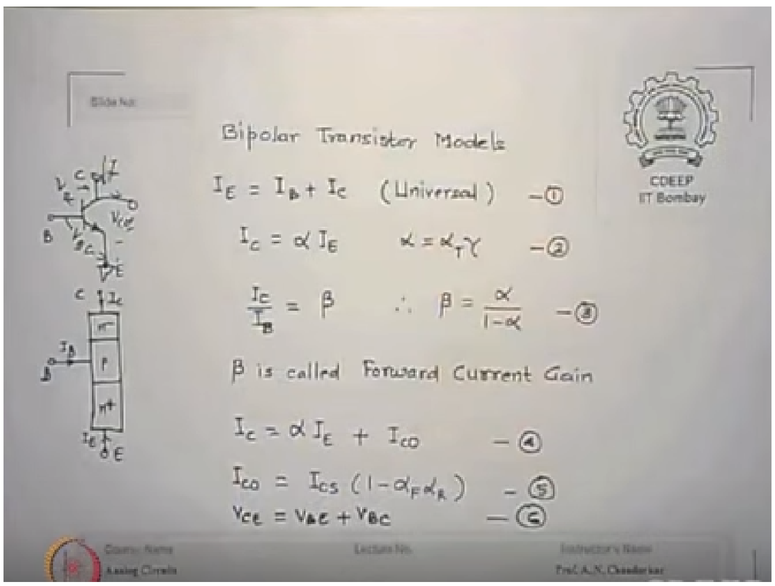

So there are basic equations we load last time and very important for us that the emitter current is always sum of base current and collector current and this is stems from the physics that whatever is inductive from the emitter side partly recombine from the base and the rest goes to collector and because of that base current +collector current must be equal to the emitter current we also said that the collector current.

If you are in the active region of the transistor active means where the base emitter Junction is forward biased at least > 0.65 volts and the base collector Junction is reverse biased sufficiently enough then we say you are in a active mode of a transistor okay and in that mode we say IC=alpha x IE or essentially IC=beta x IB this is the law only followed when the transistor in active mode if transistor is cutoff mode.

When the both junctions are reverse biased then none of the curved junctions are conducting or reverse currents are only flowing you may say transistor is in off stage. If base emitter Junction is not conducting and base collector Junction is also reverse bias re base emitter Junction is forward bias with base collector Junction is also building forward bias then both collector will emit as well as emitter will emit carriers in the base.

There will be a huge base current converter is saying that the huge base current the transistor with entered saturation is that clear that the theory which we learnt earlier hopefully so so in our analog codes will new neither work on cut offs nor work on saturate states we will see saturation in limit for us so we will see only work in normal active normal mode or active mode when base collector Junction is reverse bias base emitter Junction is forward biased.

So all of our analog theory assumes that if not we will tell you what has happened otherwise and let me say in case you are more interested in plates, there is a leakage current coming from IC and everything so ICO is the current so essentially what it says even if emitter Junction is switched off that is VBe on negative then the base collector current can still flow through base and collector Junction and therefore that is the ICO okay.

That is exactly what that decays currently the one so more accuracy can be built in case but in circuits let us look at situation something like this unless said otherwise the typical currents will be millions and typical reverse saturation current will be in sequence so adding something tens of amps billions amps to it few nano amps a few amps numerically does not matter okay.

That is how physics wise if you say you get out in or something some will shout at how can it happen and so it will never work them so that is not our idea where will number and therefore to some extent we will /pass such a certain values in case but in case your IC is very small then are all very small when it just starts on yeah those that current may add actually, so let us K take a case unless that otherwise you will neglect small currents, but you may write then neglect saying oh.

I cannot add so in my circuit we normally do not believe too much these numbers are great you also said although that the collector emitter Junction or collector emitter voltage from one node collector to emitter difference is always equal to because at one node there cannot be 2 voltages so if you go through this slope or you go through this loop so Vbe +VBC must be equal to VC at any cost.

Now that is exactly we will see when the saturation start something VC must go down so that VB and VBC must go opposite that is why both Junction get forward bias therefore VBe VBC will become opposite subtract out of VBE or opposite this and VC will follow otherwise will always add otherwise VBC+ VBC this will always add to get VC, so VCB is 2 point some volt VB is 0.7 volts.

So VC will be 2 point and volts that layer in normal active mode these 2 voltages VBE and VBC always add to make your VC is that clear normal active so this is something we said last time we go ahead and we did something more also we also showed you some figure.

We are interested in small signals we said okay this the model so far we talked are called large signal models the device is swinging in inputs too high and some x may not reach into it may enter saturation so we must take care and we say our symbolization is capitalized I small b= equal to Ib + IV, which essentially says the total base current =AC current base current+ DC base current and similarly for all similarly we can also write for voltages for example I may write maybe sorry.

I may write Vbe=VBE +Vbc that is the total base emitter voltage is DC emitter the base emitter voltage +AC emitter base voltage so you can always say that the DC part +the AC part is equal to the total color and that is our symbolization nothing very great nothing just to say how do we take numbers or how do we express things we also said if I plot the output characteristic IC versus VC for a bipolar transistor for different base currents the slope of this characteristics is such each for each IB.

If we extrapolate them on the - VCX is right now all of us are talking only of NPN transistors the polarities will change just opposite of that if we talk of PNP transistor so normally PNP is will not be used as compared to anything why anyone okay you said it, but if I say you are wrong or at least on face you are wrong why do I say the reason why is show the current in a semiconductor is there are 2 kinds of current transport we are discussed I hope so one is called the drift current.

The other is called the diffusion current the drift current is velocity proportional to velocity that is mu e so current is proportional to electric field and the mobility availability, but in the case of bipolar transistor the transport is diffusion limited you are injecting the majority carriers from emitter into a minority they become minority in the base because that is opposite polarity electrons become minority in the base is that clear to you and they diffuse you do not drift there they actually diffuse.

So there is no drift part their mobility should not come into picture it is the diffusion term we should come but you are not wrong why I say, but in case you should not say so okay it is the diffusion limit limited term which is gradient proportional how the gradient it creates J is proportional to DN/D X or D and Delta if you are seeing a dimension so essentially DN turn / Einstein relation is related to KT/Q into mu okay.

Since D is proportional to mu you are not wrong but essentially that is not correct because it says it is proportional to the current day's diffusion limited and not written so you should always say that is the diffusion limited current the gradients are such that it always will dominate you are very large emitter source here and you are very few will approach the other side in the base p type NPN is that correct.

So the QR the huge gradient the current flows is that correct so you are right to some extend that DN a larger compared to DTS and then also the gradients normally because of the available dopings of nnp in actual technology and channel or NPN currents will be larger for the same area same biasing compared to PM. your statement of it was not wrong my because fortunately D is proportional / Einstein relation to mu but otherwise the phenomena wise is not correct okay.

