Introduction to Electronic Circuit
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Lecture 34
Small Signal Models
& Small Signal Amplifiers

Yes, this is the 34th lecture and we are going to talk about small signal models and small signal amplifiers. The amplifiers that we have discussed in the last few lectures namely power amplifiers they basically use very large driving signals they are large signal amplifiers and that is why we have to bother about the placement of the Q point and maximum voltage and current swings because the objective there was to obtain as much power as you can from the given amplifier.

It is non-signal amplifier that is not the consideration, the consideration is a faithfulness of the fidelity of the amplifier that is whatever wave form you put at the input the same waveform should arrive at the output also; the object is either voltage amplification or current amplification but not both. We do not want power from small signal amplifiers, what you want is large voltages and large currents.

So it is not important, the Q point placement is not as important as in power amplifier. In a power amplifier you can tolerate certain amount of distortion; in fact certain amount of distortion is a fact of life, in a small signal amplifier where the fidelity or faithfulness is more important you cannot do that. We have already introduced this small signal model in the case of a diode.

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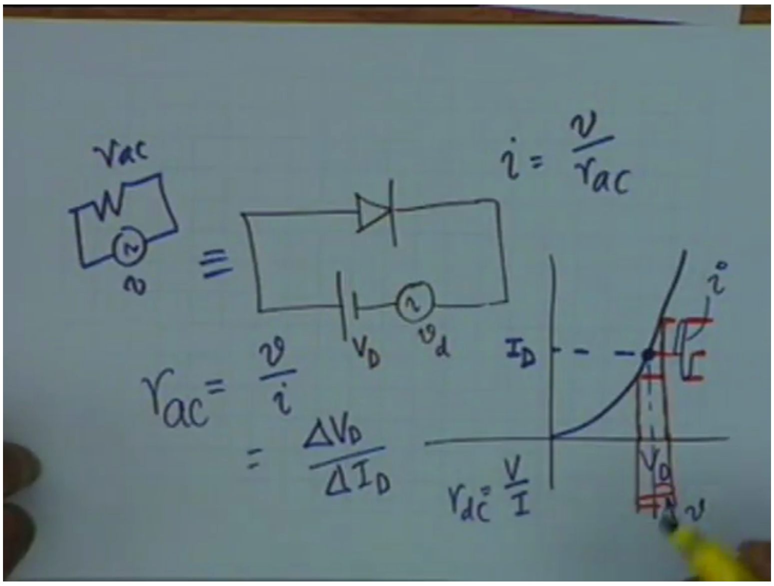

If you recall, if we have a diode which is driven by a battery in series with let say an AC source of value small v. Let us say this is V sub D, this is small v sub small d that is if the diode is being driven by a DC in series with a very small amount of AC then the Q point is obtained, first Q point is obtained by drawing characteristics and then ignoring this signal that is you find out the point at which v is equal to VD than this current capital I sub capital D, this determines the Q point the operating point and on this operating point you super impose a small signal.

Let us say this is AC then maybe the diode voltage can vary between these 2 limits, the limits drawn by the red lines, alright. Maybe the diode voltage varies like this, super imposed on a large DC where is a small voltage small v and then the current. So the diode shall also be sinusoidal and it will flow like this, alright. If you wish to find out this current i in relation to this voltage v then you know that you can work in terms of the slope of this line at the Q point.

In other words you can define that AC resistance small rac as equal to small v divided by small i which obviously is Delta VD over Delta ID incremental resistances and if it is imply that the diode is sitting at this Q point then given a signal you can always find the current i, the signal current i as v by rac. In other words this whole diode, this whole circuit can then be replaced by a simple resistance rac and a voltage v, we forget about the DC part, alright. This is called a small single model of the diode, alright.

If we imply there is a diode sitting at the Q point such that it always conducts or there is a small v it conducts. What I am doing basically is to invoke linearity; we are making a linear equivalent circuit where DC and AC can be superimpose to get the total current. The DC resistance here for example rdc is not equal to rac, it is simply equal to V by capital I which is quite different. V by capital I is quite different from rac, alright. DC resistance and AC resistance are quite different from each other.

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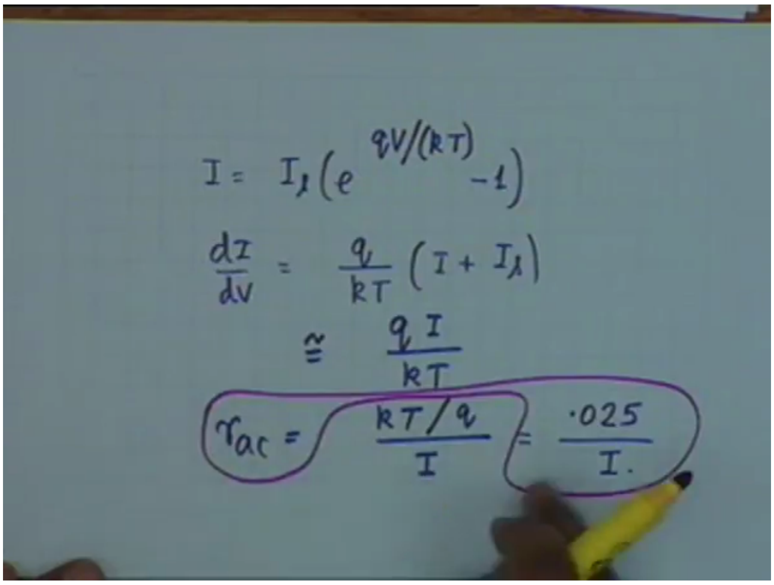

For a diode for example you know that the current is given by Is e to the power qv by kT minus 1 and from this you can find out dI dv by differentiation and if you do a bit of algebra then it simply comes out as q by kT I plus Is if you actually differentiate you can put it in this form which is approximately equal to qI by kT, alright. So that rac for the diode, would be given by kT by q divided by capital I, capital I is the DC current, DC Q point current of the diode and kT by q at room temperature you know this is 25 millivolts, so this is this will be 0.025 divided by capital I.

And this is an important relationship which you should be utilizing in transistor is also that is for a junction diode, for a junction PN junction, the dynamic resistance of the AC resistance is simply giving back 0.025 divided by the DC current in the diode, alright. It is related to these because we have found out that the slope of the current voltage characteristic depends on the current depends on the DC current, alright. This relation we shall be utilizing in the case of a transistor also.

