Analog Electronic Circuits
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Lecture no 16
Module no 01
High Frequency Response of Small Signal Amplifiers

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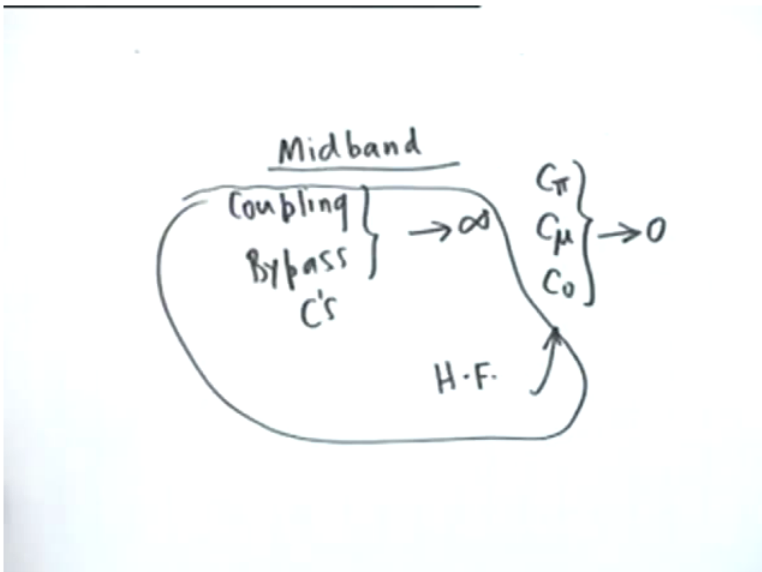

Lecture today on high frequency response of small signal amplifiers. So far we have only talked about mid band frequency response in which we ignored all capacitors, we ignored the coupling and bypass capacitors, we assume them to be infinitely large and we also ignored C Pi the base to emitter junction capacitance, we ignored C Mu the collector to base junction capacitance and we ignored C 0 which is across the output that is collected to emitter which mostly consists of stray capacitance and load capacitance, in mid band we assume this to be tend to 0 so that all capacitor effects are neglected.

Now we consider the effects of these capacitors in 2 steps; one is we 1st consider the high frequency response in which these are the capacitors which will show that and the capacitors coupling, bypass and coupling and bypass capacitors are large enough so that at high frequencies they act as short. So for high frequency we still assume that the coupling and bypass capacitors have negligible effect that is they act as short circuits, we consider the transistor internal capacitances and the load capacitance and the stray capacitance across the load.

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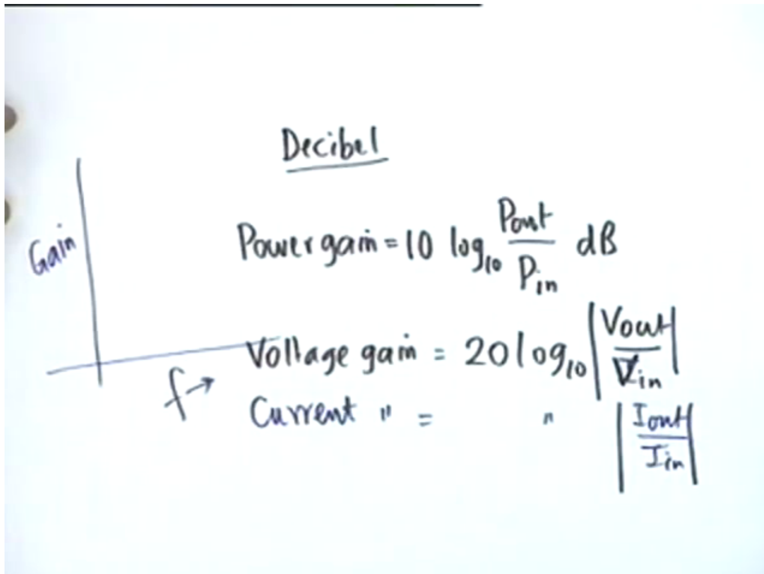

In the process we bring in the concept of decibels which I am sure you have been introduced to but it is usual to express gain in terms of decibels, and if it is power again, then power gain ratio is P out divided by P in and what we do in decibels is we take the log of this and multiply by 10 for many dB d small B capital okay, many people make this mistake, capital B stands for Bell Alexander Graham Bell and d is deci; deci, centi, milli, in the same sense okay so this B should be written as B okay because it is the 1st letter of a proper name. And if it is voltage gain on the other hand also expressed in decibels then since power is proportional to voltage square, this would be multiplied by 20, 20 log 10 V out by V in or if it is current gain V in yes if it is current gain then instead of V out by V in it would be I out by I in that is it that is the difference.

And the major advantage of the decibels scale is compression range compression, you see if we out by V in is 10 then the value is 20 dB, if V out why V in is 100 that is 1 decade higher than the value is simply 40 dB so what is n times gets reduced to only twice. On the other hand if this is 1000 V out why V in is 1000 then it is simply 60 dB okay multiplication by 3, so it is a range compression. And most of the frequency response plots that we make if we take the ordinary ratio then we require a large size graph paper and also it may not be possible to accommodate all the complete range of gains similarly, the complete range of frequencies so you plot on a log scale and the idea is again compression okay.

Student: Sir in this decibel case this ratio is a phase.

Professor: This ratio is a magnitude ratio okay that is a good question good question. The gain that we expressed here is usually a magnitude ratio not a phaser, decibels with a phaser ratio does not mean anything okay decibel is always with reference to the magnitude.

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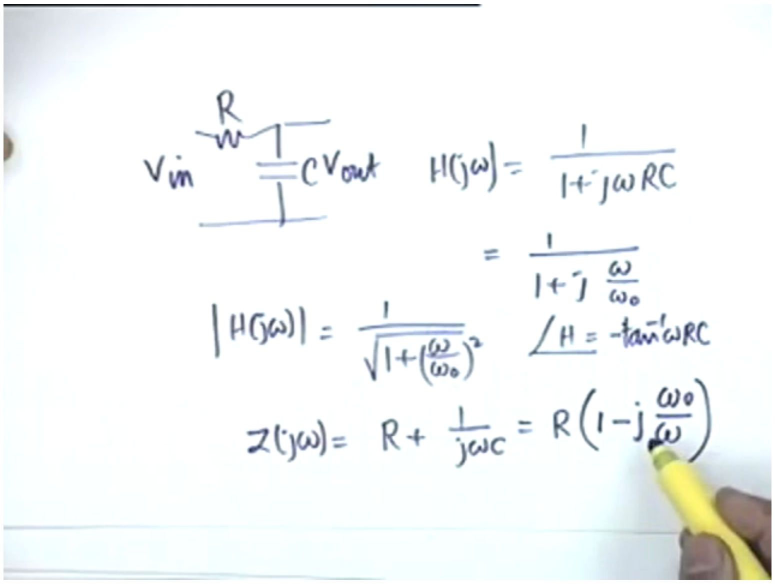

Okay, before we take up actual high frequency response we also like to recall a few simple facts from circuit theory. If you have an RC network like this and if there is an input here and an output here V in and V out then the transfer function of this circuit is simply given by 1 by 1 + j Omega RC for sinusoidal excitation which I can write as 1 + j Omega by Omega 0 alright. And if I take the magnitude, this is simply 1 by square root of 1 + Omega by Omega 0 square and the angle of it is – Tan inverse Omega RC. It is important to recall this because I am not going to derive this every time, whenever such a network occurs we will simply recall what it is and the input impedance Z of j Omega is simply R + 1 over j Omega C which I can write as R 1 – j Omega 0 divided by Omega is that clear? Why it is so, if I take R common then j Omega CR which is Omega by Omega 0 and 1 by j comes with – j okay.