So to say okay, so normally NPN transistor will be preferred as far as we are concerned for because same area same everything I will get larger current from the same everything so clearly now it's not the other prophets that is what we are looking at however I limited for you to think later maybe at the some way I may ask you please PNP transistors are never out many circuits still need appeal why there must be something in PNP.

Which makes it first choice come for again 99 cases amplifying cases everywhere will use ambience but certainly some circuits some blocks are they never put a PNP why do they say think of it if you cannot find in a bowl if you cannot get to your friends and find you come to me someday I will tell you why but otherwise NPN should be normally used okay.

So will not discuss too much about PNP not that is bad device because of advantages even fabrication I may tell and pins are much easier to fabricate compared to PNP compared I do not mean very large difference in terms so those are all characteristics upper impedance and the book if you extrapolate all of them they end up in a single point and that would be we call it early voltage and this is essentially telling that the base emitter Junction or sorry.

Base width is getting punched depletion layer from base collector Junction touches the base in internet and short circuit can occur that is the ugly mood that is why current is infinite in fact okay but thin the device will become infinite we will actually shut it off there is a limiter as we say therefore no current okay this is what I think I did let us do now what is our actual work for the day we are interested in small signals.

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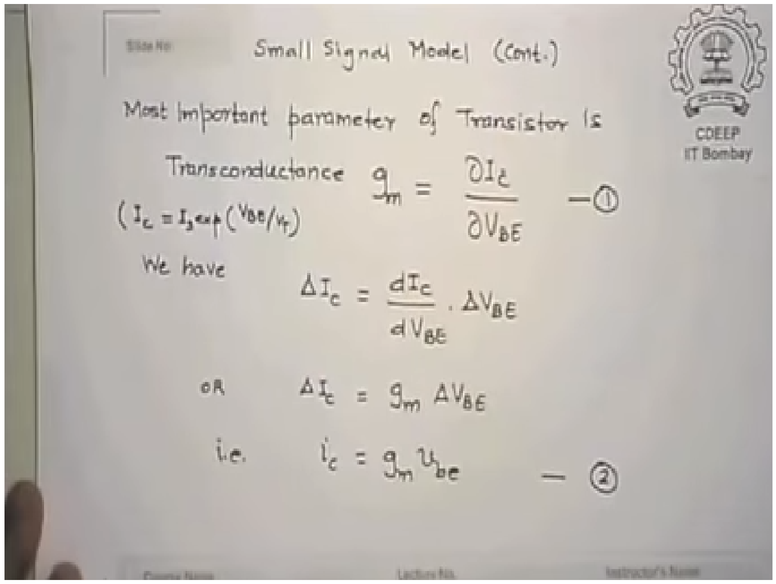

I keep on yelling you why because the slope of V0V in characteristic what did I say it falls sharply what is DV0/DV n in your opinionDV0/DVN what is it neuron think only V0Vn this is a device I am putting Vin getting V0 / being essentially a gain if I feel normal transfer characteristics of a and mass of CMOS or bipolar transistors inverters or amplifiers only in this region of VN you have large DV0/DVn.

That is gain is only available in a small range of inputs this side gave me B0 this side also gave may B0 is that correct so we cannot use an amplifier in regions where there is no gain then why call it amplifier and therefore also we must operate within this range of DC values and therefore signal should not exceed either side of let us say if I bias here.

The signal which I put here should not cross these 2 points any day because otherwise you will get into gain 0 kind of say all much lower gain and those points therefore the amplifier will not act like a good amp is that clear so small signal is not that I want to adore I cannot do better and therefore that is the limit which I will always try to follow.

However all said and done it is fine we would like to see what parameters we shall be using in our circuit the first and the foremost parameter someone said wrongfully but now it is correct is the tranconductance. Tranconductance would say current divided / voltage is the conductance what is in the output of our transistor collector color what is the input of a transistor base emitter voltage there where the signal is going to be applied.

So what do we say changing collector current for the change in date emitter voltage is called tranconductance okay is that for VB is related to IB also how is e to the power of Q will be / NKT this is a diode so VB is related to IB directly or in a diode and therefore we need not of current we should talk about base emitter voltages as our inputs where signals will be actually applied with this is that okay.

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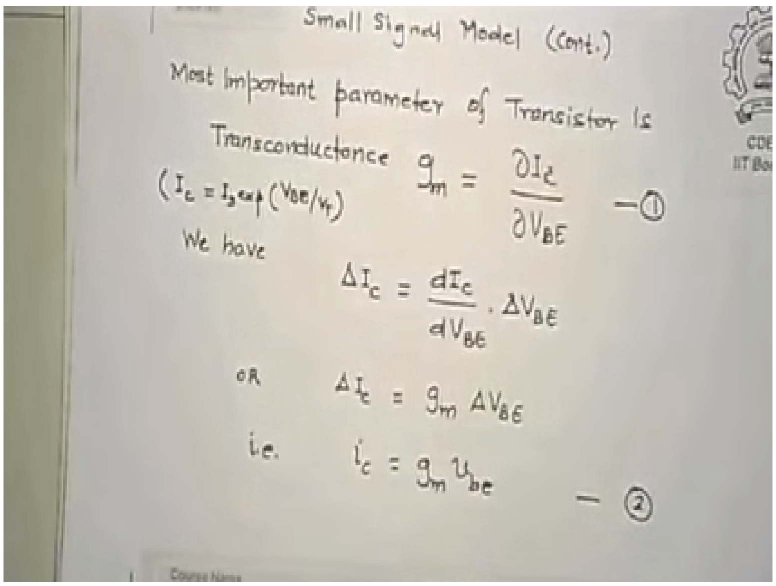

So because of that we say change in collector current to the change in base emitter voltage is gm if I take Delta G of this I can write Delta IC as DIC/DVB x del this is partial equation simple right change in IC to the change in VV will be DVDI/DV this is how we write partial terms or Delta IC this is gm x delta VBE.

So we say Delta s is one change in IC is what the AC current total current is DC+8 if I sat a DC part for what is change is the AC part we say Delta capital Delta IC is nothing but AC components we say far IC see small ic is gm x vbe this is a very important relationship for us what is it trying to tell okay we may draw a little figure here I do not know I am a left hander and it becomes difficult for me to keep doing like this.

So if this is where this Junction this is your emitter values this is your collector x browning this voltage here AC voltage here is VB okay so if I see the collector here it is G and x is that okay so the collector current which I will see at the output side is essentially gm x x the input signal at the base emitter side is that correct this is what amplifier is going to do now if this IC current first were registered IC x that our RL will be the output voltage the correct so far apply a resistance here which is load then the V0 is essentially - IC well okay.