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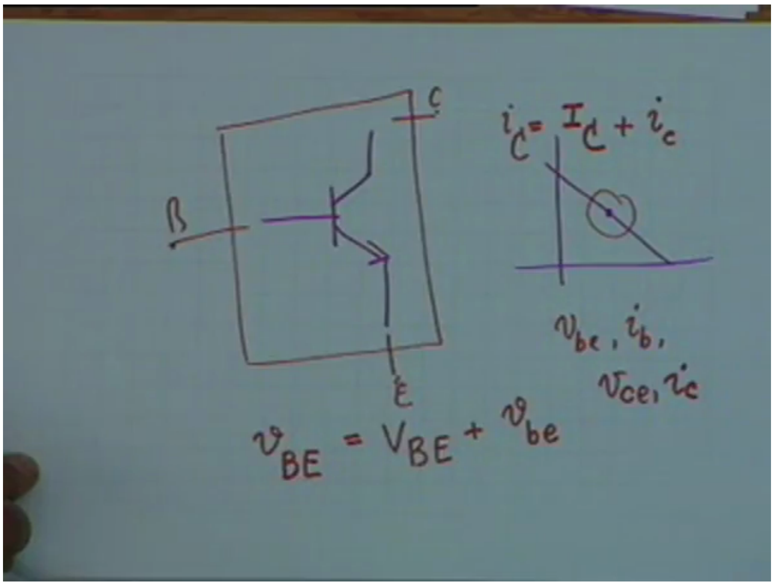

Now let us look at a transistor and for the specific lessons it a common emitter transistor while you know we have to use DC, you have to use power supply VCC, we have to use resistances to biasthe transistor properly and you know we have to determine a Q point at the middle of the load line to make maximum possible swing and all that.

Now for maximum linearity also the characteristics are maximal linear near the middle of the characteristics at the saturation point or at the end they become curb. So let say we had a Q point, now we want to operate around this Q point. We want to operate around this Q point that is at this Q point there is a certain value of IB base current we want to superimpose ain alternating current on this and find out what is the corresponding change in the collector current? And we have seen that there is current amplification, alright?

So let us say we enclose this within a box, alright. And we have 3 terminals the collector, the emitter and the base and you see this is a 3 terminal method or 2 port networks which can be characterized in various different ways, this characterization is a small signal categorisation. In other words if you are talking of let us say and this pointy the voltage between this point.

That the total voltage is small v subscript capital B capital E this notation I have explained earlier, let me repeat. The total voltage between base and emitter a small v subscript capital B capital E and this is a sum of a DC and AC, DC and an incremental value, the DC value we shall see VBE capital V sub capital B capital E plus small v subscript small b small e, alright. This is the way we are going to represent every quantity.

The collector current for example, the total collector current would be i sub C capital C this is equal to capital I sub capital C this is the DC value plus the incremental value which you shall represent by small i subscript small c this is Q for all such currents and voltages. The problem now, we know how to bias that, we know how to put the transistor at a particular we know how to choose the resistor, we know how to stabilise the bias point.

The next question is if you are concerned with small signals which do not drive the transistor to its limits, alright. That is maximum dissipation is not (()) (10:37). How do we characterize the transistor? Is there a simple way of doing it? Yes, we treat the transistor as a linear device, alright. For small signal purposes it is absolutely linear and therefore DC and AC quantity can be divorced from each other.

And therefore we recall, what we do is, we relate the voltages vbei sub small b that is the current going into the base, this is the signal current then vce that is the voltage from collector to emitter this small signal voltage and i sub c as the 2 port variables there are 2 voltages and 2 currents and you know that the any 2 port can be characterized in 6 different ways. I repeat this characterization which we are talking of for the transistor is for incremental quantities only, small signals only we are divorcing DC from the picture altogether, is that clear? Okay.

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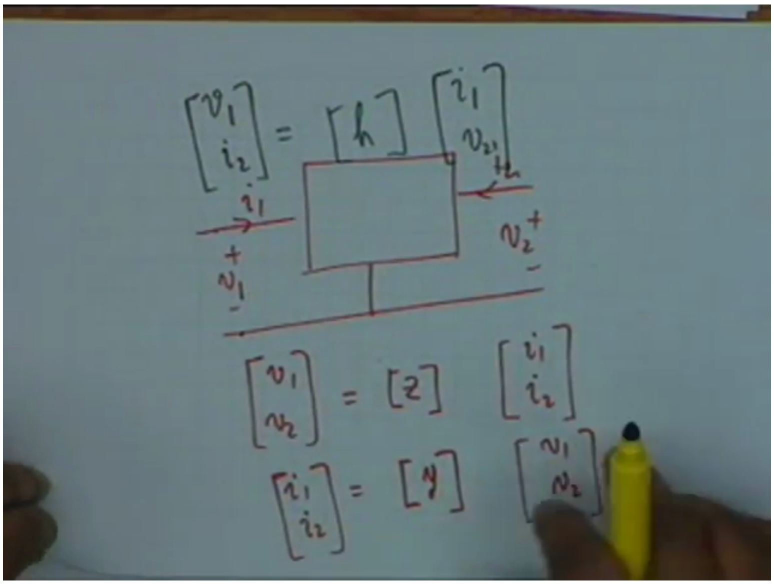

If we do that then you see any 2 port device which has 3 terminals. Well, we see this is v1 i1 in general, v2 i2 you know that we always use currents wave in v2 i2 and you know that this can be characterized in 6 different ways, if we take v1 and v2 as dependent variables and i1 and i2 as independent variables then the parameters are the so-called z parameters as(()) (12:23) circuit impedance parameters.

On the other hand if I take i1 i2 as the dependent variables and v1 v2 as independent variables then the parameters that come into effect short circuit admittance parameters or small y parameters. There is third way which is been found very effective for transistors and these are the hybrid parameters that is yourdependent parameters are v1 and i2.

Dependent parameters is a combination of one voltage and one current, the input voltage v1 and output current i2 these are expressed in terms of i1 and v2, i1 and v2 are made the independent variables and naturally the parameters shall no longer be impedance or admittance there will be a combination, is that clear? And this is where they are called hybrid. They are one of them is in impedance, one in an admittance and the other 2 as you will see a dimensional less and therefore they are represented by the h matrix, h stands for hybrid, alright. It is always the input voltage output current v1 i2 expressed in terms of i1 and v2, it is the other the (()) (13:56), alright.

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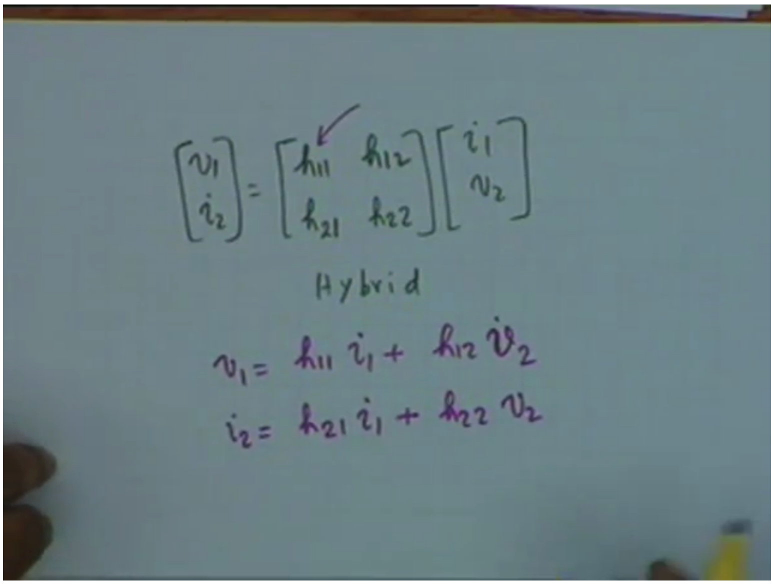

If we expand this relation, let me rewrite v1 i2 is the h parameter i1 v2 this parameters are named in the same manner that means recall h11, h12 first row first column is h11, first row second column h12, second row first column h21 and h22 and these are called hybrid parameters, hybrid, H y b r i d. You can see very clearly that h11 for example, how would you define h11? h11 is v1 divided by i1 with v2 equal to 0, alright.

