Analog Circuits
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Week - 08
Module - 05
Current Mirror

Hello, welcome to another module of this course analog circuits, so in this module we shall be introducing you to a class of circuits known as current mirrors which are also DC circuits based on the BJT devices but and they serve a very important purpose in providing the required bias currents various circuits, but before we go to the current mirror let me also introduce you to the various small signal BJT models that are used.

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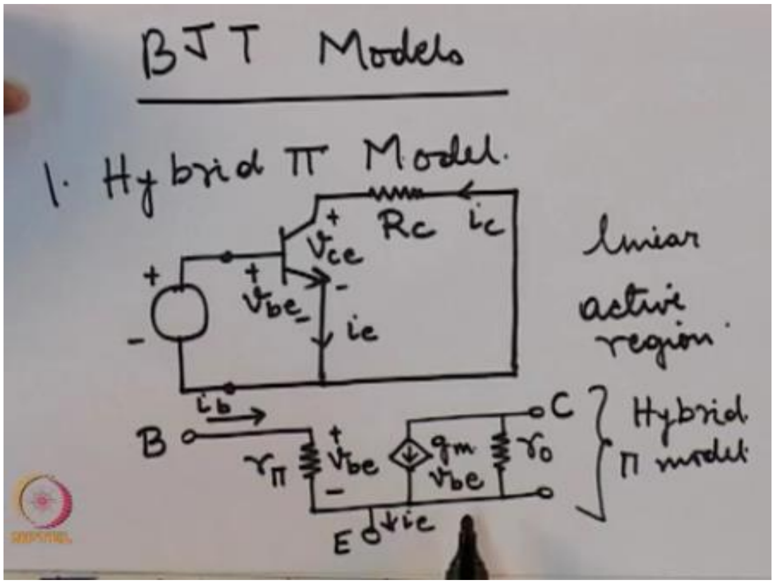

So, there are a number of models for BJT's reported in literature of which 2 are very popular the first one is known as the Hybrid pi model ok, so in this module let us see first consider a BJT which is connected with proper bias voltages and currents, now note in this circuit I am not adding any DC sources I have not added any DC source sources like the vcc or vbb that I mentioned in the previous module instead all the sources here are AC or the actual signal that has to be processed by the BJT ok.

So, the equivalent circuit or equivalent hybrid pi circuit or hybrid pi model for this BJT is given like this, this is the hybrid pi model first thing to note about this model is that this is a linear model even though the BJT is a fundamentally nonlinear device that is the voltages and currents do not exactly have a linear relationship this particular model linearizes the circuit over its active region.

So, this particular model is applicable only in the active region not in the saturation or in the cutoff region, the active region by the way is also known as the linear region of the BJT, because in this region the voltage and currents are somewhat linearly related not strictly but somewhat so once we linearize our BJT then the model we get is something like this, now the important thing is what are these parameters, to understand what are these parameters let us consider the currents and voltages as represented by this model.

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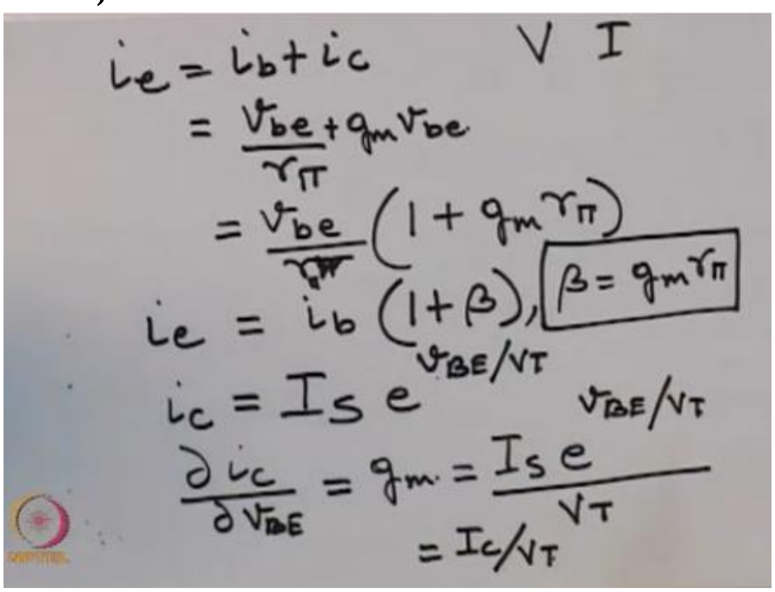

So, I have my emitter current IE, so this is my hybrid pi model the curve current I note that this IE is the AC current okay not the DC bias currents this is the actual signal current that is present and note also that this hybrid pi mode or any other AC model of a BJT will always exclude the DC sources, because since we have linearized our circuit we assume that the DC circuit the final response of this circuit will be a combination of the DC and AC outputs or the DC or AC currents and voltages at the various nodes, hence because of the linearity property of this BJT at its active region.