Why because our current is gmvb is opposite sign so it is - ICRC but IC is proportional to IB through what term IC and IV they are related / what term beta so I can write V0-V0ib xRL okay now I can say what is VBE then what is the input value say I also know oh sorry RL okay V-0 is ICRL and VB let us say put a small resistance here so IB xRI=Vbe let us say there is a resistance here RI so RI x IB=vbe.

So if I substitute here I can get V-0/BBE=-beta 0RL / that okay just substitute IB from here and collect the terms is that correct and what is V-0/VB gain AC gain AC is correct a CD so transistor has amplified your input voltage to output voltage V-0 and can be evaluated if I know the beta of it honester I know the load a hassle if I know my input resistance is that clear is that clear so if I choose R >RI and if my beta is large in a 50, 100, 200 and I am certainly going to get sufficient gain from this amp is that correct.

So a small signal of the value of micro volt or millivolts can get into at least few words they should not be greater than power supply but at least few words and that is what amplification I can of course you say proportional to RL/RI the whole circuit theory which will now apply is to get to use to this how do I adjust this RL/RI to get different kinds of amplifier this is all that I do so basic circuit will remain is this.

I have a built in emitter input signal and I will get output current this is my basic thing because that is what I believe transistor tells me this is what I am going to use in my circuit analysis why do I want to do all these circuit equivalence of that because in real life if I am really solving equations and I write I is equal to is E to the power QV/NKT and if I write this kind of nonlinear equations or transmittal equations are difficult to solve analytically numerically maybe yes and I wrote an even emigrated a long time to solve so we say okay.

Why do you want to do this anywhere look at a small signal so we will put an equivalent of something there which represents the actual currents anyway is that clear so all that we are doing is putting an equivalent of what physics is telling in our so that circuit can be easily solid which equations will use in circuits Kirchhoff's laws maybe 2 more eminence and Norton's equivalents and nothing more than that is needed to solve any of the circuit.

In this case of course I will give you some hints one is called the hint without solving you can give the there are methods called observation oh this must have this now they accurate but that would be sufficient to tell me okay it has again or it has something so much so how to choose that and how to get that values can be found but generally circuit is very simple wonder how many loops you have one loop here and one loop here very simple to solve or 2 nodes.

Whatever we if you want a nodal equation solver or you want the current mesh equation problem you can solve either B is that clear so 4 equations are all that we need to do analog circuit analysis to shove laws and to one of the evidence equivalent theorem and not insecure nothing more and nothing less so there is one more theorem have you done any course in network so far ok good which is tell against theorem so some other day when it will come to you why was so great okay.

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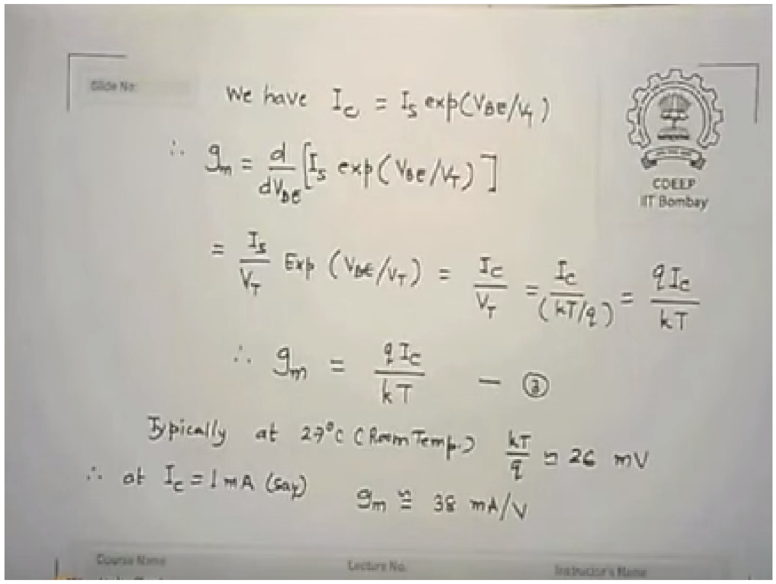

Thus now I said I see the collector current is equal to is some proportion AE to the power VV/VT this is from the theory of it understand so if I if I want to have a definition of gm I know DIC just now I wrote an equation of gm Delta V/delta VBE so I do this I'd appreciate this equation okay that is what I said soil differentiate and if I differentiate this and Is/VT exponential VBE/ VT.

This is again I see current so it is IC/VT about ever this VT will long onwards that is why I wrote ahead VT is thermal voltage and since few minutes after we are going for MOSFET there VT the turn on voltage are very important for a threshold voltage so we say okay onwards maybe use KT/Q okay.

So it is IC upon KT/Q so QIC/KT so do you find something interesting on the left side gm is what parameter is your DC AC Delta s on the right IC/KT IC the DC current is that correct IC is the DCK so are you not thinking that the DC current where the transistor is going to be biased is going to decide the case parameter tranconductance is that point here.

This is the most important fact we must know the DC that is why I say biasing word I said the capital IC is going to decide the AC tranconductance of the term amplifier okay and that is most important for us so if I say I am biasing the circuit for a 1 milliamp DC current am I not directly give you gm if I say temperature at which we are if we do not specify any temperature 300 degree Kelvin is what we assume otherwise in some words may use 25 degree centigrade from you 27 degree centigrade.

So assume that normally calculations can be performed to 300 degrees Kelvin typically 27 degree centigrade, but I am using 25 degree centigrade then KT/Q will be 26 millivolts if you are using 3 are no get are 27 degree may slightly 26 point something okay so ever we may use KT / Q use 26 millivolt which as a number is not even if you decide to use KT/Q is 25 milli volts or 2010 / 25.8 circuits these numbers do not matter very much at the end of the day okay.

So I understand it is roughly 26 milli volt is what KT/Q are you going to use let us hope I see is 1 million Bashar Bhai Singh, then the gm is around gm must not be given I must not be without units it almost always be specified as amps / volts okay.

Can you tell me gain should be specified the voltage gain should be specified / half V-0 / being how should I specify this number a be world / volt is that clear please right world / volt exactly why we say so because I am going to give you 4 gains later okay some may be bold / IV/I some I/V/I so I want to be very clear to people that I must specify the units of gain V/B or whatever way.

I am doing I must specify this unit wise may say V/V is no because L same unit but we must write in analog circuit even if it is both sides same units that layer this is some symbolization for correct thinking so this is the typical gm which I am going to get 38 milli.amp per volt this is the transconductance how will it increase or decrease only one expression it early enough either the biasing current increases or the temperature increases offer declared nature decreases okay.