If I write this specifically h11 i1 plus h12 v2, alright. I2 equal to h21 i1 plus h22 v2 then you notice that h11 is simply v1 by i1 with v2 equal to 0 which means that this is an h11 has the dimension of impedance. Similarly you can see that h22 is an admittance whereas h12, h12 is vi by v2 with i1 equal to 0 and therefore h12 is dimension less it is a voltage ratio and h21 is a current ratio and it is dimension less and therefore these are called hybrid parameters. In terms of an equivalent circuit you see that we can represent these relations.

What are these relations? v1 equal to h11 i1 plus h12 v2 and i2 equal to h21 i1 plus h22 v2, we can represent this in a very simple manner as a 2port, this voltage is v1 and this current is i1, this voltage is v2 and this current is i2 and if you notice v1 is h11 i1 and therefore I shall have a resistance here for impedance which has a value of h11, let us talk of resistive elements to start with.

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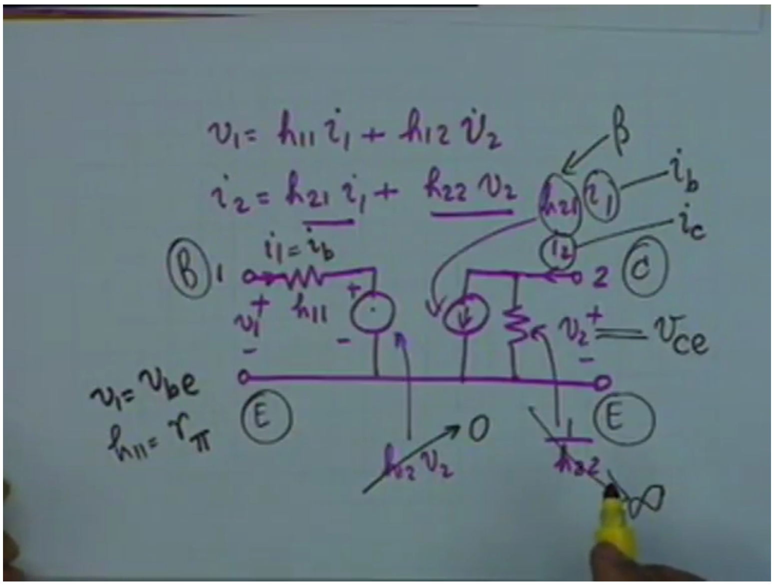

v1 is equal to h11 i1 plus we want a coupled term, coupled, v1 is now coupled to v2 the other curb voltage through a term h12 v2 and the simplest way is having voltage generator here whose value is h12 v2 what would you call this voltage generator? It is a dependent generator. This voltage depends on v2 and therefore this is a controlled source of dependent voltage source.

In a similar manner i2 has 2 components 1 is h22 v2 which means that this is v2 which means that i2 has 2 components, one flows through a resistance value 1 over h22, not h22, 1 over h22, so that h22 is its admittance. So v2 h22 is the current and the other current is h21 i1, once again can be represented by current generator, a dependent current generator. A current controlled current source this is h21 i1, alright.

Now in a transistor if the terminal one is a base, terminal 2 is a collector and the common terminal is the emitter, this is emitter then you see v1 is nothing but vbe, alright. v1 is nothing but vbe, h11, what is h11 then? It is dynamic resistance of the forward biased emitter base junction between base and emitter there is a junction, so h11 is resistance of the forward biased emitter base junction.

So h11 is represented as rpi the subscript pi shall be clear a little later. h12 is usually a very small quantity 10 to the minus 3 is a typical value and therefore we usually ignore this, alright. h12 is usually ignored similarly h22 is a very small quantity, so that this resistance is very large and therefore this resistance also, yes, should be put equal to infinity.

That is this resistance one can do without, alright. And h21 can recognize what h21 is? What is i1? i1 is simply ib the base current and therefore this i1 is ib then what is h21? It must be beta, h21 is beta, i1 is ib and i2 is i sub small c the collector current and v2 shall then be equal to vce, alright. With these simplifications therefore we get a simplify equivalent circuit of the common emitter transistor.

Note that the simplifications have been done under 2 conditions, one is that this controls source can be ignored because h12 is a small quantity, this resistance can be ignored because h22 is a small quantity, alright. h12 and h22 both tend to 0, it is only under that condition that we have an equivalent circuit just one resistance and one controlled current source, alright.

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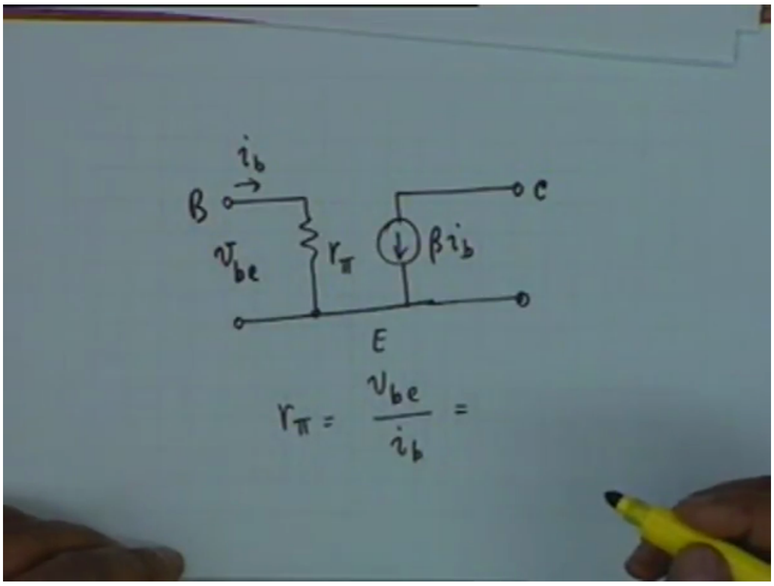

Beta ib and therefore my equivalent circuit simply becomes rpi, this is vbe, this current is i sub b and we have beta i sub b that is it. This is the collector, this is the base band this is the emitter, this is the equivalent circuit of the common emitter transistor. Well, you can find out what rpi is? rpi as I said is the dynamic resistance of the forward biased diode and therefore rpi shall be **it is** it is clear it is vbe divided by ib, alright. And you know what this is?

This is as we had already found out 0.025 divided by capital i subscript capital b where is the DC value of the base current. Usually this is written in terms of the collector current, this relationship is written in terms of collector current, so if I put i sub c here, naturally I should multiply this by beta, beta times 0.025 divided by i sub c, this is the value of rpi and you see rpi depends on the Q point, rpi depends on the collector current at the Q point, alright.

Beta of course is the, beta is h21, now this beta is slightly different from DC beta, this beta is AC beta, this beta is i sub c divided by i sub b that is it is the ratio of incremental collector current incremental base current, alright. And this beta is slightly different from the DC beta which is i sub C divide by i sub capital B for very obvious reasons. It depends on a slope the other one depends on the total quantities. Nevertheless the values are very close to each other, alright.