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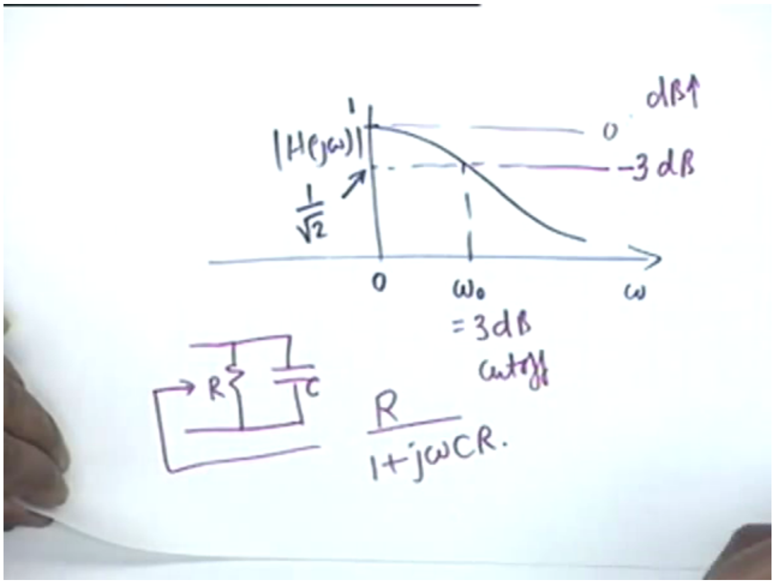

If I plot H of j Omega magnitude versus Omega then it starts from 1 and Omega = 0 and then it goes down like this okay. At Omega = Omega 0 the value is 1 by root 2 or 0.707 and in terms of decibels if this is taken as 0 dB in the dB scale if this is taken as 0 dB then naturally this corresponds to - 3 dB,because ratio is less than 1, 0.707 and therefore Omega 0 is called the 3 dB cut-off frequency or simply cut-off frequency okay, Omega 0 is called 3 dB cut-off or simply the cut-off frequency. One more fact which shall occur again and again is if I have a resistance and a capacitance in parallel then the equivalent impedance is R divided by 1 + j Omega CR this also we shall get again and again and we will not do this calculation again and again.

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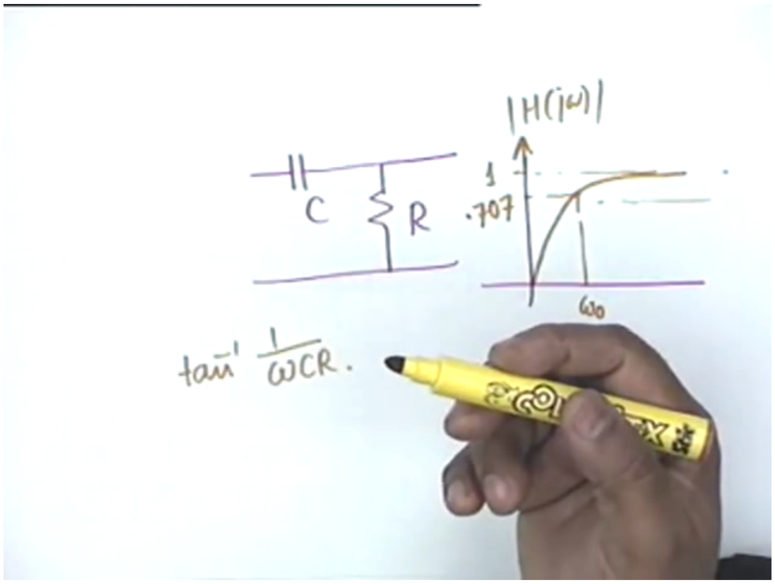

Obviously this circuit this series RC circuit acts as a low pass filter circuit that is it favours low frequencies and it discriminates against high frequencies so it is a low pass filter. On the other hand if the capacitance and resistance are interchanged that is if we have a C in series and an R in parallel then you can show that this is a high pass filter and its response is like this, at infinite frequencies the value is 1 this is magnitude H of j Omega, at infinite frequencies the value is 1 and at Omega 0 once again Omega 0 = 1 over RC, the value is 0.707 okay or 1 by root 2 and in terms of decibels again this is 0 dB, this level corresponds to – 3 dB and Omega 0 is again called the 3 dB cut-off.

This is a high pass filter because above Omega 0 frequencies are favoured, below Omega 0 frequencies are not favoured that discriminates again and therefore Omega 0 is kind of borderline artificially defined 0.707, there is no reason why you could not defined 0.5 level is the cut-off frequency but this is artificially defined 3 dB is a very nice figure and that is why we always concentrate on 3 dB cut-off, this is a high pass filter. As far as the phase is concerned, phase would be Tan inverse 1 by Omega CR, the phase would be Tan inverse 1 by Omega CR, no negative sign, negative sign comes in the low pass filter because the voltage output relax the input voltage, here the output voltage leads the input voltage okay.

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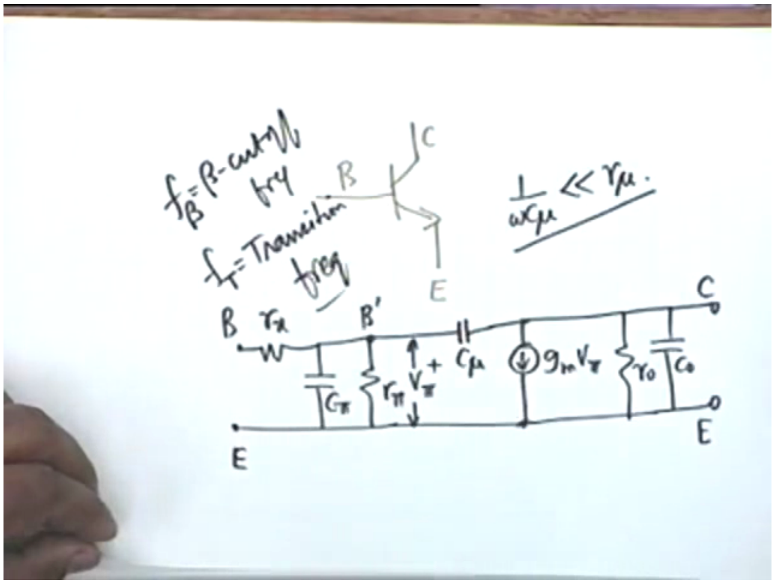

Now if I take the take the BJT the bipolar junction transistor; emitter, collector and base then all that is needed to take care of high frequency response is to include C Pi, C Mu and C 0 so the hybrid Pi equivalent circuit would be r x then instead of r Pi we have a C Pi and an r Pi, this voltage is V Pi okay this is the internal base B prime, external base B, this is the emitter terminal E and then because we are now including C Mu and we are considering high frequencies, reactance of C Mu usually shall be much smaller compared to R Mu, remember at mid band C Mu was considered open and therefore R Mu had come into the picture in some cases we considered, wherever inconvenient we discard it.