We can separate the AC circuit out and just analyze the AC solution of this circuit later on, we can combine this solution with the DC solution and the final output will be the sum of the 2 or the super position of the 2 so ie my emitter current is equal to as I can see off the collector current and the base current, so this is equal to ib + ic also note that I am using this small letters the small letters that is small ie's the or small v they represent the AC signal whereas capital V or capital I they represent the DC signals.

So, what is my ib I can see that ib is nothing but the vbe upon r pi okay and ic is equal to gm times vbe okay here we are for some time ignoring this resistance R0 okay if we ignore this resistance R0 assume that the r0 is infinite and no current is flowing through this then this equation will be true.

So, I can take vbe upon r pi common ok and that will give me 1 + gm r pi, here this pi should have been here like this and this I can say is equal to ib because vbe upon r pi is equal to ib and suppose I write it like this then I get back my original relationship between ie and ib, ie and ib are related by this equation therefore the beta of this small signal model is given by gm r pi, so this is the equation relating the traditional beta this beta is irrespective of whether you linearize the circuit or you have an equivalent model beta is always present but this gm and r pi are specific to this model and this is the equation that relate the 2.

I can further proceed along the same similar lines by considering the equation for Ic, Ic should be equal to Is times e raised to vbe upon VT here my v is the AC voltage and ic is the AC voltage if I differentiate this with respect to vbe then that will give us the value of gm because after all gm is the dynamic trans-conductance that is gm is equal to the change in ic due to a change in vbe gm is not equal to simply ic upon vbe this is the DC trans-conductance but the AC trans-conductance is that or the dynamic trans-conductance is the change in ic due to a change in vbe.

So, once I get this value of gm what is if I now evaluate this derivative then that comes out to be equal to Is e raised to vbe upon VT this whole upon VT ok and this is again equal to IC upon VT ok so then gm is equal to IC upon VT this is the formula so these were my 2-unknown's odd for this model one was this r pi and the other was gm.

I found out gm was given by Ic upon VT and r pi was given by beta upon gm from this equation so first I can find out gm from this equation substitute it here and I can find out r pi so this is how this model is defined now another module that is very commonly used for the active region of a BJT is the T model, so let us see what is the T model.

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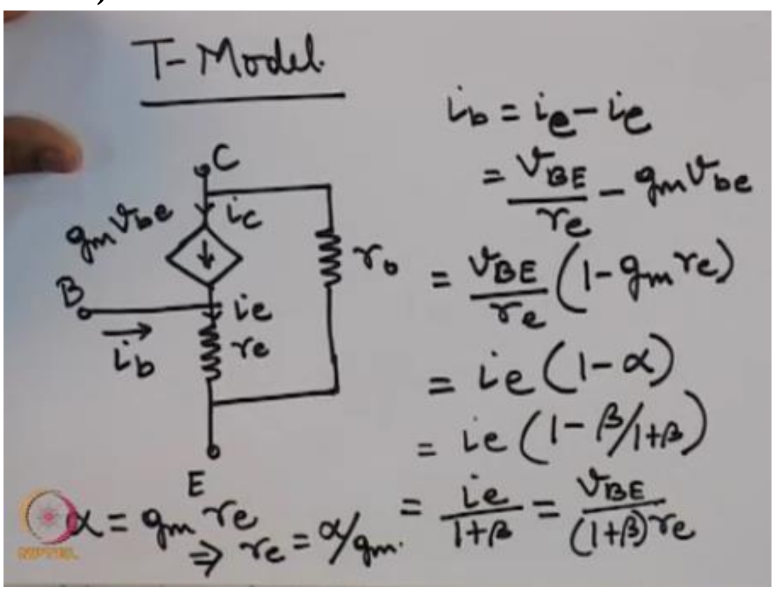

Now the r0 that I had mentioned in the previous hybrid pi model is will be defined by this, when we discussed this particular model so here we see that this ib base current is equal to the difference between the collector and the emitter current or I should say this is equal to ie - ic and ie is given by vbe this is my base upon re and ie is given by gm times vbe so this whole comes out to be equal to vbe upon re multiplied by 1 - gm re and this is equal to of the form ie multiplied 1 - alpha which can be simplified to ie upon 1 - beta upon 1 + beta which is equal to ie upon 1 + beta and which is equal to vbe upon 1 + beta re.