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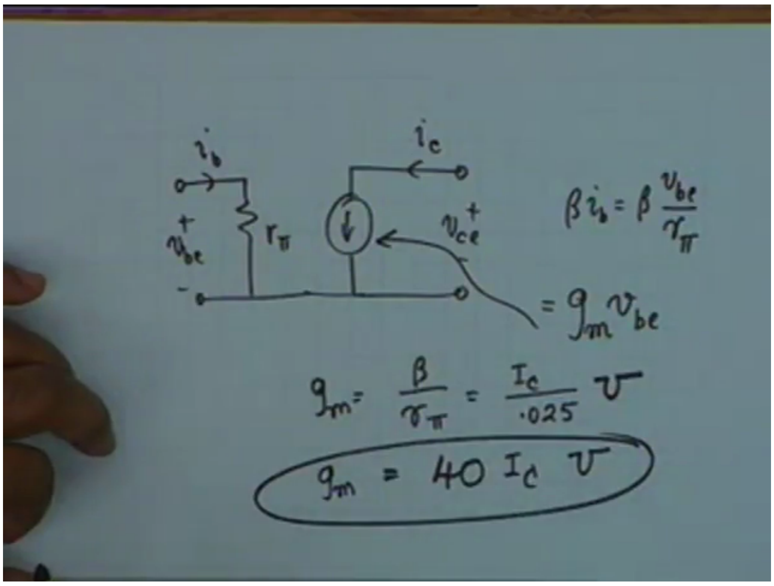

Now I want to represent this equivalent circuit it is so important that one has to draw it again and again. I want to represent this equivalent circuit in a slightly different form i sub b, v sub be and v sub ce this current generator is beta i sub b and I can write this as beta i sub b can be written as vbe divided by r pi, alright. And therefore I can write this as, what would be the dimension of beta by rpi conductance and therefore I represent it by gm. gm stands for transconductance or transfer conductance.

It is transferred because; well I represent this as gmvbe, okay. This is a current generator which can be represented by gmvbe the current here depends on the voltage here and therefore it is a transfer conductance or transconductance. The value of gm as you can see is beta by rpi and if you recall what rpi was? You simply see that this is I sub C divided by 0.025, alright and the unit is (()) (24:45). 1 by 0.025 is approx is exactly 40 therefore this is extremely nice relation for 40times I sub C (()) (24:55) and this is what is used in practice rather than rpi rather than beta.

It is convenient to use gm because it is very easy to calculate gm, it is very easy to remember that gm is simply 40 times I sub C. For example if I sub C is 2 milliampere is then gm would be 0.8 mo. Is it okay? 0.8 mo 80, no it is 0.08, 0.08 mo, alright.

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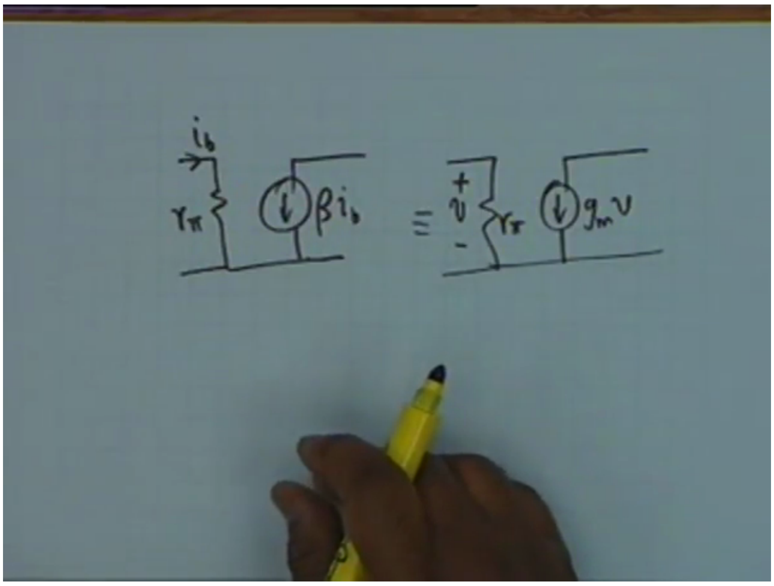

So we shall use either of these 2 circuits one is called the rpi beta circuit beta ib, this is ib equivalent second of the transistor or the same circuit represented like this, we shall use this as small v, it is vbe actually and we shall represent this as gmv this is your circuit, alright. They are absolutely equivalent to each other. Suppose now we make an amplifier, we make amplifier.

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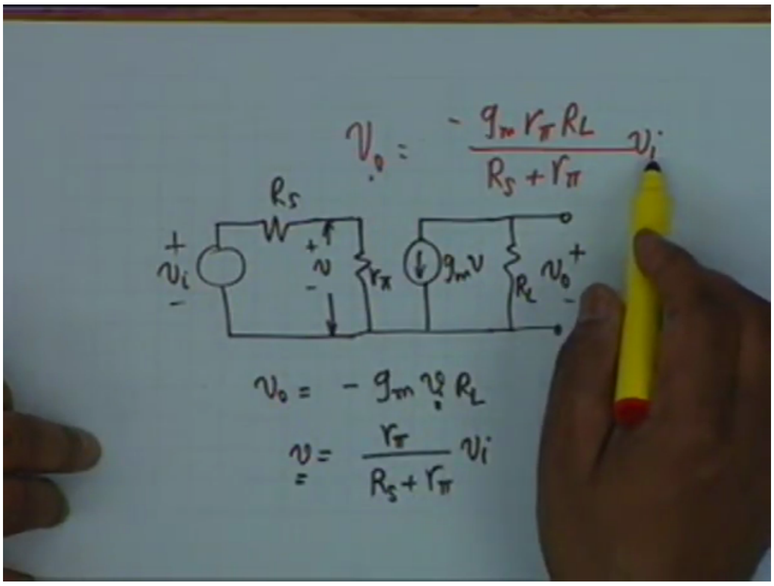

The most elementary amplifier that is we have a that is vi, perhaps we can include a source resistance Rs then of course we have the DC bias let say VBB, is the polarity correct? The base should be positive with respect to emitter, this is a PNP transistor and suppose in the collector circuit we have a load RL and the collector biasing supplier minus plus and this is VCC, this is our elementary amplifier and we want to know, what is the signal voltage across RL?

It is elementary amplifier; we wish to know what is the gain of the circuit? What is the amplification of this circuit? Alright? What we will do is, we will place this transistor and its associated DC biases by the incremental equivalent circuit and then calculate the ratio of this signal at the output to be signalled at the input and as you will see this would be extremely easy we do not have to refer to the characteristic curves at all, alright.

We shall do simply in terms of the equivalent circuit. What I do is, I divorce all the DC quantities viRs then between emitter between the base and the emitter I have simply rpi and this voltage I call v alright. Then I have g and v at the collector, what else do I have? Simply R L, alright. The load RL and this would be my output voltage v0.

Easily see that the output voltage v0 is simply minus gm v times RL, why is the negative sign? Because the current flows like this, the voltage clarity is positive and negative down, alright. So if I can find what v is? If I can relate v to vi then I shall know what is the ratio of the output voltage to the input voltage and you can see that small v is nothing but rpi divided by Rs plus rpi times vi.