So please take it that these are therefore very difficult to ICFL I will control but IC is limited what just to care what is the ba/ started IC=beta ID so if I keep increasing IBIC will start increasing because VT a x, but I said do not increase too much but what is the reason I said it may be 8 saturation and then there is no amplification both junctions get forward biased okay therefore ic will need some maximum is that correct.

So you cannot go beyond that you cannot reduce temperature to liquid nitrogen or liquid helium how can you operate you core will not feel the device anytime okay you and your wires may not be function at liquid I mean liquid helium temperatures because the conductivity of you may not be remain at 0 may be infinite also nano it may become otherwise in some materials so one cannot operate circuits in a core in specific areas in satellite we do cooling as well as whenever we need but normally circuits will be open okay.

Therefore we should not we cannot play too much on the temper in the contrary we may have one is the core temperature will keep rising and because temperature is rising your gm will start following that means gain will start falling and that is my major worry okay so I must control my temperature as much as possible is that clear that is the worry which we will use okay okay coming back to okay.

So this expression you have written QIC/KC there are certain limitation which I own anyway I already said but I am a repeatedly little more detail me I already said calculation (FL: From 27:41 to 27:42) Isabella cello saturation level, where are we you know like this transfer characteristics we may not be here we may be here also again is less because slope is much smaller here the slope is larger.

So now we are in a smaller this and we are moving other side now okay now here is the case if I add if I add a input AC signal along with the DC what is it is superimposed or modulated I add an AC signal over a given DC well that in my hand I effects may be wherever I want then add a signal over it in the input side this is an NPN transistor so I believe if I change VBe the actual VBe will be VBe+VE in because we are added input signal to the DC value of VBe then the collector current total will be is exponential DC+AC/KT right.

Now my assumption is that n factor is 1 therefore in real life the diode ideality factor also comes but right now show main is 1 and someone should engage without the harm inv of that, but we have my circuit mess up cello okay so if I say this is the total current and if I take the DC it is I=IS exponential VBE/VT no way near it.

So this is DC this is total so what is AC part in that so this total part is therefore IC x Vin just substitute here so you get total IC=DCIC x exponential VN/VT is that okay this term substitute in this okay so you get IC which is this term is exponential QVB/KT is IC the remainder term is exponential Vin/VT exponential you can always e to the power A+ x e to the power B is A+B is that correct the formula which I use is exponential.

So I get I see exponential VN/VT and here is that condition which are say other condition why small signals are required this is exponential term VN/VT let us say Vin < VT okay input signal is < 26 milli volts is that correct Vin < VTI expand this exponential function what is the virtue initial function is expanded+1 over factorial 3 x cube and so on and so forth so if I expand this term I get 1+Vin/VT half BN/VT square +I pro tyramine 6 1/6 VN/VTQ+1.

So forth higher terms is that clear to you is that clear what do I say I just expanded this exponential function in the series form okay if you now say and we also know the small AC current is total is I I seek - TCI C, so you see from here if I subscribe this IC-IC1+1 will cancel 1 will go away because IC will subtract.

So if I do that I get IC=IC/VT x VL +half IC/VT square wins square+1/6 IC/VG cubed V in cube and so on and so exactly AC current how many x I am getting first is the major term which is first order term this is second order term the third order term and their way in order terms if we in this now you can see if your way in is closer to VT but what does that mean or larger than VT the second order third order terms will start increasing or even dominating is that correct is that point clear.

So now you are trying to say that if that happens the gain should really increase because you are getting more and more terms out of it but really what will happen gain will finally go to 0 okay so what is the condition that this only term it comes to our requirement which is called the fundamental term Vin should be very small compared to VT then these 2 terms and all higher order terms can be if Vin/VT is smaller much smaller than 1.

Then we can say the second order third order in earth order terms are negligible is that clear is that clear if that happens IC=IC/VT xVN then the gm is IC/V and therefore is to IC/KT and if you want therefore this gm equivalent circuit to stand which we did earlier condition is what is the condition on input signal it should be smaller or much smaller than 26 mini boards is that clear to about 21 is from the transfer calculation.

You will get harmonics out even without that I say normal thinking I can prove that I cannot exceed too many because remember V will be sine omega T okay sine square Omega T means for madam a Omega 1+Omega Omega- third other terms will start appear is that correct, so you must understand in this there is only one Omega T term going on which is called fundamental.

I have a signal at one frequency and I want output also at the same frequency if the power or energy is given to other harmonics I will not get enough power for my fundamental, so my amplification will become lower and lower and is that clear to you so the second and third yes because the biasing is such done that we always remain in that that is exactly what it that is why I say biasing word is very good.

That is what why we are going which I want to work the circuit quicker but I want to make you clear that why I actually restrict myself every time so this is only a few lectures I am taking for you modelling so then you know why I cannot do more or less than this is what is only possible for me is that here so those limitations is only I am trying to compare if are the out of the ranges what we say will happen and physically.

What can happen is I may actually get into power and inner energy into other frequency terms which I do not want is that correct there is a greater power so much if I do 80% to other harmonics I am get 20% so I must restrict that is that that is the idea very good so in that small similar word is clear why small signal why another people do not want to talk too much about large signals is that okay that okay.

So this is only to prove my points that why I do something, which I say okay yes normal because the output which you will put will have some are 2 time constants so it will only address to those

4 it means one frequency one are see the time that is frequency so at a given base it will only respond to a frequency okay.

If what you are saying is not very absurd or not if I can tune those other harmonics that is what we say your power can be pumped back but then you require additional hardware to do that which is what in micro as we do the higher armored terms we actually convert back to fundamental but there is a huge circuitry to do that okay so we lose power in converting back okay that is the idea but that is doable you are right okay.

Let us look into the other things of the BJT so far we looked into only one parameter which one gm which is our major parameter so we say okay pile of curriculum a big goose rotten koala feminine of now in a locally a bandwidth is that bandwidth is something to relate with some output gain or gain of this amplifier remains constant in certain frequencies okay.