So, here this alpha my traditional BJT alpha is equal to gm re which implies re is equal to alpha upon gm so this how this re resistance is defined. Now comparing the value of re and r pi that I had defined in the for the previous model we can obtain a relation which I leave for you as an assignment to find out.

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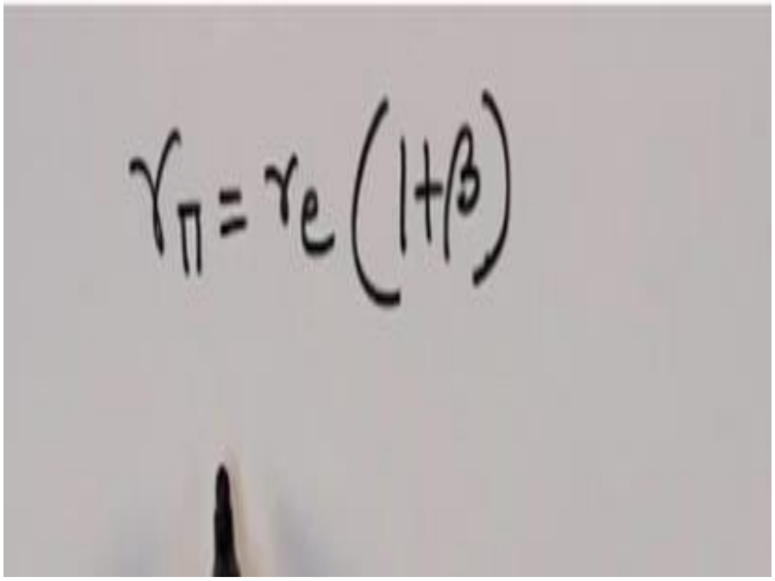

That r pi will be equal to re times 1 + beta now once these models are known we can use these models for various AC finding out the AC response of various circuits, for example the common emitter circuit that we had discussed earlier we can find its equivalent model either in terms of this T model or the hybrid pi model here connect the AC source that is been applied to the base of the original circuit and find out the voltage and current at the base and collector junction, so that is how we solve for the AC response of a BJT.

Since time is short and we don’t have many modules left so we will I will not be covering any further topics on the AC response of BJT’s, but as promised at the beginning of this module I shall be showing you a circuit which is known as a current mirror. Now current mirror is a circuit that replicates a current, so it is a mirror if the word mirror is used because the same current that is applied at one terminal appears across another terminal and it is very commonly used in various circuits.

For example, if we want identical operation of 2 amplifiers then we cannot just simply design the circuit to ensure that the equal currents flow through them. We need to actually ensure it using current mirrors so we connect 2 branches of the current mirror to the 2 amplifiers and since they are in mirror there is a mirroring effect so the currents will definitely be the same in both the amplifiers so let us see how this current mirror is constructed.

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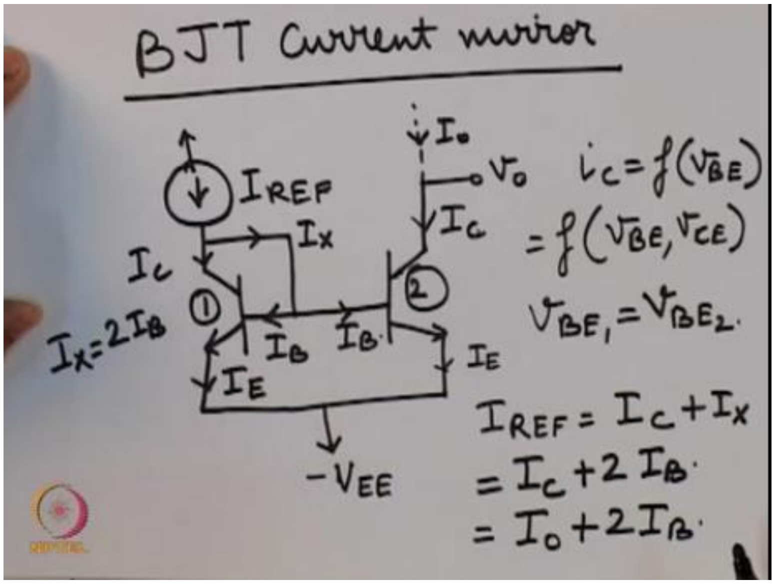

The circuit for this mirror is given like this now at the beginning of this at the beginning when we this first started discussing BJT's I had mentioned that the current ic is a function of only vbe this is true to some extend but actually in reality ic is also a function of VC, however this dependence is very tenuous not VC doesn't influence or variation in VC doesn't change ic to that extent to which ic is changed due to changes in VBE and we shall be assuming that ic or any of the other currents of a BJT are only functions of VBE.