So if I substitute this value of v in this relation then I get v0, let me use a different colour, v0 I get equal to minus gmrpi RL divided by Rs plus rpi times vi therefore the gain of the circuit or the amplification of the circuit which is given by v0 by v1 will be simply equal to.

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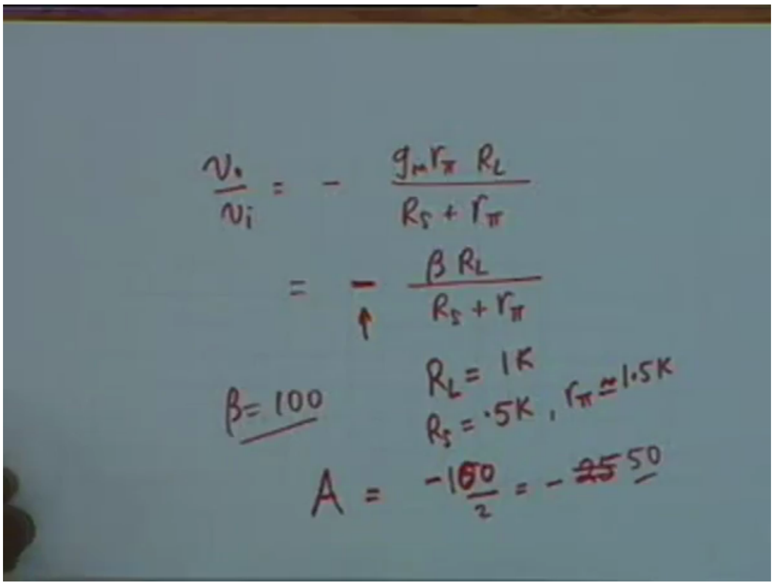

V0 by v1 the gain of the circuit will be equal to minus gmrpi RL divided by Rs plus rpi, what is gmrpi? Beta and therefore this is minus beta RL divided by Rs plus rpi. What is the significance of the negative sign here? Phase shift, the output voltage is out of phase with the input voltage and this I have explained again and again that an increase in input voltage causes an increase in the collector current and an increase in the collector current leads to reduce the value of collector voltage VCE and therefore there is a phase change and this is reflected with the minus sign.

And this ratio has to be dimension less because it is the ratio of 2 voltages. Typically for example you may have a beta equal to 100, RL can be let say 1k, Rs we would like to be as small as possible, let say this is 0.5k and rpi maybe of the order of let say 1.5k, alright. Then you say that the game which is usually represented by the letter A standing for amplification, for this typical circuit it is minus 50 divided by 2 that is equal to minus 25, beta is hundred, okay. So this should be minus 50.

In other words if you put 1millivolt at the input, 1 millivolt peak then you get at the output voltage which is 50 millivolt peak, alright. And if you say higher beta transistor or you can reduce Rs you can get a higher gain. A gain can be increased to there is an upper limit but it can be increased to a useful value. For example you have a signal from maybe a process instrumentation of the order of let say microvolt which not be read by a meter, alright.

A microvolt meter is a very costly equipment, so what you do is, you put an inexpensive amplifier in between and erase it to 100 micro-holes, alright. Then you read 100 micro-holes is how many millivolts, 0.1, there are millivolt meter fractional millivolt meters and so on or maybe you want to lose this to drive a power amplifier. For example in the in the (()) (32:03) system, a microphone amplifier the microphone signal does not go directly to the power amplifier there is something called the preamplifier. Now what preamplifier does is simply to raise the voltage level, so that it can drive the power amplifier stage to its complete capability, alright. So that is the basic idea of amplification.

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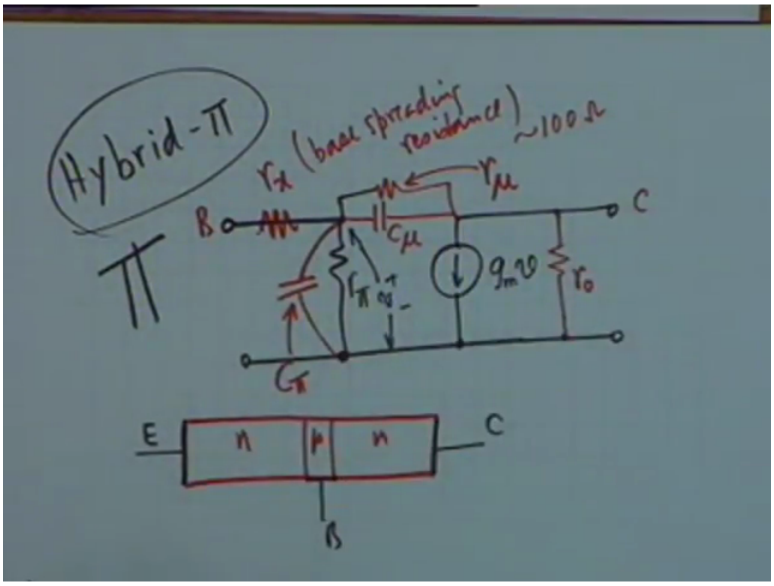

Now let us go back to this rpi beta model, rpi m plus gmv model and see as I said this is a very simple model, there are some modifications needed to take care of elements, to take care of performance at high frequencies in particular and this is a very gross model to sharpen the model we require several modifications. One is if you recall this structure, if you said npn transistor, np there is a connection heren, which is the emitter, there is a connection here which is the collector, there is a connection here which is the base.

The base as you see is a thin long region and between the actual conduct of base and the base emitter junction or base collector junction there is a certain amount of resistance sometimes plays havoc and this resistance is called the base spreading resistance and it is denoted by rx which is called the base spreading resistance. This happens because of the thin and round nature of the base.

The base spreading resistance a typical value is of the order of100 ohms. A typical value for rpi that is the dynamic resistance of a base emitter junction of the orders of typical values about k. So rpi is usually 1 order of magnitude higher than rx and in most of our analysis we shall neglect rx, alright. The between the base and collector but there is a junction, what kind of biasing is there in this junction? Reverse biasing.

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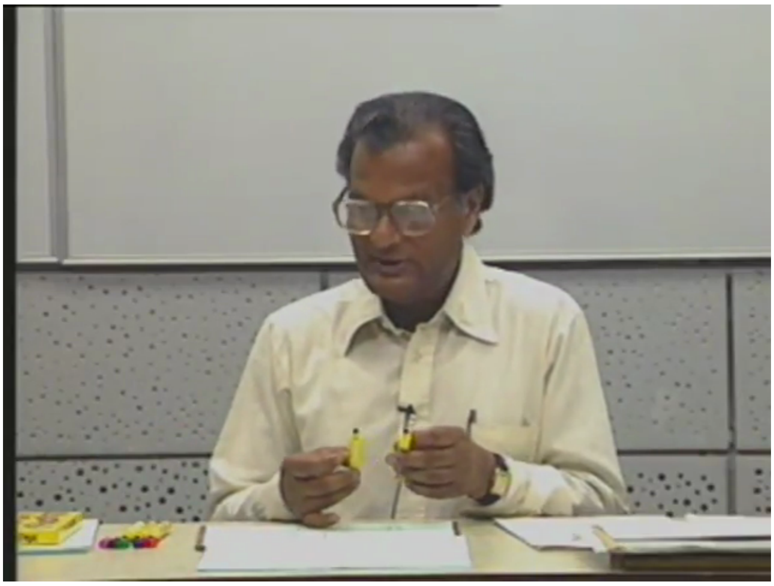

And therefore in a reverse biased junction, as you know there is a separation of charge, alright. This operation with reverse biased increases and therefore this acts as a capacitor which means that between these 2 points we should have a capacitor and this capacitor is given the impulse Cmui, the capacitor between the base and the collector Cmui. Unfortunately it is not a pure capacitor, there is also a conduction current and this conduction current is usually represented by a resistance in parallel (()) (35:29) Cmui and it is called rmui, alright. rmui, rmui is usually very large of the order of several (()) (35:40) and in an usual circuit considerations rmui can be ignored compared to 1 by omega Cmui.