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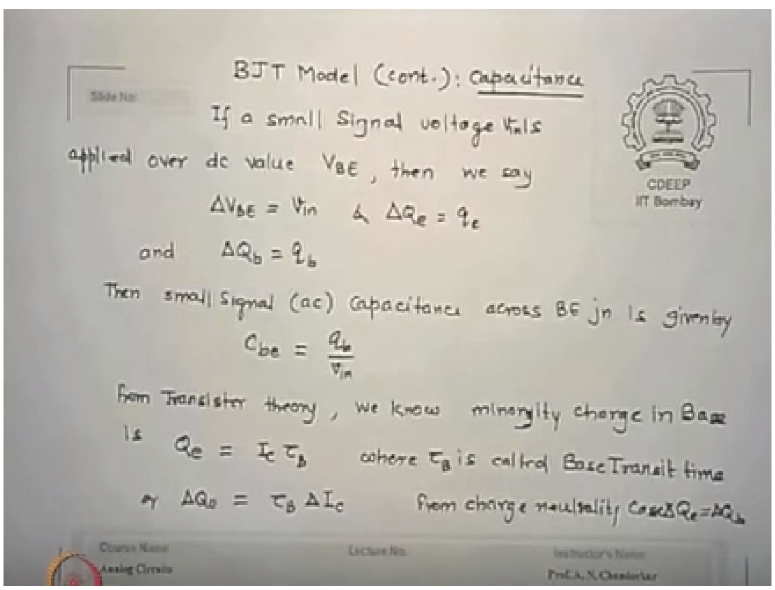

You are looking for no frequency this one whenever I gave just now I said to him frequency word comes and constants are associate is that correct 1 upon RC2/RCS time frequency so whenever I say frequency I am looking for are T terms okay so now I must look onto to vote on gm of course is the trans conduct as well as CS because I am now looking for bandwidth gm know gm will really help me out there okay.

But I also want bandwidth so I want to know how will I control that or do I go in a small signal grain is applied as the circuit I showed you here then we say delta VBE is small again repeating is VN delta similarly the charge which electrons will inject emitter charge QV changing emitter charge is small QE similarly is change in base charge a small qb but charge neutrality in transistor in steady state.

What do they say the change in base charge should be same in emitter charge in gather what injected cannot remain can increase the entirety must hold so after we may say small q=qe because neutrality has to hold okay, but right I am giving separate names finalized okay screen okay but to make a point I am separated because in real physics.

If you are done it they will say the best cannot increase the concentration electrons and empathy must be combined because otherwise charge mentality will be violated is that correct that term is valid here also but just to make a point I am not change so we define a capacitance which is related to base emitter Junction and that is given by the change in base charge/input voltage Q=CV no bare things still seven standard physics Q=CIN.

I do not know because of this thick marking system there obviously are many problems in this charge and capacitance Gauss's law you know point to point at least in a ruler J in our x there are huge problems in electrostatics I do not know how much part now in your viewer James what is the purpose in your G to get 8000 people earlier used to reject one foreign and only so 6,7600 must go so for our ejection system final before a selection system good.

Now we say that change in emitter charge is nothing but the current x time or Q/T is current is that correct charge / time is current so emitter current which is received at the collector side through a transit time which is called based on the time remember electrons are injected at base emitter Junction transit through the base are collected.

So there is a finite time which we say based on the time transit time please sir it is not minority carrier than what is it called transit time taken from here to here based on the time so whatever received is collector current so collector current be based on the time must be the charge injected from the capital side.

So similarly we can also say Delta QEB x Delta Y is the Delta I am adding I want to make AC part in that as soon as I add Delta I get an AC value so Delta Q=tau B x delta IC, please remember I said right now here Delta Q= Delta QV why I said so charge neutrality will always be held so we are interested to know this CB what are we trying to do we want to now show your equivalent circuit.

So any component which will change my bandwidth of the gain I must find so this is first thing after gm I want to see the capacitance system so Delta Q is tau V x Delta IC that okay is that okay you just say otherwise I will wait till you write Delta QE is tau B x delta T now this tau V and devices is Watts anyone remember device theory last semester we related to what (FL: From 41:12 to 41:13) the Milano mania you just think of it.

This is my base they should yah CI a-- halogen a time n k SP depend base weight larger the base with larger the transit x followed the base with smaller is it on the time is that correct is that current so obviously tow b must be related to base width okay is that okay since I say delta q is same as delta V so delta q=delta qv is Delta ie tau dr cube is ic x tau V and therefore, the PvE which is called / the way this CBE is called diffusion capacitance.

What is it called diffusion capacitance was called diffusion capacitance it is related to diffusion phenomena of carriers in the base is that correct so it is called diffusion capacitance it is not a junction capacitance which you have to calculate so far this only a carriers moving charge is changing any change in the charm is capacitive effect is there that is why charge changes is that q=cv.

So if charge there is a capacitance and same charge is the proportional to the voltage as I apply therefore capacitance is varying term okay so cbe is also some x called C Phi - is qIc/KT and what is tau b now WB square/2Dn WB is the base width so smaller the base word smaller is tau b smaller is tau B smaller tow cbe is between base and emitter so what will happen if cbe is smaller what will happen for the lower frequency.

What is the impedance it will offer if cb is smaller for lower frequency Omega is smaller cb is smaller impedance is very high if this impedance as seen from the input side is high what does that mean equivalent Li saying is it important or not important if input impedance across 2 terminals is very high is it is it important or not important not in parts like an open circuit it does not flow gains is that correct.

Whatever voltage you are current applying it will pass because it is like a hardhead sitting there however if Omega is higher and cbe is low higher then what will happen then this shunting effect with start short circuiting will start if Omega is larger and cbe is also larger that is the base width is long enough okay then Jaden will be very small and then whatever I will pass through this will be divided in the and in worst case.

If this is very small everything will go through is that correct no divider their currents will just go through shorts therefore is that now clear why I am interested in cbe because for my given operating signals and at frequencies I want to see whether this pathogens will have any influence or not having okay so I must know the value because if I get the value then I will say okay Omega c you may decide whether it is required or not required is that correct but I must know first what is c is that point clear.

Why I am doing this because I do not know if I otherwise if I increase my input signal frequency 200 megahertz nothing will go to the output everything is here shorted out is that correct so input is not allowing signal to get in is that correct so I want to know wait is that limitation am i reaching that that is why I want to know the value of cbe other or what is called the diffusion capacitance.

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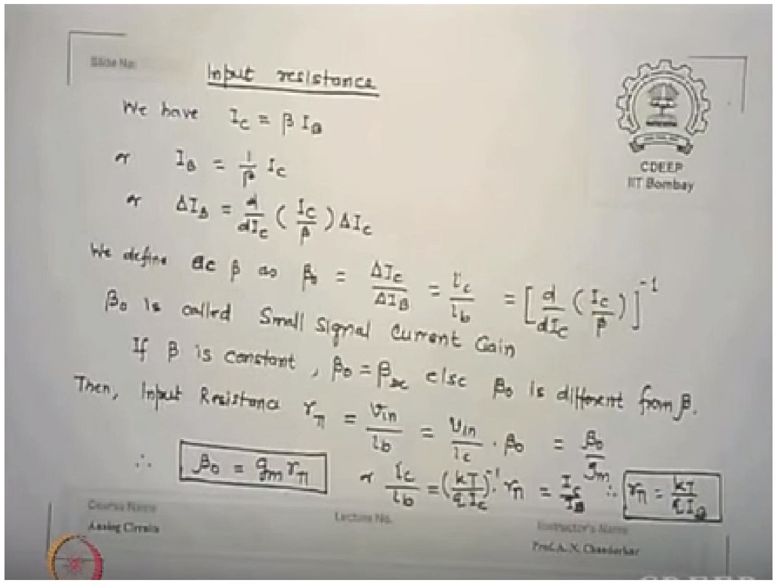

But that is not the only capacitor there you will see another one is that point clear why I am doing this okay coming back few more thing we should like we come to other capacitance but let us see the other 2 major worries about it I just now say for bandwidth what are the important terms I said R and C one of the see I saw C other fees also but let us see are quickly first I am also interested at the looking at between base emitter.

