**Analog Electronic Circuits**
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**Lecture no 18**
**Module no 01**
**Low Frequency Response of Small Signal Amplifiers**

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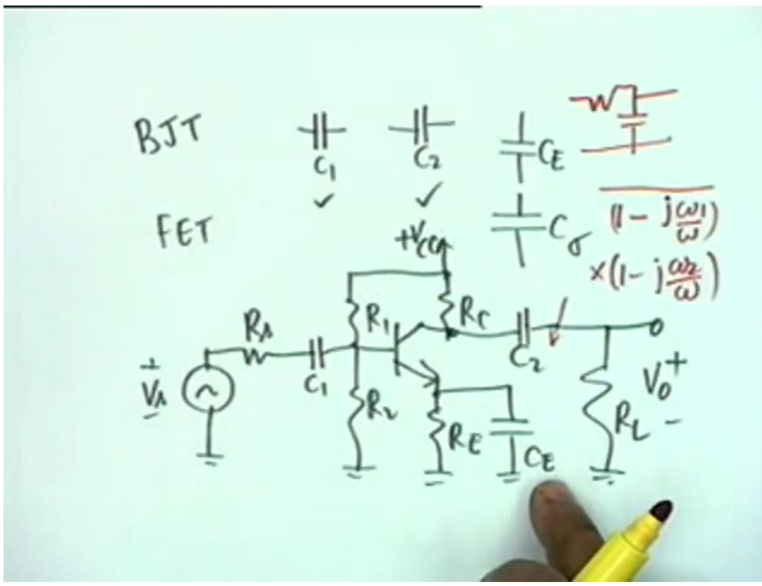


Consider the effects of C 1, C 2 and C 3 these are the 3 capacitors whose effects have to be considered in a BJT. And in an FET, C 1, C 2 the 2 coupling capacitors and the bypass capacitor is C Sigma okay. We start with BJT, the usual circuit is V s, R s, we consider a common emitter circuit is usual this is C 1, there are 2 resistances here R 1 and R 2, this goes to + V cc, we have a resistance R sub C and this is the transistor and there is an R sub E shunted by C E, then we have a coupling capacitor C 2 and the load R L, this is V 0, this is common emitter BJT circuit which we wish to analyse at low frequency. We have done its analysis at mid band where all capacitors were ignored that is that is C 1, C 2 and C E were shorts and C Pi, C Mu and C0 were open this is the mid band situation. In the high frequency situation we consider C 1, C 2, C E as short only the effects of C Pi, C Mu and C0 now we go to the low-frequency situation where it is only these 3 capacitors whose effects have to be considered.

Now I must point out that that in integrated circuits, one is not allowed to use capacitors and we have seen different kinds of Circuits at least for biasing with the help of current mirrors or current sources, where coupling capacitors are not permitted and therefore what you have to do is to adjust the DC levels such that the DC level of the previous stage does not affect the biasing of the next stage and therefore you require current mirrors, you require what is known as DC level shifters and things like that. We shall come to those when we consider Opamp circuitry in this class but at the present time at least in discrete circuits we have to consider the effects of C 1, C 2 and C E.

Now a few qualitative remarks before we go to the actual analysis you notice that there are 3 capacitors and if you draw the equivalent circuit we will see that these capacitors are independent of each other C 1, C 2 and C E are independent of each other, one does not affect the other they are not connected in series or in parallel that we can combine okay they are independent capacitors. And therefore what we expect is that there shall be 3poles corresponding to 3 capacitors and qualitatively you can see that C 1 will have a high pass effect. Obviously the DC response DC cannot pass through C 1 so the signal is at 0 frequency no signal shall come to the transistor and at high frequencies C 1 acts as a short so it is a high pass effect.

High pass effect means that in the denominator we expect a term like 1 – j, is it Omega by Omega 1 or Omega 1 by mega?

Student: Omega by Omega 1.

No it is Omega 1 by mega, at DC when Omega is 0 it should be 0 is not that right? High pass filter, I did this at the beginning of the discussion CR series see and shunt R this is the kind of factor that we get, 1 – j Omega 1 by Omega alright. Similarly, due to C 2 which also blocks DC there shall be another high pass effect and therefore we expect another term 1 – j Omega 2 by Omega alright due to C 2. But due to C E, C E comes in shunt and therefore it shall have a low pass effect it should have a low pass effect C E comes in shunt okay, series resistance shunt capacitance this is a low pass effect but you see that even if C E = infinity the gain is not 0 there is a gain okay and therefore this is not quite pure low pass. Also if C E = 0 even then there is again for it is not high pass either, do you understand this?

Student: No Sir.

If C E is infinity okay if C E is infinity there is a gain, the gain is larger the gain is the mid band value is C 1 and C 2 effects are neglected okay. If C E is 0 then the gain drastically reduces because I am bypassed emitter resistance but there is a gain, the gain is not 0 so it is neither low pass nor high pass it is something in between and as we shall show as we shall show the effect of C E...