At high frequencies when Cmui comes into consideration it dominates that is one way omega Cmui is much smaller compared to rmui, so rmui can usually be ignored, alright. In addition you know the base emitter junction also contributes to a capacitor, alright. The base emitter junction also there is any separation charges, so there is a capacitance here also and this capacitance is called Cpi. The capacitance in parallel with rpi is called Cpi, alright. Between the collector and emitter if you connect the battery a small current does flow and this current is taken care of by a resistance r0.

All that I show in red here are not desirable, they are all undesirable elements they are called parasitic elements. Unfortunately however parasites are facts of life and 1 has to take care of them, alright. Whether in public or in politics or in electronic circuits parasites are facts of life, okay. Now so in our infernal amplifier analysis at, yes.

“Professor -Student conversation starts”

Student: Sir, what is v?

Professor: Oh! What is v? We is this voltage, I forgot to mention this v is the voltage across rpi. This is why you prefer this model not only because gm is very easily calculate it 40 times ic but also because it does not take account of the current division, you see the ib comes here it divides into one part, two-part, 3 and 4 parts we did not take care of the current we take care of the voltage and gmv this is the most accepted and the most general model of common emitter transistor.

And you see the model looks like pi, you see it looks like a pi and therefore it is called a hybrid is pi model of the transistor. It originates from the hybrid parameters h1or h12, h21, h22. We first went through a simplification and then brought back all the parasites and it looks like a pi and therefore it is called a hybrid pi model.

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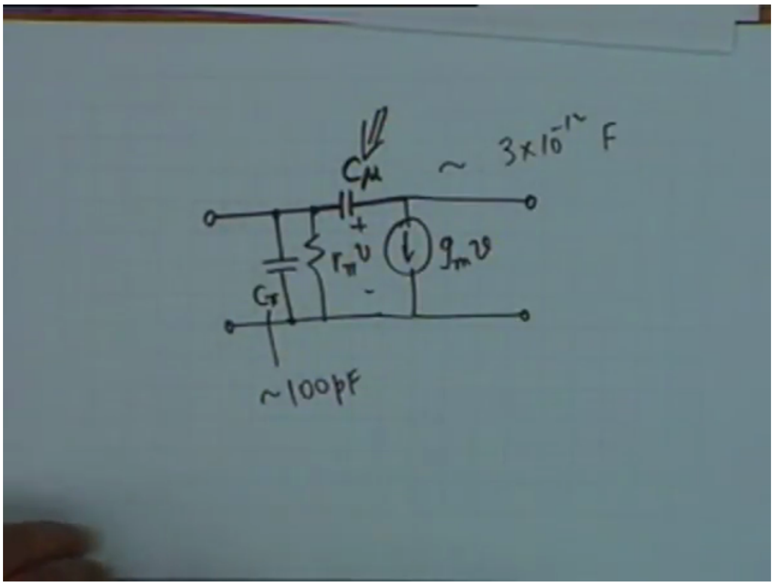

For the purpose of this course and for the rest of the lectures we shall be satisfied with a simplified model, we shall ignore rx and therefore what we will have is in an rpi, in parallel it is Cpi and this voltage is v then I shall have current generator of gmv and very unfortunate this capacitor Cmui is inferior very small capacitor of the order of 3pugs that is 3 times 10 to the minus 12 farad.

Cpi is of the order of 100pugs about 30 to 40 times larger, even than because of this voltage control current source Cpi can cause havoc am sorry Cmui, Cmui can reflect an input and can even swamp Cpi that means affective value of Cmui reflected across the input much larger than Cpi and therefore cmui has to be considered in practice. We take an example to illustrate the usefulness of the model and this example is the so-called Darlington amplifier, Darlington it's a name.

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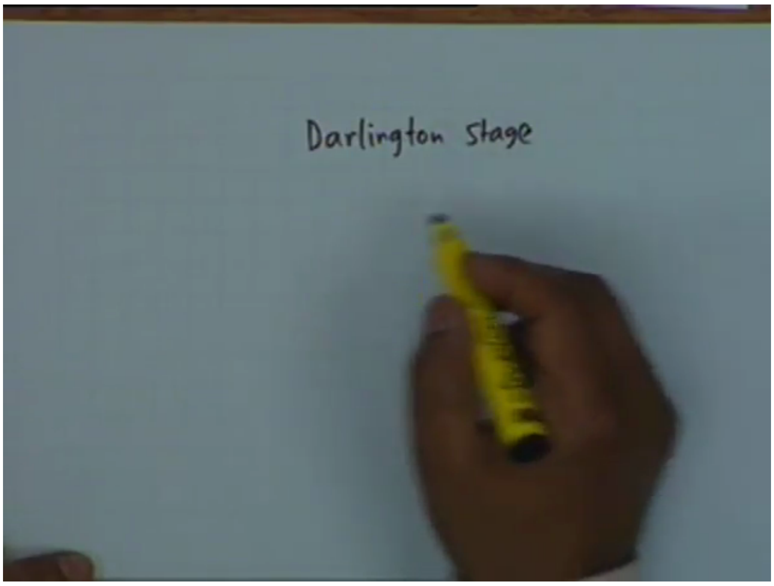

Darlington stage as it is called. What is Darling? Is the following, you have common emitter stage, not common emitter common collector, the collector is connected directly to VCC and you apply an Rs and vs here, this is the source I am not showing the Vc biasing I am only showing the incremental quantities or the signal quantities, alright. This emitter instead of going to ground goes to the base of another transistor, alright.

And the collector of which is connected to the same VCC, okay. Then this goes to ground through a resistance R sub E and it is across R sub E that you take the output voltage v0 I am not showing the DC quantities I am showing only AC quantities, alright. Across this you take v0, we will see what in effect as it has that instead of a single transistor emitter follower as I have introduced last time in 23rd lecture.

A single transistor is not replaced by 2 transistors, the emitter current of 1 becomes the base current of the other and you can expect that there would be a very large current amplification. The current amplification would be very grossly you can see that the emitter current would be better plus one times the base current and this emitter current will be beta plus 1times this base current and therefore the current amplification should be beta 1 plus 1 times beta 2 plus 1.

If this transistor you call Q1 and this you call as Q2 this is what will happen and this is what indeed happens you see if you have beta 1 is 100 that approximately this is 10 to the power 4. A single transistor you get beta of 10 to the power 4 cannot be fabricated and therefore this is a way to have a high beta equivalent of a high beta transistor. If I draw the equivalent circuit then I will leave the rest of the analysis to you.