What is the resistance offered the same logic will go if the resistance is very small what will happen by same logic if this resistance is very small any signal going from here will be shortened up nothing will go out go into the circuit is that correct so what do I expect this R to be as high as possible but I may not be able to control for variety of reasons very high value then at least I must know how much is this.

So how much is the only made available to me actually that number I want to okay I do not mind it is there but how much is there at least I should know because then only I know what is I am going to get here is that clear so I must evaluate the normal input this is not external what values we are calculating simply of the transistor sitting there forever additionally externally what we will do will make more mischief for us but at least internally what is happening.

We like so we say IC=beta IB over standard active region equation IB is 1 upon beta x IB again use Delta IB so we write D/DICIC beta we define a AC beta as Delta IC/Delta Y or small

IC/small i this is called AC beta is that clear to you so far earlier what beta we define here this beta and this beta are not same that is called DC beta what is DC beta capital IC/capital IB is DC be you apply DC signal DC voltage you see what is out.

So the collector current divided / base current is dc value this is dc if I now substitute in this equation I get IC / IB which is beta 0 Delta IC but this however in this differential if beta dc beta is constant please look at the case what I am saying if DC beta is constant this beta can come out is that a differential it will not be useful then this will be 1 so what is it trying to say KC we charge equal to dc beta if beta is deceit is constant.

So in your design or in your circuit you must ensure if you are using same values of beta that beta is constant why beta can change can you tell me you are done devices now beta can change because of the 2 things this should describe but I am looking from external by alright base which is major that is the beta factor Utley it will decide alpha T okay temperature.

You are very good it also will be limited by the currents which you are passing levels of beta falls our current increases as I see start rising the beta will start falling initially as collector current Rises beta will become constant for a great time and if you further increase IC it is start falling okay because of the emitter efficiency in transfer factor defects temperature affects beta is not constant.

So where we should therefore operate in those icy regions where beta roughly remains constant you can use DC beta is same as AC beat and therefore operation of that is the DC biasing again is very very important because I do not want to always separate the CNA feeder is that clear so I am giving you why we operate only this management because otherwise we are not sure what values we are actually going to get okay.

Till that point here dc beta=ac beta as long as dc beta remains constant and that is the day we will actually make circuit to work. So that ac beta value so manufacturers gives you beta of 200 I do not have to recalculate what beta I should use in my analysis because I will see I will operate by my conditions that beta remains constant okay the next thing which we would like to know is the input resistance I mean from this we want to know actually input resistance.

What is input resistance will be input signal or AC input divided by base current there just now I showed you so it is Vin/IB but IB now can be written as IC/beta and now we talk at the beta 0 or beta DC. What are you wish because you are made sure that beta is same for both this is that here so if I substitute our B/IC/beta like this but what is mean / IC / mean just how define earlier first term first parameter gel IC/gm so it is beta 0/gm gm is related to.

What I said which/thing in dc I am connected to collector current DC collector current I know the bias current I know gm I know gm and if I am ensuring a beta DC same as beta zero. The transistor will tell me what is beta so I know my beta I know where I am operating therefore I know my gm so I also know my input resistance R Phi is that clear to you our pi is equal to beta / GL r to say this is very San Jose and relation beta is gm r phi beta is gm r phi.

This is a very good relation for always the analysis part on the search is that correct conditions why we said DCAC constant other value minute. If I now substitute gm r pi values as we did one can show from the via written here r PI nothing but KT/QIV so whatever your base current which is proportional to IC see why IC/beta LIV so if you know your base grant you also know your input resistance is that correct or if you know your bias current IC.

And you know beta which is saying IB is known you know your input resistance R/is that clear so r pi is not a constant quantity. It is variable what with what it is varying the biasing current so is that point got into all of you that bias curve no anything odd you know it will cannot be added across the junction internally how do I get inside the junction transistor under top hot needles bar terminal may a cross Kappa the bars elegant or come the other communion anything you put a parallel to this will be lesser than this is that here.

So externally under gives each Cottman package atom so I must do or again that idea exactly if I have it what do I say in a way is that during your firm yes I can do something but once I founded that is then that is the fixed value what dopings are used whatever process I go through that will be fixed for you I cannot do anything on that we take our DMM base with it a base emitter junction doping this curvy time done.

It timepiece curvier minority carrier lifetime piece crab they are sub take sodium in our division externally it is going to spoil something but that is what the limit is coming this is internal in itself creating a problem so first to say what is internal to us then equivalent circuit when we move the transistor will be replaced by all this together and then externally, we will put whatever we are actually getting in a circuit and then solve the whole of it is that point clear.

Why I am doing it I want to represent this transistor as if it is in a circuit form okay otherwise why socket a with make a model you know I cannot write IC is so much cottage something that equations I cannot write but on this is okay in circuit so I want to put everything in circuit so this is also one value which I want to know equivalent very good the second parameter to us is r0 okay.

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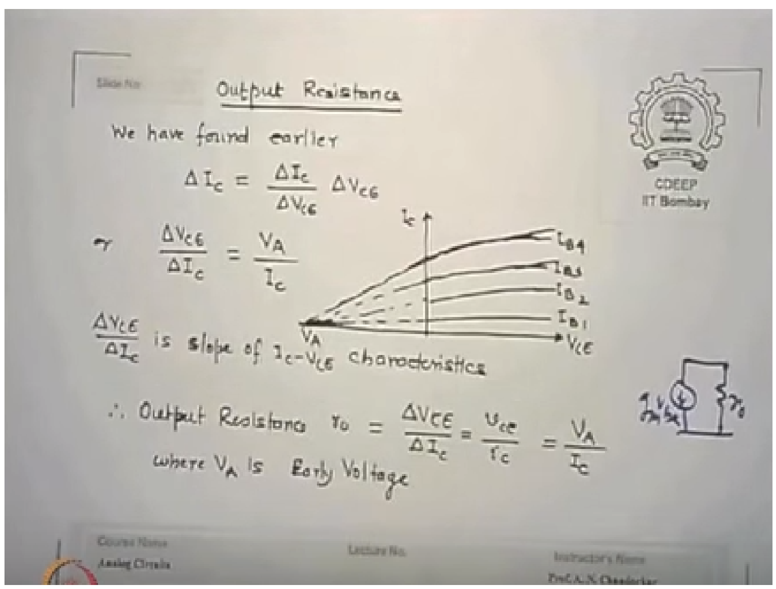

What is it output resisting input they cannot let us see at the output side what is the resistance I am saying that circuit which we did gm vbe the collector hey if you have er0 a shunt in Canoga why it will be shunting what is this guy source a guide resistance shunt ago so we want to know what is this uh but can you convert into series kind which theorem not incur on set have an image of gm x r0 worker KRG OCA equal and our binnacle effective but right now we are only the Norton's equivalent side okay.