Here it is extremely inconvenient to include R Mu and the logic for ignoring is not inconvenience, it is that R Mu usually is large compared to the reactance of the capacitor so we do not include R Mu, is the point clear we do not include R Mu and then we have the g m V Pi in parallel with R 0 and C 0, this is the other capacitance that has to be taken into account so this is the collector this is the emitter, this is the hybrid Pi equivalent circuit. Before we incorporate this in a common emitter amplifier let us consider the definition of 2 relevant quantities; one is called the Beta cut-off frequency f Beta, Beta cut-off frequency and other is called f T or transition frequency for the BJT for the device, let us see what these quantities are, usually manufacturer specifications manufacturers specify either f Beta or f T or both okay let us see what these quantities are.

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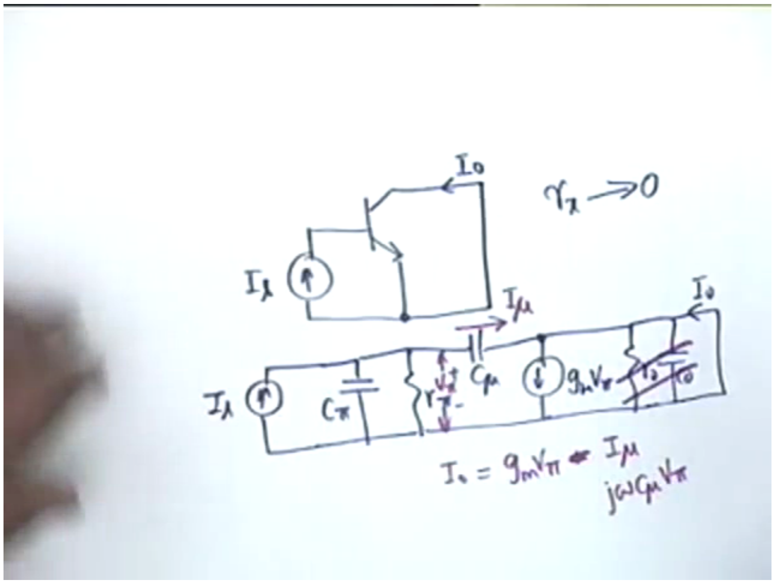

Suppose we have a common emitter circuit driven by a current generator I s, we are drawing only the AC equivalent circuit we are not drawing the biasing resistors or anything, we are drawing only the AC operation. And suppose we short-circuit the collector and let the current that flows be I 0 okay, you consider this very simple circuit, we have bias this properly and then as far as AC is concerned we have short-circuited the load, the load is short-circuit maybe we have connected the large capacitor okay and we want to measure the current in this short-circuit. The input is a current generator that is it is a voltage generator with infinite impedance or a current generator, it is shut impedance is infinity okay.

Now if I draw the equivalent circuit AC equivalent circuit, what we have is I sub s then it is very convenient to ignore r x so ignore r x okay. We ignore r x, wherever necessary we shall include it but at the present time it does not add much and it is a current generator, is not that right? Even if r x was there it does not have any effect because internal impedance of a current generator is infinity and r x + infinity is also = infinity so it really does not matter. C Pi, r Pi then we have C Mu and g m V Pi then we have is parallel combination of R 0-C 0 but this is short-circuited and this is I 0 and this voltage is V Pi of course.

As far as R 0 and C 0 are concerned they are ineffective because they are shorted okay they are ineffective therefore I 0 would be = this short-circuit current would be = g m V Pi + okay now the current through C Mu let us call this I Mu it should be – I Mu. At this node I 0 should be = g m V Pi – I Mu and what is I Mu, I Mu is what is the potential of this point? 0 because it is short-circuited. So the current I Mu should be simply = j Omega C Mu V Pi. Now usually this current can be ignored because C Mu in any case is a small capacitor as compared to g m V Pi.

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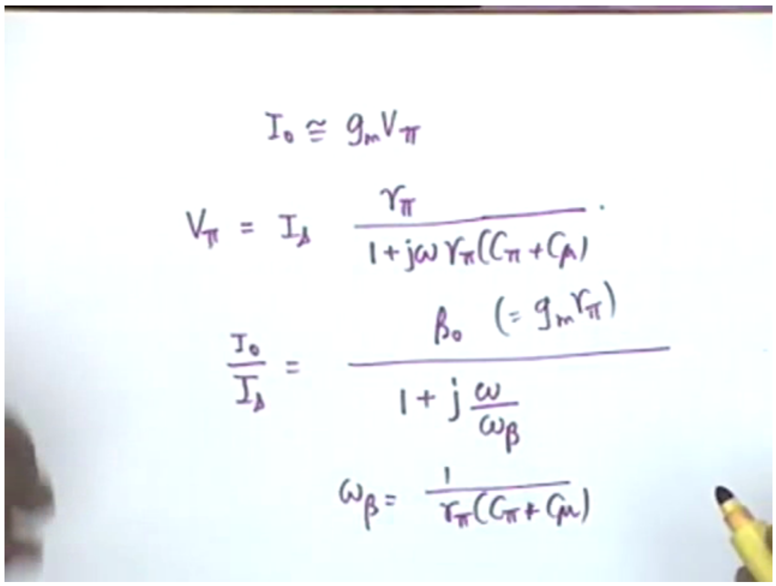

Professor: And therefore we write 1st approximation I 0 is approximately = g m V Pi, which ignored I Mu.

Student: Why do you ignore I Mu?

Professor: Because I Mu is usually very small quantity as compared to g m V Pi as we shall see in example, we validate this later but we can ignore this.

And as far as V Pi is concerned in order to calculate the current gain I 0 by I S, as far as V Pi is concerned V Pi is I s flows through a parallel combination of r Pi C Pi and C Mu because C Mu also comes in parallel with this okay so V Pi would be = I s multiplied by the effective impedance, effective impedance would be it is a parallel RC combination so it would be r Pi divided by 1 + j Omega r Pi multiplied by C Pi + C Mu absolutely correct. And therefore I 0 by I s would be = if you substitute V Pi here you get g m r Pi which we shall call Beta 0, Beta 0 = g m times R divided by 1 + j Omega multiplied by this quantity, this quantity we call as 1 by Omega Beta that is Omega Beta = 1 over r Pi C Pi + C Mu okay, what is the significance of this expression, look at this expression.

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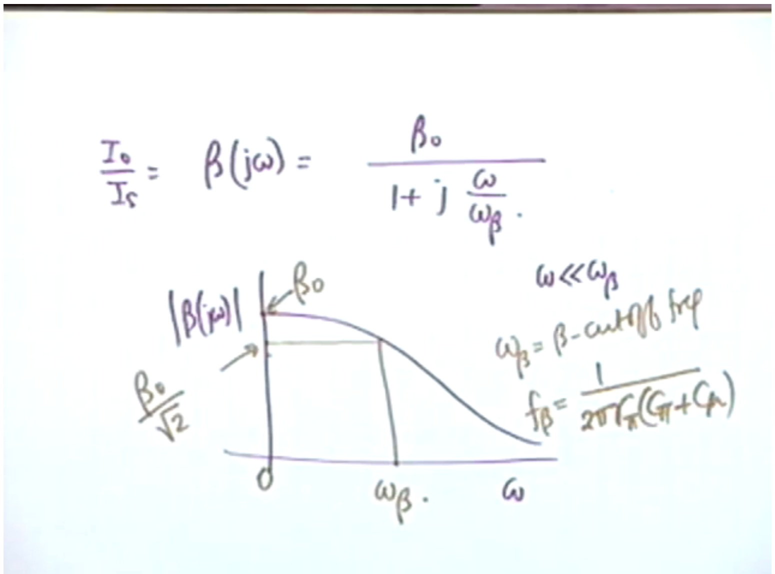

Let us call I 0 by I s as Beta of j Omega because Beta is now this ratio is now a function of frequency this ratio is a function of frequency, this = Beta divided by 1 + j Omega by Omega Beta, do not you see that this is exactly similar to the expression for transfer function of a low pass filter that is why I did that earlier. And you notice that the short-circuit current ratio short-circuit current ratio this is the definition of Beta but now because of C Pi and C Mu, Beta depends on frequency and you see that if Omega = 0 at DC or at frequencies much less compared to Omega Beta, if Omega is much less compared to Omega Beta then Beta = Beta 0 that holds up to about mid band up to about mid band Beta is approximately = Beta 0.