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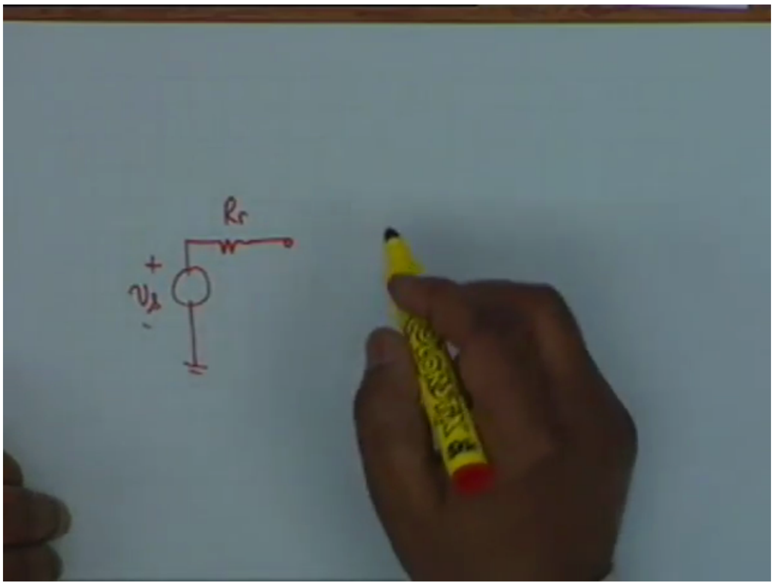

If I draw the equivalent circuit I have vs in (()) (42:53) with Rs then for Q1 I have rpi 1, alright. And I have beta 1, if this current is I sub B1 I have beta 1 ib1, where does this go? This point is the collector.

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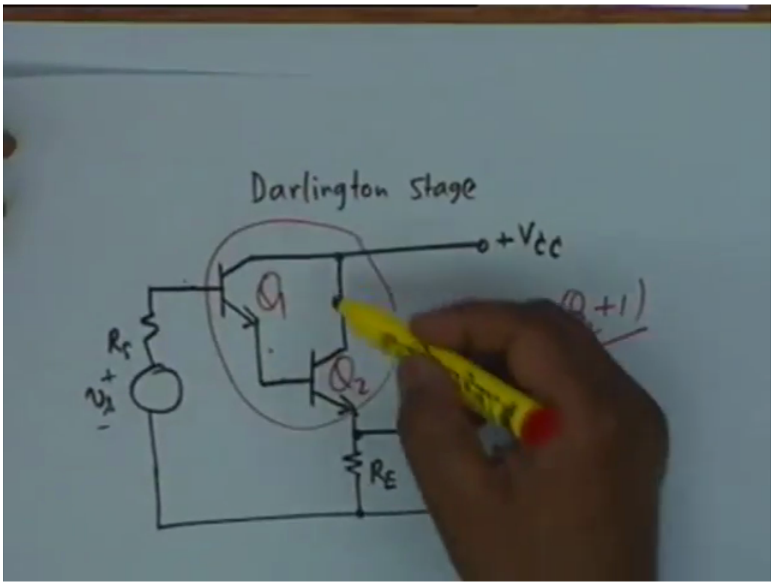

This point this is the collector, the collector is connected to VCC therefore it is equivalent to going to ground.

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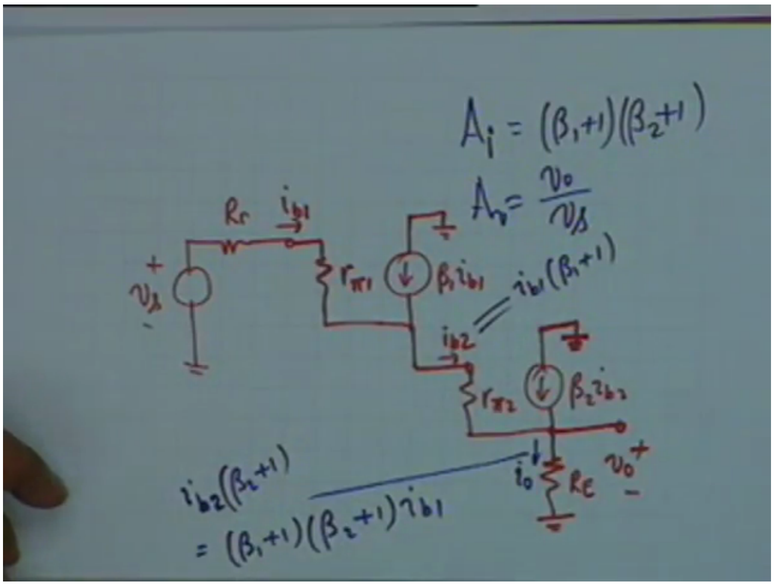

And therefore this goes to ground. Now this current whatever the current is goes to the second transistor B2 and we have rpi2. So this current is ib2 and then we have beta 2 ib2 the 2 come together, where does this go? Ground once again and then this current now flows to R sub e and this is the circuit is v0, this is the equivalent circuit and you can very easily analyze this just by looking just by commonsense.

You see that ib2 is simply ib1 times beta 1 plus 1 and therefore this current is ib2 times beta 2 plus 1 and therefore this is beta 1 plus 1 beta 2 plus 1ib1 this current, this current is this current generator plus the current here, alright. So indeed you see that if I call this current is i0 the current through the load then i and current should be source is ib1 and therefore the current application Ai simply equal to beta 1 plus 1 beta 2 plus 1 is I have indicated from commonsense, alright.

“Professor -Student conversation starts”

Professor: If you are going to calculate v0 by vs that is the voltage gain Av will be equal to v0 by vs, what is your guess? What should be the voltage gain? Can the voltage gain be greater than 1?

Students: No.

Professor: No, it would be slightly less than 1 in fact, alright.

“Professor-Student conversation ends”

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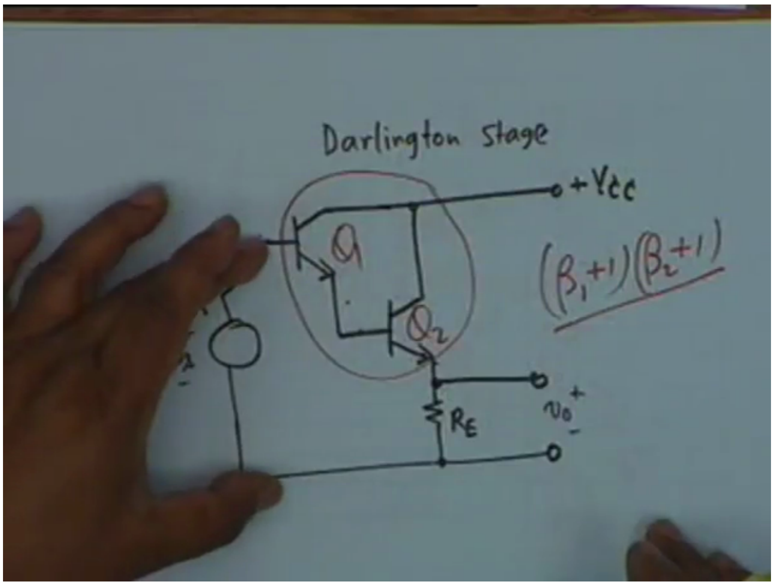

If you look at this circuit, you see this voltage minus vbe 1 minus vbe2 is this voltage and for AC this voltage should be exactly equal to the AC of this voltage which means that the voltage gain should be equal to 1.