So I want to know what is this so-called output resistance r0, so I said okay just now I do not Delta is Delta vc x Delta VCE okay Delta Ic can be written in a intercept on a Delta VCE in vector VP x Delta V no match you do not know same done man but we can always write like this but this term Delta is VC/delta T essentially is early voltage a popular tie schedule slope a barley voltages.

So VA/IC schedule slope a whoa early voltage divided by is that point clear is that one care so if I specify to you the early voltage 20 volt 50 volt and what I am saying I am biasing at this bias current of I see what I am giving you r0 value is that clear is that here if I am specifying hourly voltage this is affected transistor has our load is a 50 volt okay and if I say I am biassing at 1 million so 50/1 million my bias current.

I am actually telling what is our zero I am using okay so please remember every time which term I am connecting everything to the biasing current is that point clear everything I am connecting to / sinker and so what is important in analog circuit design or in an analysis, where you are at I see which value of IC or operating that decides everything is that okay that okay all IC is the mildew see IC is the main parameter for us to get so that we know what is the final circuit equivalent urban exactly okay.

So anytime I only voltage is given to which we will specify to you 20, 30 volt 40 volt can be 100 volts is it good or bad if it is cleaning what is the reason I said you are right larger the early voltage good for us why are zero will be larger in a current source what should be the parallel resistance preferably or ideally infinite ideal current source.

So larger the r0 you are going to get closer the good current source you are going to get is that correct and that is why we will be very keen to get larger r0 if possible other possibility may reduce IC but if I reduce ICl what I am going to reduce gm and again layout that so I am worried I cannot, to low to high is that limitation is clear to you I mean I am I have to worry everywhere.

If I want this I will do this if I want this I mean so somewhere what do I get that is why all these theories are again brought to your front is that r0 clear to VA/IC normally these values will be specified to you is that okay yes IC if the collector your bias and this any point here actually it is VR+VC small let us say your point is taken okay.

We are biting here sorry is not a straight line properly so actually this value + this value divided by this IC is the slope is that correct but what I say how much is VC will be less than power supply value few words how much will be VA 10s, 50s, 100 support so in calculation VA+VC divided by that instead you can always use VA/I is that point clear what he said probably I should have said is that here.

In reality slow pace this by this not okay this is little smaller compared to bigger value so that is much nothing more okay there is another term which transistor people keep talking is called ETA term it is not NKT kind it is a ETA in very important factor it is decided as is defined as KT/Q1 upon VA where early voltage theory we can do someday as you wish and if I substitute KT/Q please do it what is the why I write all this fun we can directly write this KT/Q.

HIC the laka a chi CU / x dia mm but this is 1 upon gm this is 1 upon r 0 so gm r0 is a figure of Merit ETA r 0 is 1 upon ETA is a figure of merit for it on this curve is that clear to you everyone gm is for a given C IC will decide gm and IC will also decide r0 is that correct therefore gm x r 0 is a figure of minute is that correct it is 1 upon ETA very important parameter in design Nordon's analysis just to show you.

How solid actually search down the steps which has smaller eaters okay that means larger gm R0 terms is that correct so when I am going to do a so called manuals of transistors and I am looking for higher gain bandwidths and I should look for answers which has higher gm r0 essentially smaller ETA values this is specified is all figure of matrix K is that point clear that here this is something some day you design a chip or circuit and you open a manual for me company you should know what you should look that is why I showed it okay.

Typically given the order of 10 to power -4, -5 large smaller the value better is gm rg, so if you use given beta values typicallyr0 values which we have got here for hourly voltage of voltage and 1 milliamp current 100 kilo means all that you are getting at Ross okay what is your preference will be at least mega okay so either you look for larger VA that means essentially look for good ETM and smaller retail that 0.004, 404, 406 kind of that is the idea behind the search.

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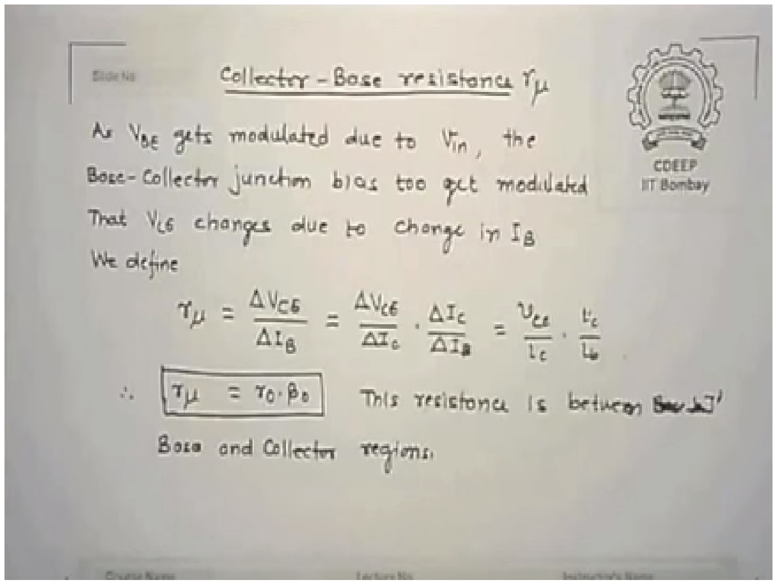

They another resistance is worrying me you know after your base collector junction is that correct in a transistor you have a base collector junction so if you see a between your base and collector there is a junction is that okay is that point clear do what I am talking about this is my base this is my emitter and this is my collector emitter collector this between these 2 terminals bill base and collector.

There is a junction there is a diode sitting there which is the normal operation diode will be in what operation mode reverse biased a reverse bias diode what is the IV characteristic universe bias typically if you see I versus V very small very small through practically saturation current is the order of Pico ions are lower so this slope is very low okay very win, if that is so if I take the Delta VC/Delta ID which is VC/IC/RB so I get R mu / same simple method r mu is beta x r0.