And then when you exceed the mid band when you go to higher frequencies, Omega Beta Omega by Omega Beta this factor produces a reduction and the ratio and the plot of Beta j Omega magnitude versus Omega naturally would be of the same form as that of a low pass filter and the value at 0 frequency is Beta 0 and the value at Omega Beta would be = Beta 0 divided by root 2. So Omega Beta is a cut-off frequency Omega Beta is the frequency... Pardon me...

Student: Magnitude.

Yeah magnitude Beta 0 by root 2. Omega Beta is the frequency at which Beta comes down from its DC value by 3 decimals agreed, if we take dB value here and here the difference will be 3 decibels okay so Omega Beta is a 3 dB cut-off but because it applies to Beta we call it Omega

Beta as the Beta cut-off frequency Beta cut-off frequency. And Beta cut-off frequency can be expressed either in radiance per second or in hertz. In hertz f Beta would be = Omega Beta by 2 Pi so it would be 1 by 2 Pi r Pi C Pi + C Mu agreed, this is the Beta cut-off frequency. Another frequency that is defined with reference to the same curve is the frequency at which Beta reaches the value 1, obviously if the short-circuit current amplification factor is less than one that is at frequencies beyond this obviously the transistor shall not be useful okay there is no current amplification.

In a common emitter circuit if there is no application, well the transistor is useless and therefore this frequency is absolutely the highest frequency up to which you can use the transistor for amplification at this frequency therefore defines a transition between usefulness and uselessness and therefore this is called a transition frequency Omega T, frequency at which the magnitude of Beta reduces to unity, now let us see what this frequency is.

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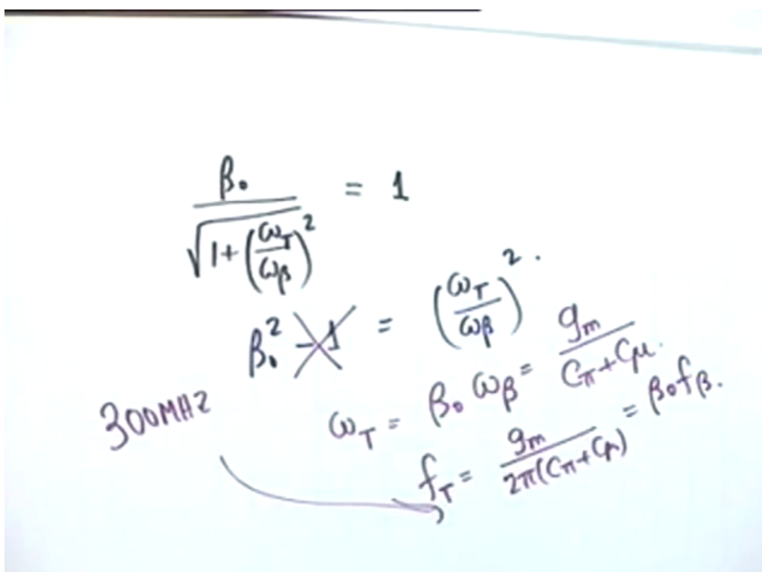

You see this magnitude is Beta 0 by 1 + Omega by Omega Beta whole square and this is required to be = 1 at the frequency Omega = Omega T, at the frequency Omega T the value becomes 1 so if I simplify this I get Beta 0 square - 1 = Omega T by Omega Beta whole square alright. As compared to Beta 0 square this one is negligible and therefore Omega T = Beta 0 multiplied by Omega Beta. And if you see the expression for Beta 0, Beta 0 is g m r Pi and Omega Beta is 1 by r Pi C Pi + C Mu and therefore this is simply = g m divided by C Pi + C Mu, this is absolutely dependent on the transistor parameters g m, C Pi and C Mu and is the frequency above which you cannot use the transistor gain fully, you cannot gain anything by using the transistor, no current gain and therefore it is a useless quantity.

Mega T is called the transition frequency and you notice that the frequency in hertz shall be g m divided by 2 Pi C Pi + C Mu and this would be = Beta 0 times f Beta okay, typical value typical value is 300 megahertz typical value of f T is 300 megahertz and if Beta = hundred then f Beta is typically how much? If FT is 300 megahertz and Beta is 100, 3 megahertz okay these are typical values. F Beta is typically 3 megahertz, FT is typically 300 megahertz okay that completes the (())(25:43).

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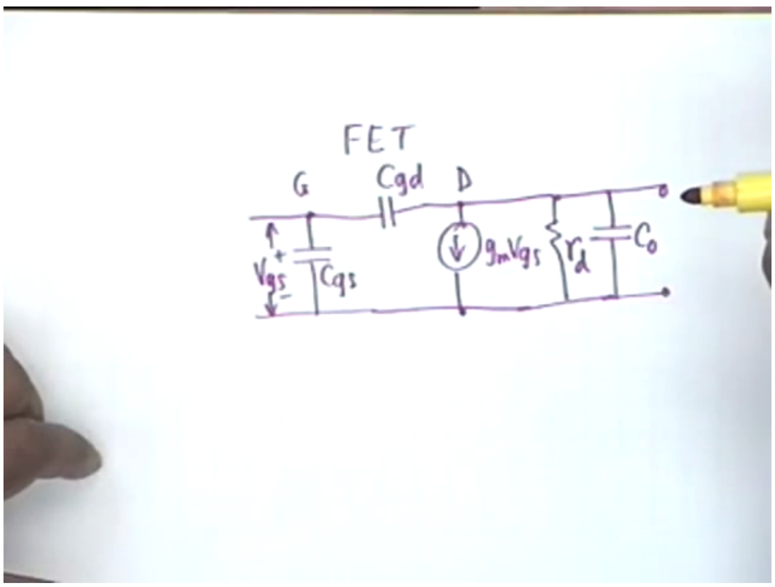

The other thing that we have notice is that instead of BJT if we use an FET of any kind it does not matter what it is, we again have to use take care of 3 capacitors; one is the C gs one is C gs and this voltage is V gs the phasor value and then we have to take care of the gate to drain so we have a capacitor C gd, this is the drain from the drain you have g m V gs there is no resistance here no resistance here because gate to source and gate to drain they are either reversed biased junction or metal oxide semiconductor capacitor okay. So g m V gs and then you have the inevitable dynamic resistance of drain r d and perhaps an output capacitance C 0 which is basically stray but it also contains a small amount of capacitance contributed by the device so we will keep its C 0, C 0 usually is a very low value quantity.