If that is the case then from just from the way these 2 NPN transistors these 2 NPN BJT's have been connected we can see that the VBE voltage will be same for both so VBE 1, suppose I call this transistor 1 this as transistor 2. VBE 1 will be equal to VBE 2, hence we can say that all the currents flowing through all the transistors the respective currents in the various terminals of both the transistors will be the same, so that's why we have the same current IB flowing through the base of both the transistors of course these 2 transistors are themselves identical okay and so will be the emitter currents and also the collector currents.

So, we have we can then write this current IREF as equal to IC + IX and IX as we can see is equal to twice of IB where IB is the base current going through the base of both the transistors so I can write this as equal to IC + 2 IB ok now IC should be equal to the collector current of this transistor which in turn is equal to I0, so I can replace IC with I0 like this IB in turn is a function of IC and given by.

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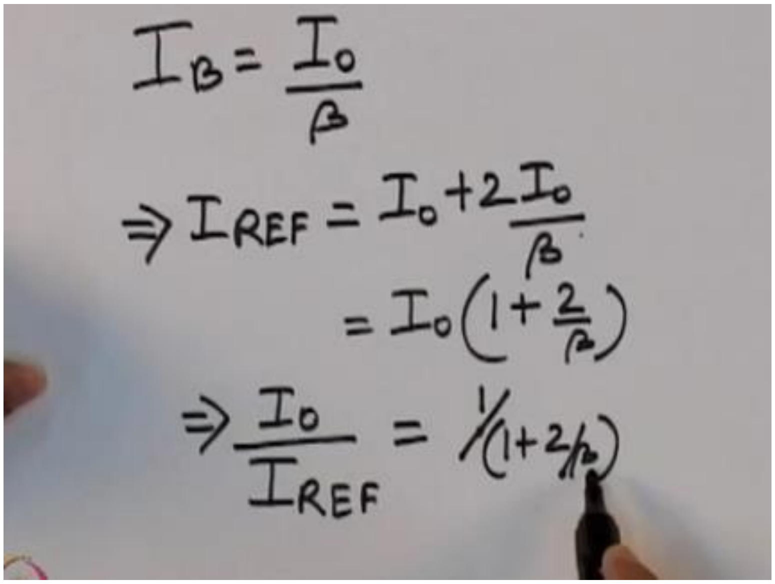

IB is equal to I0 upon beta now this implies IREF is equal to I0 + twice of I0 upon beta which is equal to I0 in to 1 + 2 upon beta so this implies that I0 upon IREF is equal to 1 upon 1 + 2 upon beta as we can see I0 and IREF are not totally same if beta is quite high of course then I0 will be equal to IREF but if beta is still the time beta is not very high there will be a small difference between I0 and IREF and that is one problem with this kind of current mirror true that IREF and I0 match each other very closely, since beta is usually quite high be we have some other designs where this closeness of IREF and I0 is even more.

So, in this module we covered some topics on transistor modeling we discussed about the 2 common AC models used in the active region of the BJT that is the hybrid pi model and the T model and we also discussed a simple current mirror using a BJT, now this is the last module of this course that I shall be taking, after this module the TS for this course will be taking some tutorial classes.

So, those will be the subsequent modules of this course it was really an enjoyable experience discussing the various topics of analog circuit design with you throughout the past few weeks and I hope you it you found it and enriching experience.

I hope you got some value out of the discussions with we had and please send me an email if you have any doubts, my email ID is please contact me if you have any questions, I shall be very happy to provide answers to your questions also please let me know if you felt that some more topics needed to be covered or something which we had to cover in more detail, of course we have a time constraint of 20 hours for this course and that's why I try to squeeze as many topics I could within this time that we had but I would definitely if I receive some emails from you regarding some particular topic that you are interested in we can discuss on that, thank you.