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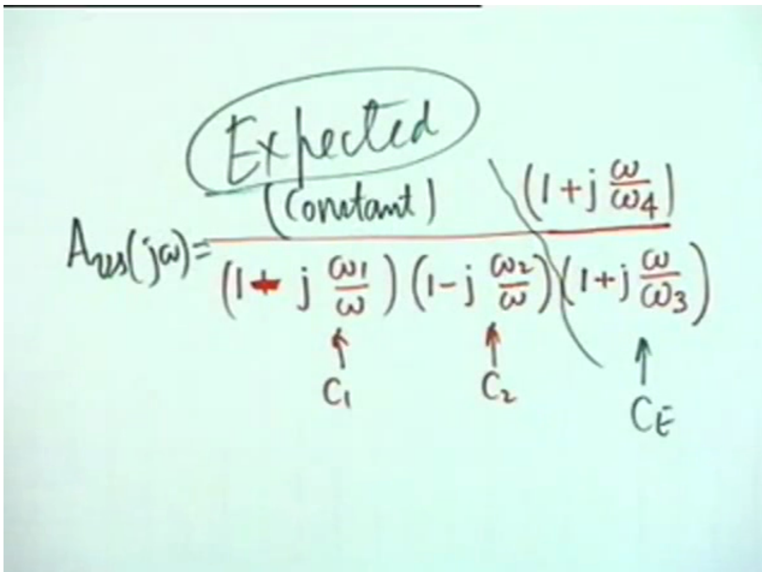


Well, effect of C 1 is to introduce a factor 1 – why – because Omega occurs in the denominator, it is actually 1 + Omega by j Omega 1 by j Omega and this j we have bought it up multiplied by 1 – j Omega 2 by Omega this is due to C 1 due to C 2, due to C E we shall have a pole of the low pass type 1 + j Omega by Omega 3 and 0 that is 1 + j Omega by some quantity Omega 4, these 2 comes due to series these are the poles and zeros, there is a pole and there is a 0 the pole is of the low pass type.

“Professor–student conversation starts”

Student: Sir C 2 is in series with R1, is not it in parallel with R2?

Professor: C 2 is in parallel with...

Student: R2.

Professor: Where is R2?

Student: Sorry R C.

Professor: C 2 is in parallel with R C that is fine in the equivalent circuit nought is not in parallel, R C will come from here to ground, R L is from here to ground, C 2 is the bridge, C 2 is not in parallel with R L we will see this in the equivalent circuit. But qualitatively an engineer's best tool is what?

Student: Approximation.

Professor: Number 1, number 2... How does we obtain the approximation?

Student: Common sense.

Professor: Common sense and observation, as I said there is difference between seeing and observing.

"Professor–student conversation ends"

I will tell you the story later but we want to look at it and see what is it that we expect because C E comes in shunt it goes to ground it should have a low pass effect and this is what is expected from this. On the other hand, C E also creates a 0 because it is not pure low pass the gain is neither 0 at infinity nor at the origin so it is neither a pure low pass nor a pure high pass in fact it is a combination as we shall see. Number 2, if Omega 4 is infinity which will occur when C E = 0 okay this will occur when C E = 0 if Omega 4 is infinity then obviously this term shall be absent, there still shall exist a gain which we shall not characterise at the moment we will simply call it a constant and this is what we expect for A vs j Omega expected, now let us see one by one what happens.

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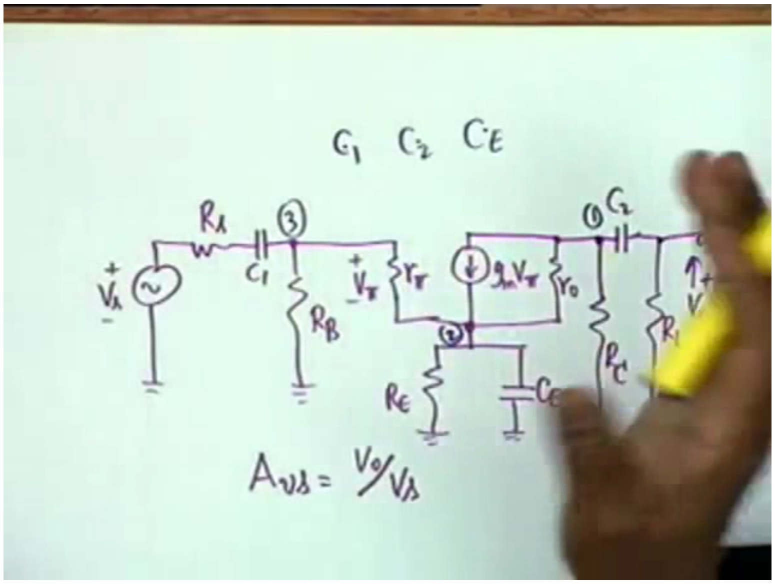


Obviously, if we want to draw the equivalent circuit lets draw the equivalent circuit and perhaps the magnitude of the problem shall be absolutely clear. The equivalent circuit is V s, R s, we have a C 1 then we have the parallel combination of R 1 and R 2, which will be R B, we ignore rx because that creates a lot of complications we ignore rx, we have an r Pi now I do not bring it to ground because we are considering the effect of C E alright, r Pi and the voltage across this is V Pi then we have a g m V Pi in parallel with r 0, this point is not grounded, from this point we have the parallel combination of 2 components R E and C E, R E and C E and then from this which is the collector point we have first R C to ground the biasing resistance then C 2 and till and R L, we cannot combine R C and R L now because there is a bridging capacitor C 2 and this is the voltage V 0 that we want to find out and our aim is to find A vs which = V 0 divided by V s.