You must also recognise C gs, C gd, C Pi, C Mu, C 0, they are of the order of picofarad 10 to the - 12. For example, typical value of C gs and C gd is 2 picofarad, typical value of C Pi would be 10 picofarad, typical value C 0 would be about 5 picofarad, but nevertheless even though these are very small quantities they cause disaster at high frequencies as you shall see... yes.

Student: Sir is there a capacitor between train and source?

Professor: Is there a capacitor between train and source... If you recall if you recall it is a channel it is an n channel and there is only contact here contact here, so if at all there is a resistance not a capacitance, there is conduction there is no depletion. Capacitance require a separation of charge, there is no separation of charge okay so there is no capacitance between the drain and the source, if there is it will be taken care by C 0. If at all there is if at all due to a peculiar combination of voltages there is a depletion or due to the defect in the substrate there is a depletion, it can be taken care by C 0.

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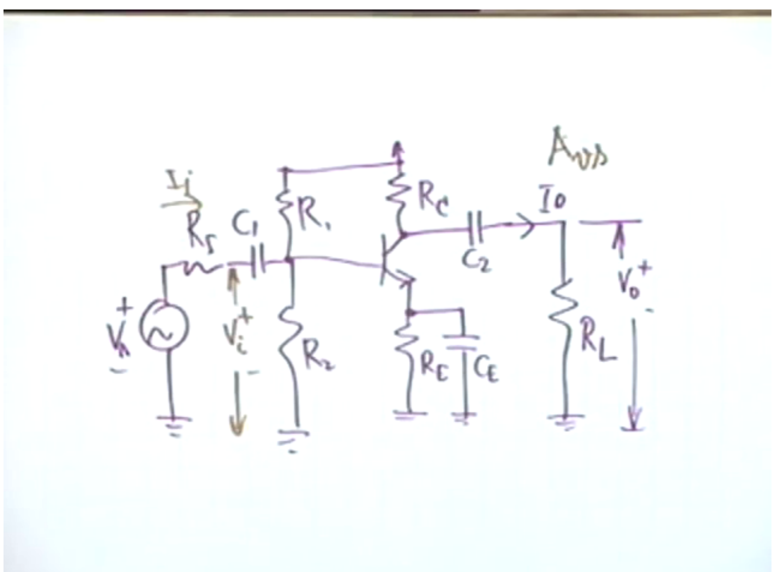

Now let us go back to a BJT common emitter amplifier and see how to analyse such an amplifier. Our circuit is usual circuit, we have R sub C, RE, we assume that this capacitor is infinitely large so that it behaves as a short-circuit, coupling capacitor we assume this to be infinitely large, this also behaves as a short-circuit, this is the load, this voltage is V 0 and the current here is I 0, the biasing we assume the usual circuit R 1 and R 2 and there is a coupling capacitor C 1 which we assume to go to infinity, the source resistance V s usual circuit okay.

This voltage is V i and this current is I sub i, once again we are interested in voltage gain, current gain, but the again that we shall mostly be trusted now which is affected by capacitances is more than A v, now it is A vs because most of the sources in practice whether it is a microphone or a let us say cartridge pickup from a record gram or a CD-ROM player whatever it is there is an internal resistance okay and mostly we shall be concerned with this gain, this gain will be very much effected by the internal capacitances of the transistor, let us draw the equivalent circuit then we will see how this is affected.

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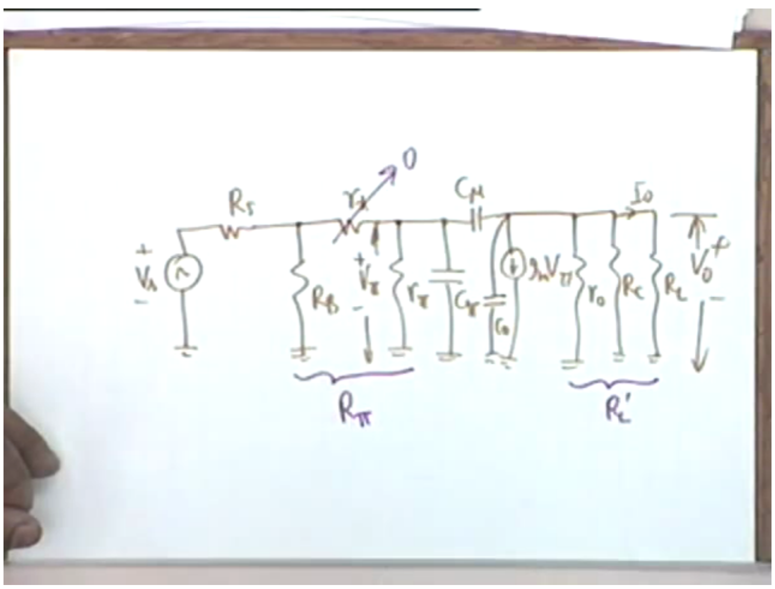

We have V s, R s then we have R sub B and then r x, r Pi, C Pi, this voltage is V Pi okay we have C Mu, for obvious reasons we ignore R M, then we have the g m V Pi, R 0, and we shall have R C and R L fall in parallel, this voltage is V 0 and this voltage this current is I 0 oh there is a C 0 there is a C 0 yes. We make some simplifications now, in this circuit we assume that r x tends to 0 r x causes a problem because then if r x is there we have to consider this and this as independent nodes, if r x is not there we can combine it usually r x can be ignored okay. And you see these 3 resistances can be combined into one resistance of we call this R L prime. R L prime we lose I 0 thereby but we can recover it if we know V 0, I 0 is V 0 by R L okay.

So R L prime is the resistance and if r x is ignored then R B and r Pi can be included in a common in a single resistance R Pi, we have of course passively assumed that C 1, C 2 and C E they go to infinity okay, with this simplification our equivalent circuit becomes the following.

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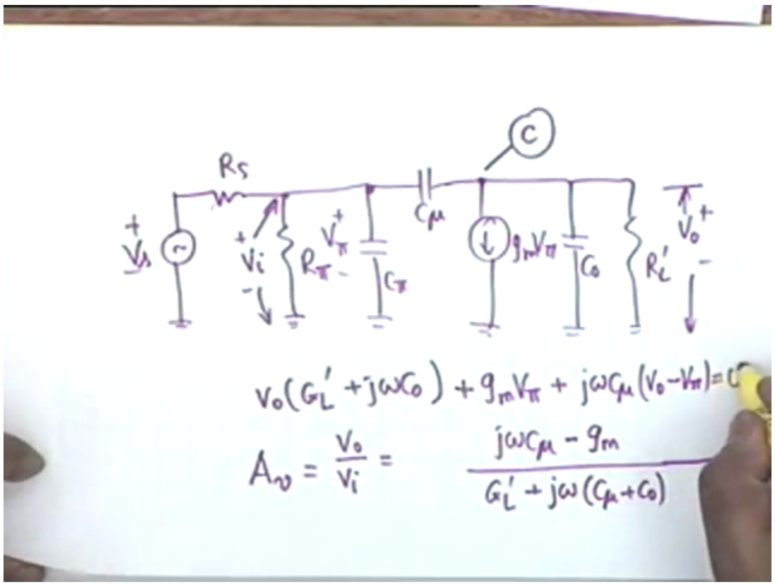

We have V s, R s, and we have R Pi, this is the notation we are using all through, the voltage across R Pi is V Pi, there is a C Pi, there is a C Mu and there is a g m V Pi the capacitor C 0 and the resistance R L prime the voltage across which is V 0. Now you see we will need to write 2 node equations, one of them is here and the other is here 1st let us consider what happens at the output, let us write the node equation at the collector nodes then you see the current through R L prime is V 0 G L prime okay, current through C 0 is j Omega C 0 V 0 okay, this takes care of current through this and current through this then there is a current g m V Pi then + another current which goes through C Mu okay, this would be j Omega C Mu multiplied by V 0 – V Pi.