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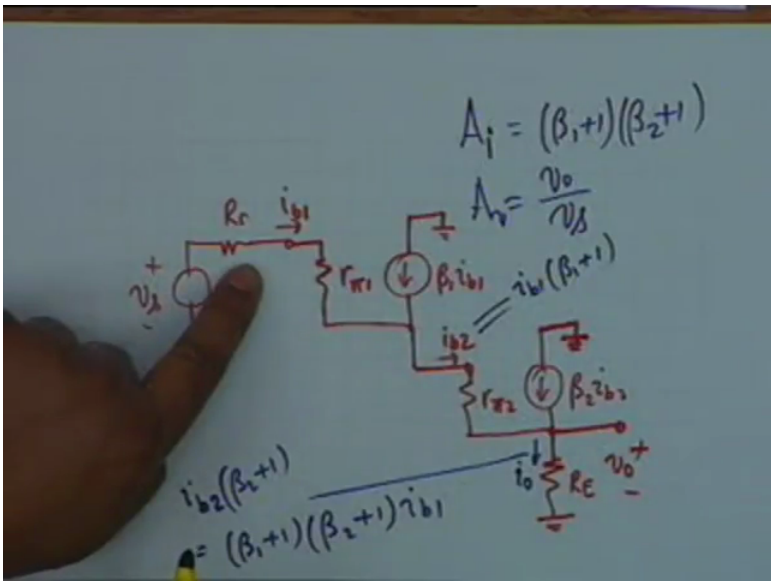

But because of Rs the voltage gain is slightly less than one because what we apply here is not vs it is slightly less than one. The advantage however, if you recall another advantage besides the current gain is that it gives a very high input impedance, the input impedance is very high. You can derive what the input impedance is, that is find out this voltage from here to ground and divide by ib1 that will give you the input impedance, input impedance is very high and this is called Darlington stage, a very popular stage in integrated circuits. In integrated circuits all input stages are Darlington stages, so that you get the benefit of a very high input impedance, alright.

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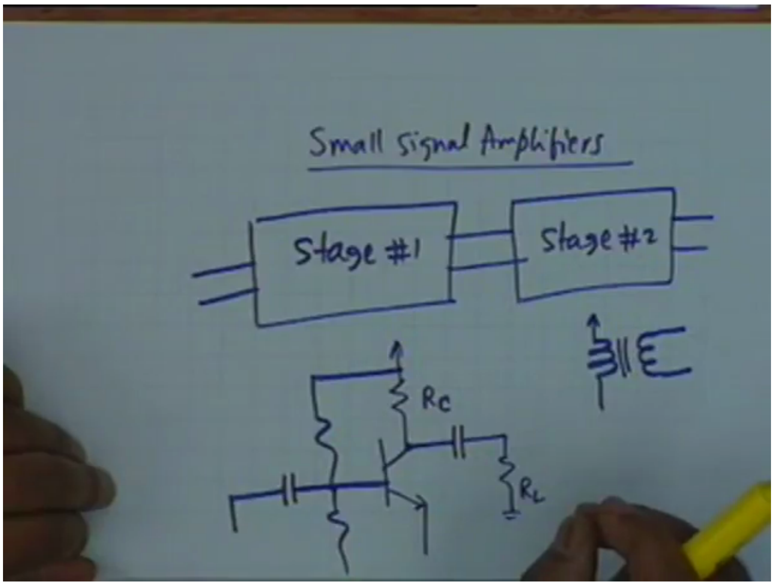

This is the model that we are now going to utilize to analyze small signal amplifiers and we shall introduce a couple of terms in this connection and then leave it for tomorrow's class. A small signal amplifier usually is classified according to the coupling that one makes from one stage to another. Stage 1 to stage 2, when 1 transistor is not enough for gaining you may have to use multiple transistors and the way stage one is connected to stage 2 is technically called coupling which is obvious.

It could be stage 1 to states 2 or stage 1 to the load for example, okay. Usually the load is to be coupled, load is to be decoupled from DC and therefore use a capacitor and then the load, okay. Maybe this is RL and this is Rc, this coupling stage 2 can be simply be load or can be another stage in amplifier, okay. For example the input stage also, input connection you know that even a biasing circuit like this and how do you connect the input through a capacitor?

Alright, so coupling to the transistor either at the load side or at the input side depending on what kind of coupling you imply? We call it by different names, for example this is called Rc coupling resistance capacitance coupling. On the other end you have (()) (48:44) in power amplifiers can coupled to the load through a transformer, this is called a transformer coupled amplifier, alright.

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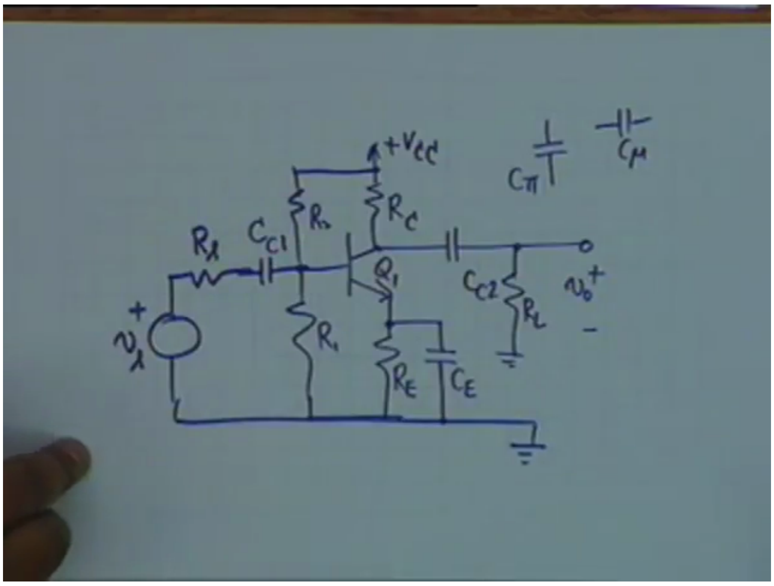

And a simple small signal amplifier that we shall analyze in great details next time is the most familiar circuit in which there is one transistor Q1, it is coupled to the load through a capacitor CRL, the base is biased to R1 and R2 this is called the self biasing circuit and the input is coupled through let us say Rs and vs our purpose will be to determine the voltage v0 in terms vs and that will determine the gain.

The capacitors I made a mistake in this, this resistance RE by means of a capacitor (()) (50:02) called CE. There are 3 capacitor is, the first capacitor, if these 2 capacitors are coupling capacitors, this capacitor couples the source to the transistor, this capacitor couples the load to the transistor which is called CC1 coupling capacitors 1 and this is called CC2. This capacitor is called CE because it decouples the AC from RE.

No AC is (()) (50:35) RE, AC passes through CE. Next time we shall see the effect of this 3 capacitors and also the capacitor is Cpi in the transistor model and Cmui by taking a specific circuit and analyzing it, thank you..