Obviously if we have to do an exact analysis of this, how many nodes do you have to consider? One V 0 well actually V 0 by V s we want to find out so so this we do not write in node equation here, we write a node equation here 1 then another node equation here 2 and the 3rd node equation would be here 3; 3 node equations are required and therefore you will have to invert if you do by node analysis we will have to invert a 3 by 3 matrix which is pretty tough so engineering approximation comes into effect. What we shall do is 1st we will consider the effect of each capacitor independently of the others. In other words when you consider the effects of C

1 we shall assume C 2 to be short and C E to be short alright then you consider we will justify the procedure later as I said engineers often justify the procedure by the end rather than logic by the end results.

If there is nothing there is no success like success and therefore if you succeed if you get an approximation which is valid in practice, well your procedure is valid okay. It is gross logically absolutely not correct but an engineer has no other way he does not want to make life complicated. After all even if you do this analysis by using a spice computer program for example or any other existing subroutine you have to make adjustments of ultimately and therefore is gaining approximations are required. So what we will do is we will consider the effects of C 1, C 2 and C E one at a time that is when we consider effect of C 1, we assume C 2 to the infinite and C E to be infinite so that they act as short. When we consider the effect of C 2, we consider C 1 to be infinite and C E to be infinite okay.

Similarly when we consider the effect of C E we shall assume these 2 to be short then we will try to combine okay then we will try to combine and this combination is very illuminating it is also a very bold step but it works. So let us see first effect of C 1, in considering the effect of C 1 we consider C E as a short therefore this point will go to ground and this will be a short alright, let us see what happens to this equivalent circuit.

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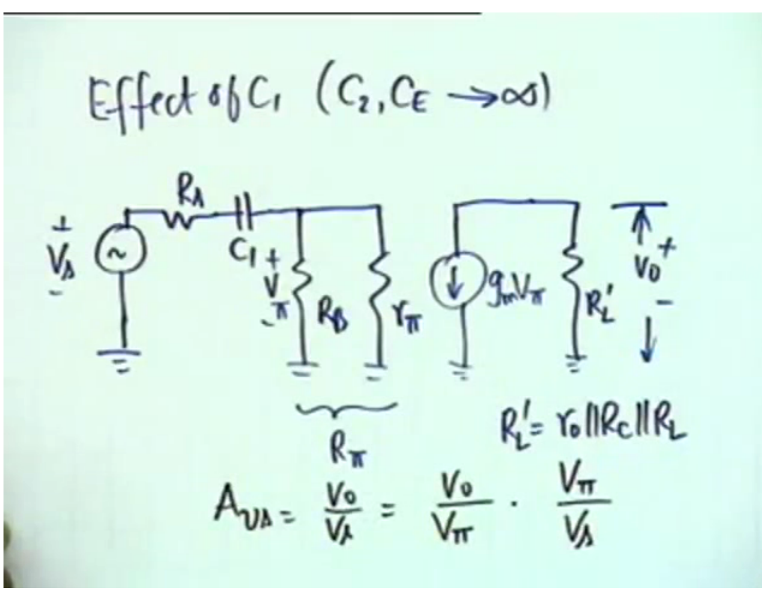

We have a V s effect of C 1 where we assume C 2, C E both go to infinity that is they are shorts. I have an R s, C 1, and from here I have R B and r Pi, we have already combined these 2 into a single resistance capital R Pi okay, this is V Pi voltage across R B and then we have a g m V Pi going to ground and if we look at this now let us do this simplification right away. If you look at this circuit C 2 acts as a short and r 0 goes to ground and therefore r 0, R C and R L comes in parallel, which we can combine into a single resistance R L prime and this is V 0, R L prime = r 0 parallel R C parallel R L. Once again an engineering approximation because it is possible to include r 0 without much of a complication we are including it, if it is not convenient then we say r 0 is very large you understand okay, life if approximation and electronic circuit is no exception alright.

Now to calculate the gain that is A vs which = V 0 by V s, I can write V 0 by V Pi multiplied by V Pi by V s in 2 steps alright, and the $1^{st}$ factor V 0 by V Pi is simply = - g m R L prime so we have to calculate V Pi over V s that is not also difficult story because there is potential division between R s, C 1 and R Pi okay.

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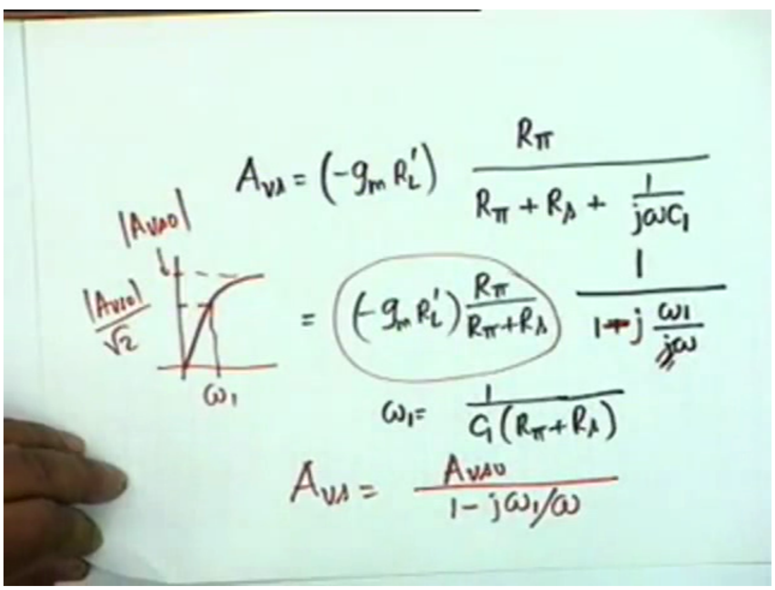