But V Pi is also the same as V i okay, V Pi is same as V i this has been affected by making r x tend to 0 okay. Therefore if you substitute V Pi = V i here and write down the voltage gain between output and input V i, not A vs this is A v then you can very simply see that this is given by j Omega C Mu – g m divided by G L prime + j Omega C Mu + C 0 multiplied by... No that is all.

Student: That is G L prime.

G L prime this is 1 by R L prime, G L prime is 1 by R L prime, is this expression correct?

Student: Sir (())(35:51)

Professor: This = 0, yes of course I should have done it. It is a KCL at node C and therefore this = 0 alright, is this expression correct?

Student: Yes.

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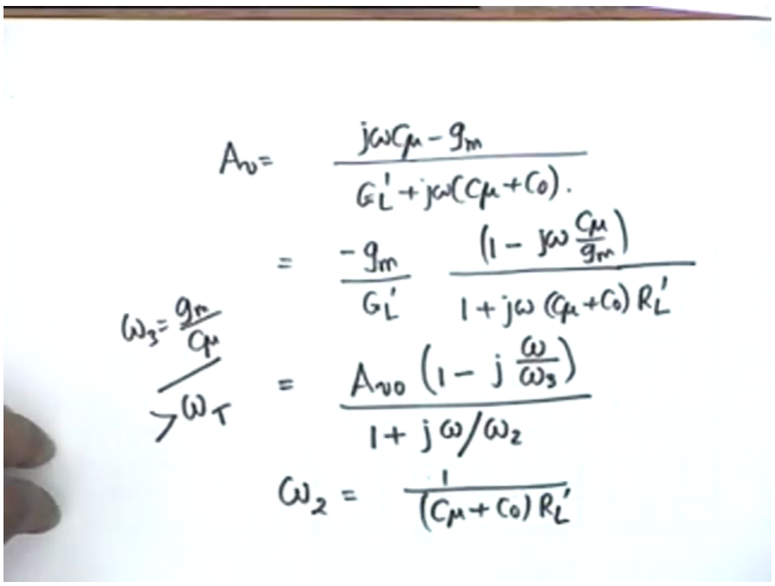

Now look at how I manipulate this expression, j Omega C Mu – g m divided by G L prime + j Omega C Mu + C 0. I can write this as – – g m divided by G L prime, what shall I get here? 1 – j Omega C Mu by g m divided by 1 + j Omega C Mu + C 0 multiplied by R L prime okay. I can write this as, what is this quantity – g m R L prime, this is the mid band voltage gain so I can write this as A v0 1 – j Omega by some quantity Omega 3 where Omega 3 is defined as g m divided by C Mu g m divided by C Mu okay, what is g m divided by C Mu? There is a quantity which is a keen to this, g m divided by C Pi + C Mu is Omega T, this is not quite Omega T, would it be higher than Omega T or lower than Omega T?

Higher than Omega T, so Omega 3 is greater than Omega T and therefore this quantity Omega by Omega 3 shall be a negligible quantity in the frequency range of operation, is this point clear? Omega 3 is greater than Omega T the transition frequency and we are going to operate the transistor much below the transition frequency and therefore this quantity Omega by Omega 3 would be very small compared to unity and the numerator I can approximate this by 1, there is a further justification which I shall show you. In the denominator I can write this is 1 + j Omega divided by Omega 2, where Omega 2 = 1 by C Mu + C 0 multiplied by R L prime okay.

Let us take the example that we have been pursuing so far to get the ratios to get an idea about Omega 3 and Omega 2 and the justification that in the numerator I can ignore this term, let us see what the justification is, let us take the example that we have been pursuing so far.

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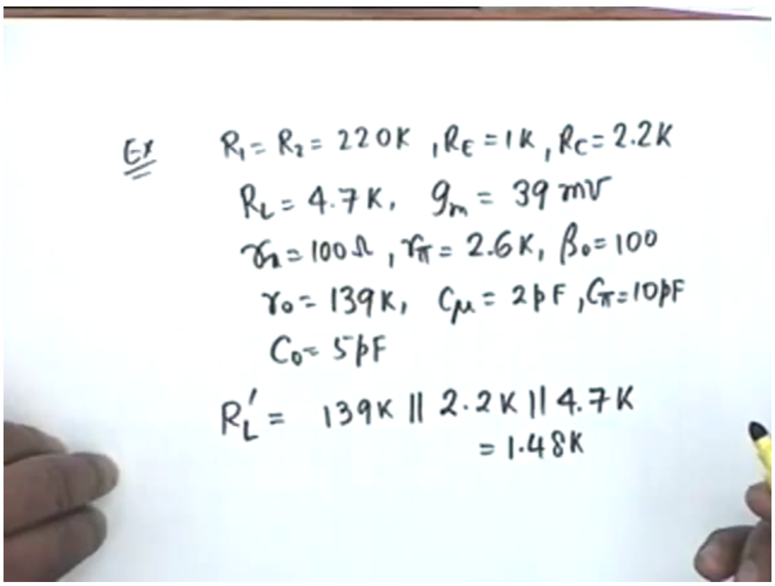

R 1 = R 2 equal 220k, R E = 1K bypass, R C = 2.2 K, R L = 4.7 K, g m with 1 milliampere current is 39 millimhos, r x given 100 ohms we ignore that, r Pi at this current is 2.6 K, Beta 0 =, now you have to say Beta 0 not Beta is 100 product of these 2, r0 is 139K and C Mu is 2 puf, C Pi is 10 puf and C 0 is 5 puf, these are the various parameters of the circuit and the device which are given. So we 1st need to find out is R L prime because this occurs in Omega 2, R L prime would be R 0 that is 139K parallel RC which is 2.2 K parallel 4.7 K and this = 1.48 K we have calculated this earlier also.