What are noted by collector current okay so I know this only thing are beta is how much not less than 100 normally r0 is how much we calculated just now 100 kilos loans x 100, how much it is tens of mega ohms are about so in between if this resistance r mu is greater than 10s of mega ohm will it have any influence or will not handle between 2 nodes if I short circuit that is r0 everything at the input will pass to the output if the resistance is very high.

We can say as if collector is separated from the base but it is not 0 it is not infinite resistance so there is a connection between output and input whether you like is that clear so arm you may be hundreds of mega ohms or tens of mega ohms but it exists annoyed value okay is that one here so we must know how fine it is that finite value so that is why we calculate beta 0 x r0 as your arm you where is it exists between collector terminal and base terminal base collector junction us bias will give you a higher resistance which is called r mu.

Yes just now I say it is a diode reverse bias diode capacitance character reverse bias diode main and zero bias Junction is called forward base reverse bias even at zero bias Junction is always good as bad there is a built in voltage door sitting there is that correct there is a built in voltage sitting there so the diode is given at zero bias is equal on top because there is a depletion intrinsically present that value epsilon a by depletion layer width is the capacitance epsilon A/D is capacitance.

Now the problem is if I apply larger VCB this depletion layer will increase or decrease increase that is what the reverse bias is the capacitance will decrease is that correct so we say this capacitance is function of reverse bias whatever VCB I apply okay, so I say this Junction capacitance is C j0 what is Cj0 at zero bias capacitance that is the depletion at 0 bias at the built in voltage and this V is the applied reverse bias and Phi 0 is called built-in voltage for the junction.

Which is KT/qLn NaNd/n1 square so you may say for the transistor c mu is c mu/(1-VCB/pi0 this half is not very correct why it is not every time correct device theory say if it is a stub Junction this half it is linearly graded 1/3 and 4.3 or something exponential it will be further different nine values but I show right now the way I do not, so I write n normally will be either value linearly graded exponential is always assumed linear or actually it is not error it is not a explain the function which you get there is called complementary error function okay.

We not look into math right now and for that 1.30 value is or one-third value for n is good enough so can if I am given c mu 0 I know Phi 0 I know the VCB I am applying then I can get C mu value is that here everyone this is like a diode capacitor nothing great okay, so where is that diode capacitance will sit where this diode capacitance will state it will be across r mu is that clear it will be across r mu.

So you have in between base and collector there is an rc parallel rc sitting where r mu and see does that give you some value are you into civil want frequency term or some time constant so input to output make I in a kind time relationship or yet got abusive revolt a feed-forward or feedback either say that also time or either say energy assets I know so we will want to know what is happening.

Now earlier what we thought input and output are separate now these 2 have suddenly brought were eastward or er Ito connection, so we must know how much is that but this is very large impedance so and so good fantastic CU was very small RV is very large fantastic that is ideal but if it is not then how bad it is I must know similarly you can also see there is a very seminal Junction is also.

There what emitter capacitance we calculate first CBE which was it diffusion capacity are variations but apart from that the there is a base emitter junction which is forward bias please remember base emitter junction is forward bias so if I write this standard relationship like CJ is equal to CJ zero on this am I right because here VB is not negative no VB is positive so this kind of because depletion layer actually may be very, very small or even negligible because you are forward biasing the base emitter.

So normally one does not evaluate like a reverse bias diode any capacitor I just want to show you why I did this is normal reverse bias capacitance calculations we see this will be negative this term will be positive so he will keep falling is that correct now we say we do not know exactly what is happening because depletion will build collapse smaller and smaller we do not like that Lao is not linear proportions now not even one-third not in half laws.

So we have now figured out over the experiments unless of them you can assume this CJE typically is that of CJ zero which is zero bias whatever capacity you have of that Junction twice you use it and that is good enough this is our what is it call when you do without any great physics on that empirical / lot of measurement and lot of intuitions we figure out generally twice the cj0 is sufficient for Achilles is that correct, so what will specify you CJ0, but when you write Cj you should multiply it by 2 that is the another.

So what is the input capacitors now you have you have 2 capacitances where I meet base emitter Junction what is the first one the diffusion capacitance and capacitor so the that total input capacitance is named as CV E+CG is that rate the total input capacitance aged between base and emitter is C five across this is our Phi so have we taken many effects of actual transistor on the input side regard C pi we got our pi we got r mu we got C mu.

We also got gm other side, we also got ours you so almost everyone is considered but few more things about this if you see a bipolar on this term in real life it has 4 layers and not 3 layers okay we were transistor in one substrate this is one transistor will be another trans the entrances in the same substrate so the collector is here base is here emitter is here so there is a 4 layer which is called substrate.

So it is NPN and there you need P layer or substrate layer so, but there is another Junction sitting you seated junction which is the junction collector substrate Junction is also the hole is that correct normally I will short circuit substrate, but still the reverse bias for it is that correct now that means additional capacitances even resistant but that normal is very high so at least CS must be calculate CJ elected to substrate capacitance which will follow like a diode law so diode.

So we write CJ CS is CSC Ca0, so whatever voltage between collector and substrate using that we must again calculate the capacitance head which is if this term is in 0 will it go to emitter then in common emitter circuit emitter is grounded is that correct but internal emitter is not grounded there is something else system in there.

So we say this capacitor must always be grounded and not taken to emitter is that here I just tell you what I am saying this capacitance from collector Junction must be grounded independent of whatever you because substrate is going to be grounded bias is that correct, so CCs capacitance between collector terminal and ground it is called CCs over sub capacitance the final teen resistance a guy or the scuba circuit say these are diffuse regions any semiconductor will have some resistance is that correct take a bar of a semiconductor or any material.

Where by a there is a resistance sitting there is that can Rho L/a each regions will also have some resistances of its own is that also added to it the contact resistance of metal with that layer, so there is a resistance associated emitter resistance associated with the base and resistance associated with collector these essentially are called rbb dash, and rc is that clear collector.

Why describe collector external pin to eternal collectible via resistance external emitter to internal emitter though the resistance and similarly for the base so if I use this final word for the day is this okay this is the final circuit you can see we start from the base the lower side is emitter this is external collector so this is the end of the all that we build is the equivalent circuit of a bipolar Junction transistor.

So all the terms we are derived that layer every term which are both here I explain why they are coming and what will be their values okay that here only thing you should know what I just said there is a B dash, C dash, and E dash done this is called internal emitter base collector points these are BEC are external in between there is a resistances as I shown here are BS res, rbb dash and rc okay.

So that if you that this is the equivalent otherwise actual equivalent will be have RC are the B - as well as re s that okay this equivalent circuit where ever transistor will appear in actual circuit between these terminals I will just replace this okay and then solve the case of log with external components connected here, here variability is that correct some more load some more nodes solving okay.