Therefore we can write A vs as = – g m R L prime then the potential division I can write as R Pi divided by R Pi + R s + 1 over j Omega C 1 agreed, and the effect of C 1 is obvious that = – g m R L prime multiplied by R Pi divided by R Pi + R s, I take R Pi + R s common then we have 1 divided by 1 + Omega 1 divided by j mega, where Omega 1 = 1 over C 1 multiplied by R Pi + R s is that okay. All we have done is we have taken R Pi + R s so 1 by j Omega C 1 R Pi + R s and 1 by C 1 R Pi + R s we have put as the constant Omega 1 alright.

And this j in the denominator can be written as with the negative sign, we can make this negative and bring j here. Also notice what is this factor, this is the mid band voltage gain A vs 0 alright so I can write A vs as = A vs 0 divided by 1 – j Omega 1 divided by Omega alright. As expected as expected this is a high pass filter and if C 2 and C E indeed go to infinity then Omega 1 will be the 3 dB low frequency 3 dB cut-off frequency okay low-frequency 3 dB cut-off that is if I plot A vs versus Omega magnitude then at mid band it will become magnitude A vs 0 and 1 by root 2 this will reach that Omega 1, it is a high pass effect alright, any question on this?

This was very simple, one thing that I want to point out here is the following that is Omega 1 is the reciprocal of time constant, Omega 1 is the reciprocal of time constant and how do you determine the time constant, if you look at the circuit the time constant is associated with the capacitor C 1 and the resistance that comes to multiply C 1 is the sum of R s and R Pi, which means that this is the resistance seen by C 1 in a Thevenin equivalent circuit sense that is resistance seen from the terminals of C 1 with independent sources eliminated, which means that V s has to be shorted, if V s is shorted than R s comes in series with R Pi alright.

So this time constant this time constant determined by C 1 and the Thevenin resistance that C 1 sees into the circuit okay. The interpretation will be useful at a later point of time when we have let say 9 capacitors in the circuit and load analysis or loop analysis is going to be extremely tough, we will have to use of shortcuts like this engineering approximations okay.

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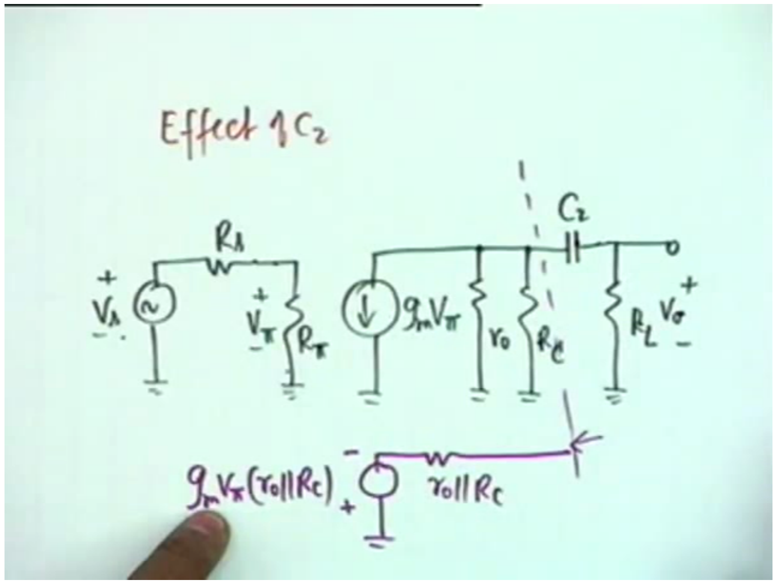


Let us look at the effects of C 2, when we consider the effects of C 2 our equivalent circuit now C 1 and C E are shorts and therefore our equivalent circuit would be V s, R s, no C 1, C 1 is a short and then we have simply the parallel combination of R B and R Pi so we will call this as R Pi, this is V Pi, then we have g m V Pi okay then now you have to be careful r 0 than an R C now comes C 2 and you have an R L, this is V 0. Obviously, one can simplify this circuit very simply but if we apply Thevenin's theorem to the left of this line then you get a voltage source g m V Pi multiplied by the parallel combination of r 0 and R C with a negative sign and the Thevenin equivalent impedance would be simply the parallel combination of r 0 and R C okay.

So if I do this, let me write this down here – + the value would be g m V Pi r 0 parallel R C and in series with a resistance which is r 0 parallel R C. If I do that then you see r 0 parallel R C comes in series with C 2 and then you can find V 0 as a potential division alright, and V Pi obviously is V s multiplied by R Pi divided by R Pi + R s okay so A vs can be written down by inspection, is that clear.