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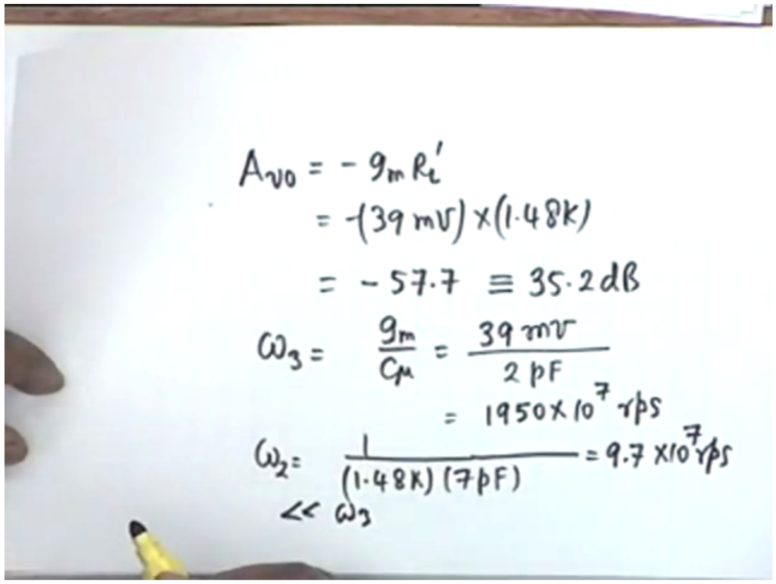

And if I know this then A v0, why the 0 now it is a mid-band value A v0 is – g m R L prime = - 39 millimhos multiplied by 1.48K and this comes out as – 57.7 equivalent to how many decibels, how do you calculate that? 20 log 10 not of – 57.7, it is always the magnitude okay so simply 57.7 and this comes out as 35.2 decibels. Mind you when I write this number as so many decibels, it cannot be an "=" sign, it is equivalent to, triple parallel line means equivalent to okay so - 57.7 gain is equivalent to 35.2, you have to retain the phase separately that the phase shift is 180 degree has to be retained separately okay.

So after this we find out Omega 3 which = g m divided by C Mu that is 39 millimhos divided by C Mu is 2 puf and this you can see is 1950 multiplied by 10 to the 7 radiance per second, there is a reason why I expressed it in 1950 okay. And Omega 2 which = 1 over R L prime which is 1.48K multiplied by C Pi + C Mu which is 7 puf and this calculate out to 9.7 times 10 to the 7 RPF radiance per second. And you notice that Omega 2 is much less than Omega 3 okay, Omega 2 is much less than Omega 3 so the numerator factor can be...

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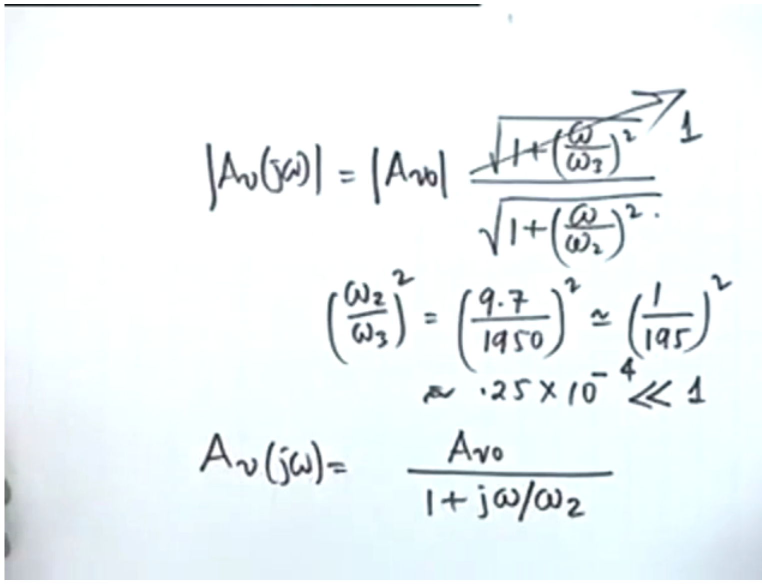

Let us see A v j Omega magnitude would be = A v0 magnitude multiplied by, in the numerator I shall write 1 + Omega by Omega 3 square and in the denominator I shall have one + Omega by Omega 2 square okay. If Omega is nearly = Omega 2 is around Omega 2 then this factor obviously compares favourably with unity but when Omega is nearly Omega 2, Omega 2 by Omega 3 square is 9.7 divide by 1950 square approximately 1 by 195 square approximately 0.25 times 10 to the - 4 which is very small compared to unity and therefore the numerator factor can indeed be ignored, this can be taken as 1. Which means that my expression simplified expression for the voltage gain A v I can write as A v 0 divided by 1 + j Omega by Omega 2 and you notice that this again is a low pass expression, it is like the transfer function of a low pass filter and therefore Omega 2 is the 3 dB cut-off frequency for the voltage gain V 0 by V i, it is not V s mind you, V s is a separate story, it is a different story.

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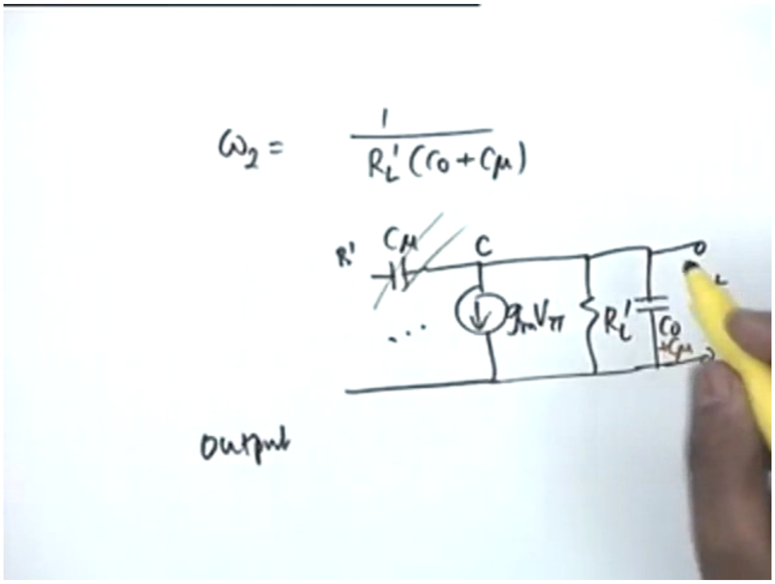

And therefore Omega 2 which = 1 by R L prime C 0 + C Mu is the 3 dB cut-off of the voltage gain V 0 by V i. It also shows a simplification in the equivalent circuit, remember in equivalent circuit there was a C Mu which went to B prime then we have a g m V Pi then R L prime and C 0 okay, I am not drawing the rest of the circuit. This bridge between B prime and collector which is a feedback bridge between the collector and output terminal and the base which is the input terminal this effect of this bridge therefore simply amounts to adding a capacitor across C 0, is not that right? Do you understand this? No, okay if C Mu was not there what would be the cut-off frequency of the output that would be 1 by R L prime C 0.

Now the cut-off frequency is R L prime C 0 + C Mu and therefore as far as output circuit is concerned what you do is you disconnect this C Mu and add a capacitor C Mu to C 0, I have not said anything about the input circuit that I am going to look at separately but as far as output circuit is concerned all that is required to take account of C Mu is to add a capacitor C 0 + C Mu, 2 C Mu, is that clear? So output without caring what the input is without caring what the input is, the output circuit cut-off frequency can be determined by considering the circuit to the equivalent of this by ignoring this feedback between from collector to the base okay, now let us look at the input circuit, the story is quite different there.