Student: Sir Can you repeat?

Can I repeat? Okay, V 0 can be written down in terms of V Pi, I have applied Thevenin's theorem here to the left of this line so a voltage source and a series resistance r 0 parallel R C, which comes in series with C 2 and R L therefore I can find V 0 in terms of V Pi and V Pi in terms of V s is simply the potential division between R s and R Pi so the expression for A vs can be written down by inspection and you will have to do that as our course proceeds, we are not going to derive everything.

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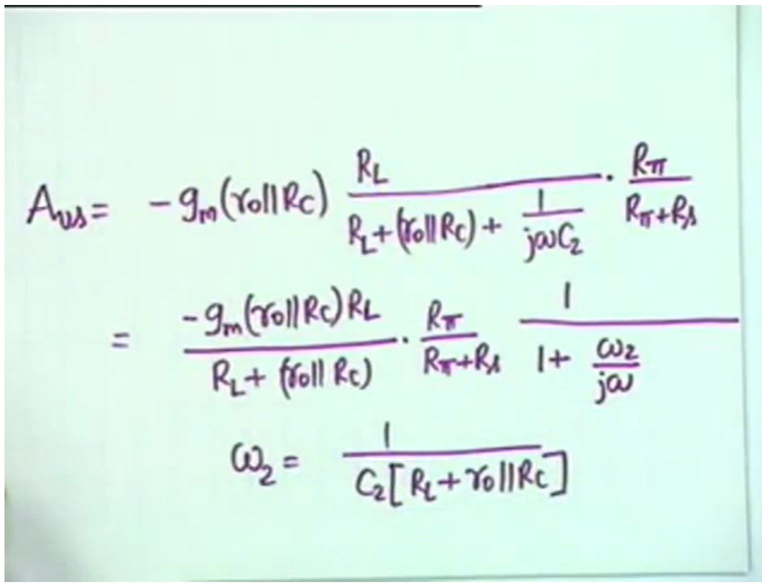


It would be simply – g m r 0 parallel R C okay let us find out 1[st] output voltage V 0 in terms of V Pi, this should be R L divided by R L + r 0 parallel R C then + 1 over j Omega C 2 this is V 0 by V Pi then this should be multiplied by V Pi by V s which is R Pi divided by R Pi + R s agreed okay. Now we notice you notice something interesting that I can write this as – g m r 0 parallel R C multiplied by R L divided by R L + r 0 parallel R C okay I have reproduced this term I have taken R L and I have taken from the denominator this term and then let us introduce this also R Pi divided by R Pi + R s, what remains is 1 divided by 1 + Omega 2 divided by j Omega where Omega 2 is 1 over C 2 multiplied by R L + r 0 parallel R C agreed. And if you look at this expression carefully what is this expression?

Student: r 0 parallel R C parallel R L.

Professor: That is correct and therefore I can write the gain low-frequency gain A vs in this form, I can write – g m R L prime wonderful, is this point clear to everybody?

Student: Yes.

Student: Yes.

Professor: Okay.

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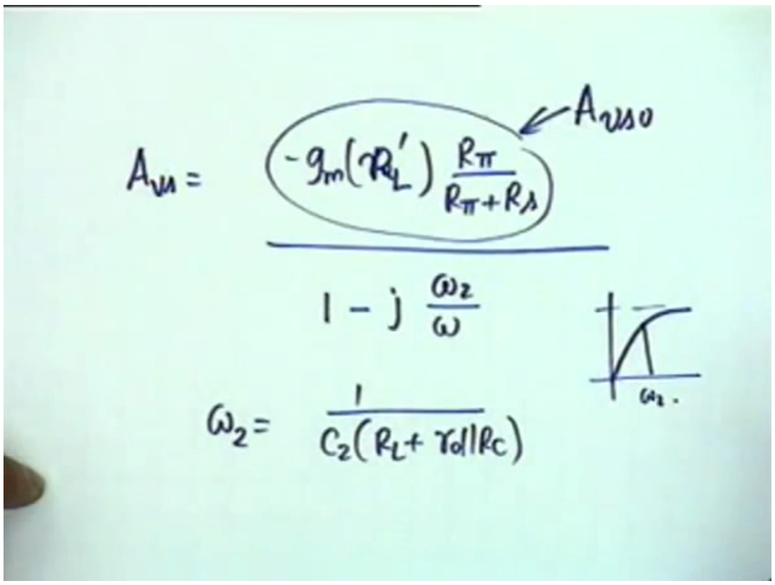


GM R L prime multiplied by R Pi divided by R Pi + R s and obviously this = A vs 0 divided by 1 - j, j in the denominator we bring it up so it becomes - Omega 2 divided by Omega where Omega 2 = 1 over C 2 R L + r 0 parallel R C okay. And I have got again I have validated the fact C 2 has a high pass effect that is if C 1 and C E are shorts then the 2 causes the DC response to be 0 and then it rises like this at high frequencies again the gain is A vs 0 and the cut-off occurs at Omega 2 alright Omega 2. If we combine oh before we combine, you note again that C 2 Omega 2 is inverse of time constant and time constant is the product of C 2 the capacitance and what resistance does come in parallel if you look at the circuit, what resistance comes in parallel with C 2 multiply C 2?

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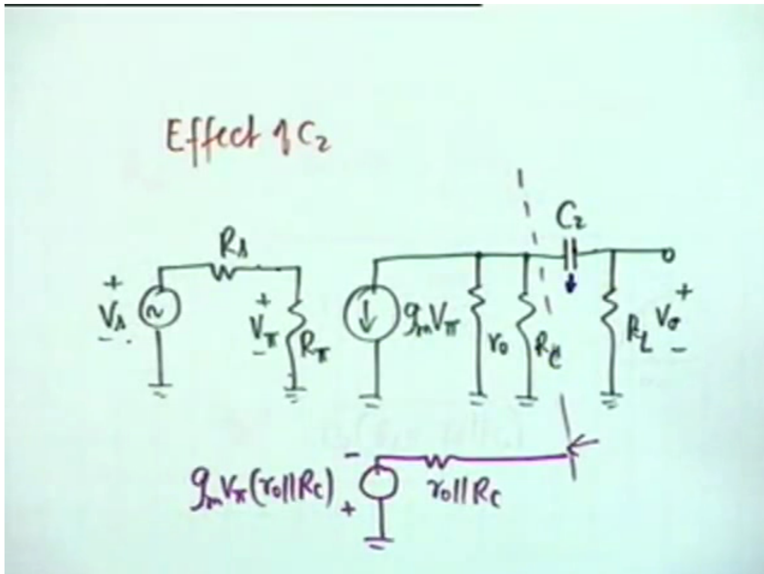


It is R L + the equivalent of this, is not this the Thevenin resistance that C 2 sees because this is a current generator and Thevenin resistance V s = 0 so V Pi = 0 so this current is 0 and therefore what you see is C 2 in parallel with R L + r 0 + R C okay.

Student: Sir in the previous case also (())(27:34) and 2 resistances on the other side.

Professor: Okay we combine them.

Student: Can we combine them all together by saying that they come in series?

Professor: Here also they come in series, what C 2 sees is this is open so what C 2 sees R s + r 0 parallel R C same story okay.

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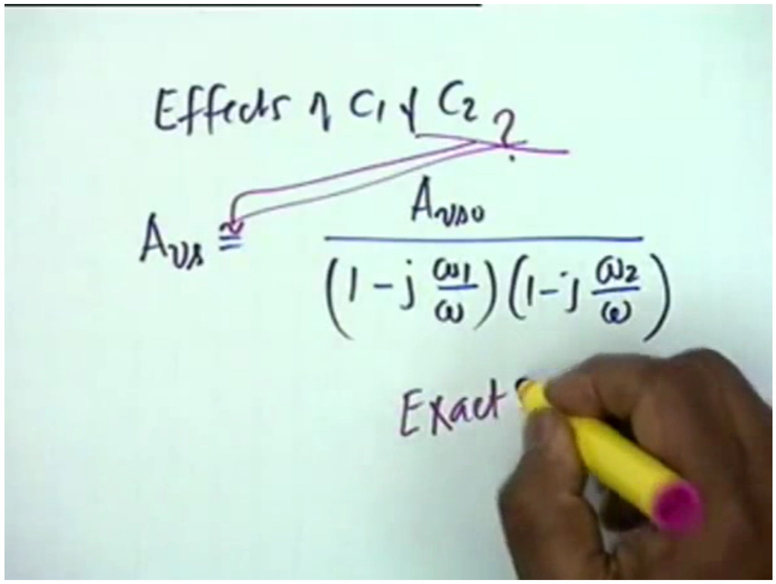


So this is another interesting and important observation which we shall utilize at a later time that is this frequency this cut-off frequency is contributed by C 2 along with what resistance what Thevenin resistance it sees across it. And now if I combine C 1 and C 2 together I can make the engineering approximation A vs = A vs 0 divided by 1 – j one frequency due to C 1 and the other frequency due to C 2. Question is whether we should write this we should put this with an approximation sign or not, should I put an approximation sign here or is it exact?

Effect of C 1 and C 2 together is both of them I found that if I ignore C 2 and C E then I get this expression, if I ignore C 1 and C E I get this expression, now I am making a combination, I claim that this is exact, no such thing is needed. If you had considered C 1 and C 2 together it would have been the same story, if you differ from this let me know your logic okay, I claim that this is an exact expression however, C E creates problem.

Student: Sir but what is the logic behind anything exact?

Professor: You find it out, why should I answer all questions?

Effect of C E... You actually carry it out and see that it is exact this happens the logic okay not the logic the clue, the clue is that the input and output circuits are isolated from each other so they do not interact with each other, C 1 does not affect C 2, C 2 does not affect C 1 and therefore you can calculate the input cut-off frequency, output cut-off frequency independently and this is the result. There is also an engineer's eye which has to detect that this is an exact equation okay.