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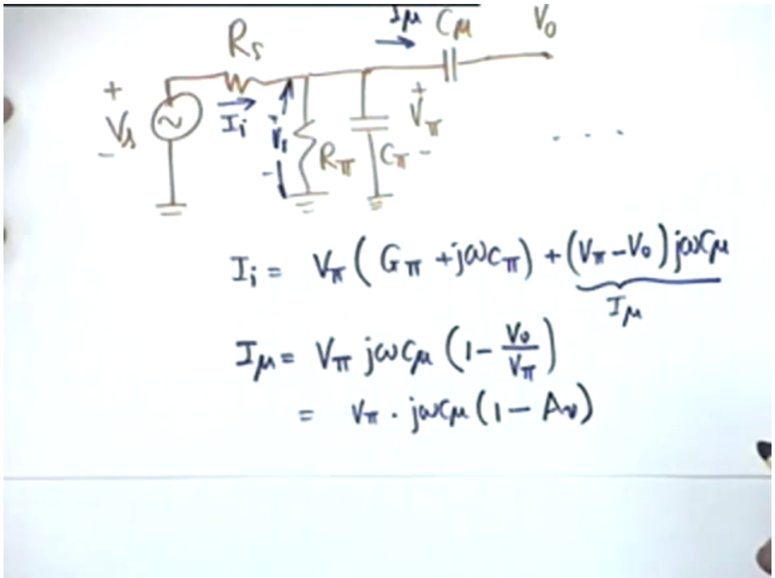

You recall the story is that there is a V s, R s then we have R Pi capital R Pi parallel combination of RB and small r Pi then a C Pi, this is V Pi and there is a C Mu then this node voltage is V 0, I am not drawing the rest of it okay there is a current generator there is whatever it is it does not matter. But what I am interested in is finding I sub i this current, obviously I sub i shall be = V Pi multiplied by G Pi + j Omega C Pi these 2 currents + V Pi – V 0 multiplied by j Omega C Mu, this current I shall call this as I Mu okay, this current I shall call as I Mu. Now I Mu can be written as V Pi j Omega C Mu okay I take V Pi common multiplied by 1 – V 0 divided by V Pi, which = V Pi multiplied by j Omega C Mu 1 – what is this, V Pi is same as V i, it is A v okay.

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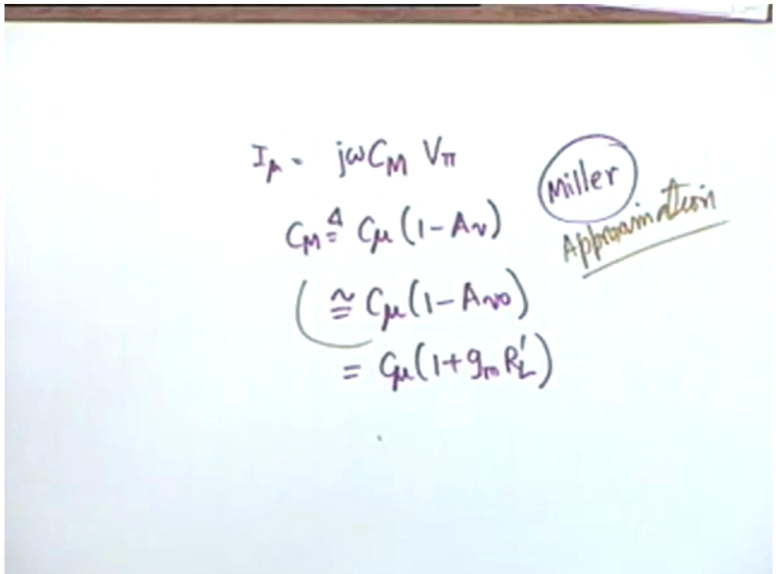

Now it would have been very nice if this was a real quantity, well what I can write is I sub Mu = j Omega C capital M multiplied by V Pi where C M is defined as C Mu 1 – A sub v okay. If I can define this if I define this as a capacitor equivalent capacitor C L then C M shall be given by this. The trouble is that A sub v is no longer a constant, it depends on frequency and A sub v is a complex quantity, it is A v0 divided by 1 + j Omega by Omega 2 and therefore C M is not a pure capacitor, C M is a complex hypothetically defined capacitor is that clear? Nevertheless a gentleman very bold gentleman by the name Miller CJ Miller very bold gentleman he said we do not care whether it is frequency dependent or not, what we will do is we will approximate this A v by its mid band value A v0.

If I do that A v0 is a real quantity which means this = C Mu 1 + g m R L prime, this bought revolution in the design analysis of transistor circuit, it is an revolutionary concept a very gross approximation because a frequency dependent function is being approximated by a frequency independent function alright, obviously this is an approximation and therefore this is called Miller approximation.

Student: Can I know justification?

This is the justification, there is no more justification than bringing convenience into an engineer's stuff, it is simply conveniently is very bold, he said let us do this let us see what happens. Now to an engineer and more often than justifies the means, do you understand what I mean? The results obtained with this approximation which is the end product compare very favourably with exact analysis and most often as I said more often than not justifies the means and therefore do not ask for any more justification. Only justification is that if you assume this then the circuit becomes absolutely simplified, circuit becomes simplified and the end results the results that we get from this simplified circuit compare very favourably with not more than 10 percent deviation even in the worst case and therefore Miller became a hero overnight alright.

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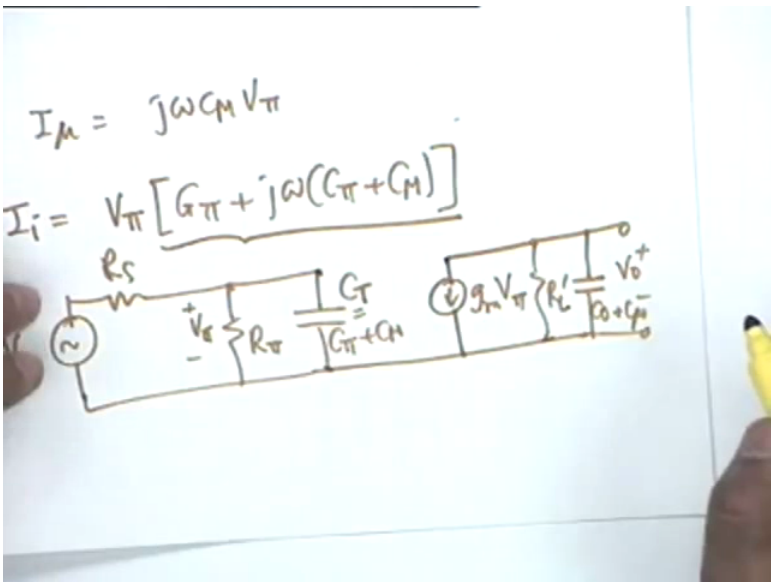

And the circuit if you notice now our I sub Mu = j Omega C M V Pi therefore, I sub i becomes V Pi G Pi + j Omega C Pi + C M, is that right? The equation that we have written for input current I sub i is simply can be expressed as a product of V Pi and a complex admittance, which means that my equivalent circuit now reduces to R s, V s, then R Pi and a single capacitor = C Pi + C M, this is sometimes denoted by C T total capacitance. Total capacitor is the base emitter junction capacitor of the BJT + the Miller capacitor and this is why subscript is capital M the Miller capacitor. And why does C M come in, it takes account of C Mu it takes account of a feed forward from the base to the collector through C Mu.

And we have already seen that as far as the output circuit is concerned this is V Pi, as far as the output circuit is concerned we have g m V Pi in parallel with what? R L prime and C 0 + C Mu this is V 0, you see what Miller has done Miller has decoupled the input and output and therefore the analysis of such a circuit can be done by inspection, nothing else is needed just your pair of eyes and a little bit of exercise of great sense in the head that is all, no node equations, no loop equations, no inversion of matrices, we do not require a computer to feed into the nodes and the parameters and so on, you can just look at it and write down things by inspection and that is what we will do tomorrow.