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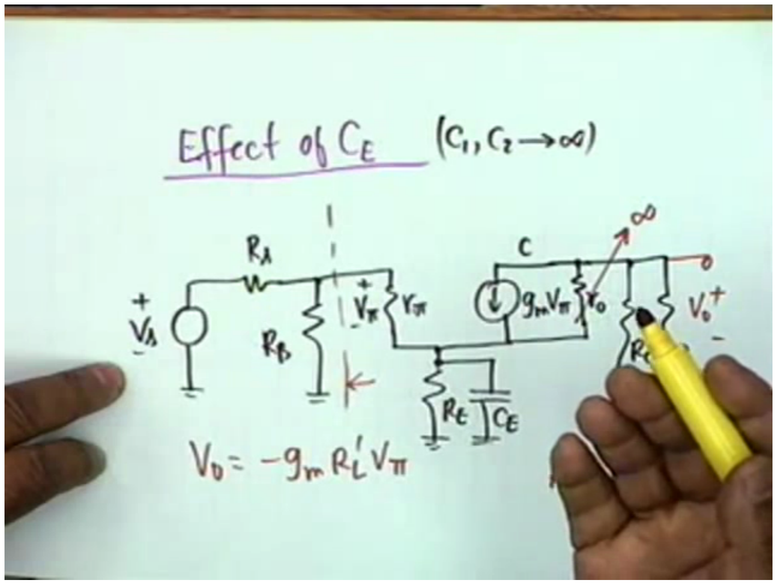


Now when we consider the effect of C E we have a problem we have a problem, look at the... Effect of C E we will consider C 1 and C 2 to go to infinity okay, let us look at the equivalent circuit then the problem that is in our hand shall be clearly understood. We have an R s and we have...

Student: C 1, C 2 goes to 0...

Professor: Infinity that is short-circuit, we are not considering their effects okay alright. Now we cannot combine R B and r Pi and fortunately because C E is not short-circuit and therefore we have to consider them independently R B and then an r Pi, this voltage is V Pi, what comes here is a parallel combination of R E and C E.

Student: We have not taken r 0.

Professor: Wait a second, we have not come to that yet. Then we have the g m V Pi and since this is the collector there shall be a resistance r 0 across g m V Pi alright and then we have, C 2 is short therefore we have R C in parallel with R L, and you see the problem now.

Student: Input and output are not isolated this time.

Professor: They are not isolated this time, they are coupled through R E and C E and therefore this circuit is a bit more complicated than the 2 circuits that we have considered however some simplifications are possible.

Now an engineer applies his common sense, he says if r 0 is included life becomes unnecessarily tough because this current generator will be shunted by r 0 and r 0 cannot be combined with R C and R L because there is something else here so we assume 1st thing we assume is r 0 goes to infinity and we say R C parallel R L, if you want to use another notation you are most welcome to do it but I will use R L prime, which is correct because we are assuming r 0 to go to infinity so this is R L prime.

Now things become a little simplified because then V 0 as you can see is still = – g m V Pi R L prime. V 0 is – g m R L prime V Pi so what you have to find out is V Pi, V Pi divided by V s however no simple potential division occurs anymore because there are 2 resistances here however this can be taken care of because a great man Thevenin has supplied us with a tool, which we can we can reduce this to a voltage source and an equivalent series resistance, let us see what this equivalent circuit now becomes with this simplification, is this point clear?

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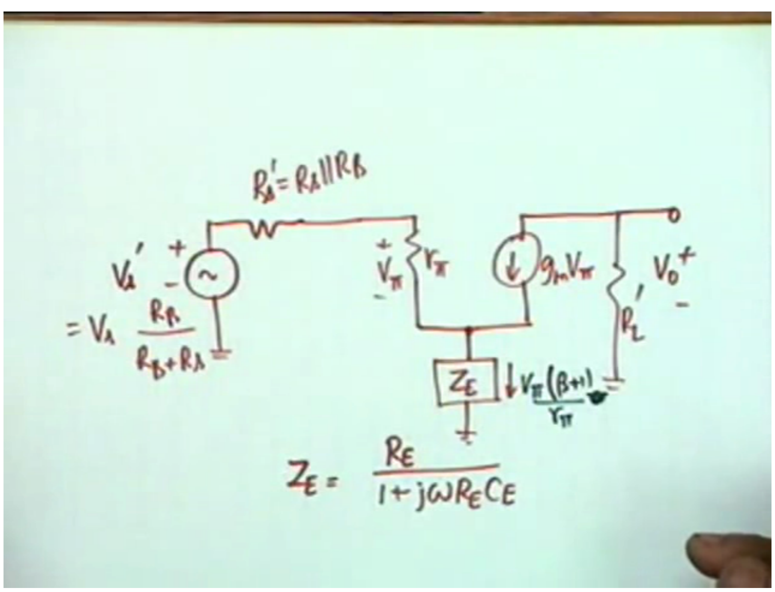

We apply Thevenin to the left then we get V s prime which = V s R B divided by R B + R s, a voltage source V s prime in series with a resistance which is R s prime, which is the parallel combination of R s and R B then we have an r Pi the voltage across which is V Pi and instead of writing 2 elements R E and C E let us write their equivalent impedance I call this Z E, what is Z E? Z E is if you recall R E divided by 1 + j Omega R E C E alright so we are writing the impedance because we require this we will require this and then we have a g m V Pi and R L prime, R L prime this is V 0 okay. The current the current through this the current through this combination ZE is obviously g m V Pi + V Pi by r Pi so it would be V Pi times g m + 1 by r Pi, which is Beta + 1 divided by r Pi okay.

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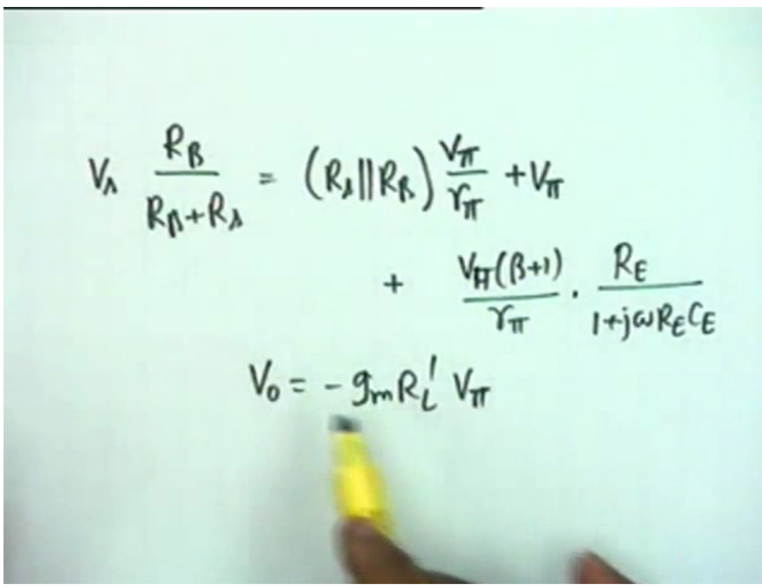

So what I do not is to write a KVL, what I have to find out is I have already found out V 0 by V Pi this is – g m R L prime, what I have to found out now is V Pi divided by V s so if I write a KVL around this slope KVL around this slope then I get V s R B divided by R B + R s, this is V s prime, this would be = R s prime which is R s parallel R B multiplied by what is the current through this?

Student: I B.

Professor: I do not want another notation another symbol.

V Pi by r Pi okay which is the drop in this resistance then + the drop in r Pi is V Pi, I do not have to ride V Pi by r Pi multiplied by r Pi it is V Pi, + the drop in V E which is V Pi Beta + 1 divided by r Pi multiplied by Z E which is R E divided by 1 + j Omega R E C E, this is the equation that will give us V Pi in terms of V s alright and we already have found out V 0 = – g m R L prime V Pi and therefore one can find out one can simplify and find out A vs, which is V s V 0 divided by V s okay I will skip this algebra and I will write the final results like this you do this algebra yourself and you can write the final results as follows, if I have made a mistake you will have to point out to me.

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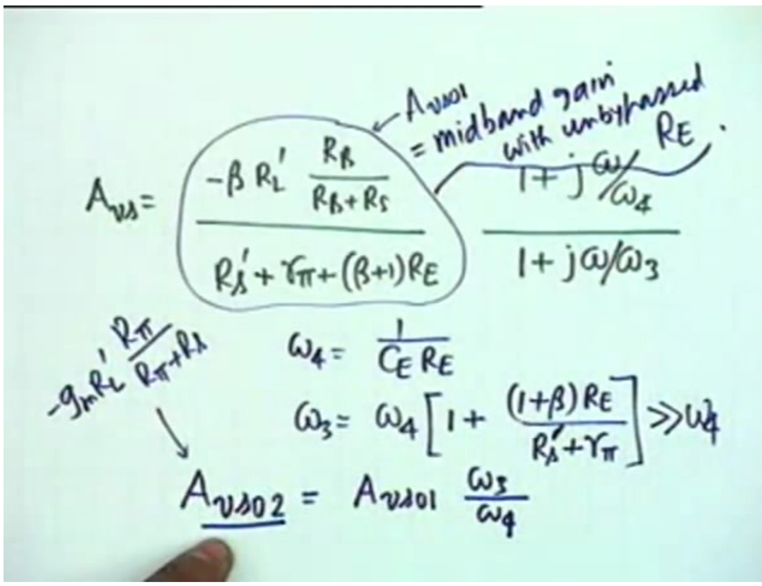


minus Beta R L prime R B divided by R B + R L divided by R s prime + r Pi + Beta + 1 R E, this multiplied by 1 + j Omega by Omega 4 divided by 1 + j Omega by Omega 3, when I will give you the values, the values are Omega 4 = 1 over C E R E, and Omega 3 = Omega 4 multiplied by 1 + 1 + Beta R E divided by R s prime + r Pi this is it. Now this expression is not as simple as the earlier one, it has a pole and a low pass kind of a pole because Omega occurs in the numerator, j Omega by Omega 3, it is not Omega 3 by j Omega so it is a low pass effect but it is 0 also at S = where is the 0? At S = – Omega 4 okay than 0 also.

And therefore when Omega tends to 0 when Omega tends to 0 the value of the gain these 2 terms shall disappear, the value of the gain will be simply this term, we call this as A vs 01 alright that is when Omega tends to 0 this term drops out so we call this A vs 01. On the other hand when

Omega tends to infinity when Omega tends to infinity the gain will again be a constant but this value shall be A vs 02 this would be that is right A vs 01 multiplied by Omega 3 divided by Omega 4, do this stands to reason? If you simplify this you shall see that A vs 01 is the gain of the common emitter amplifier with unbypassed resistor, or Omega tends to 0 means what? Capacitor C E is open alright and you can show that this is approximately – R L prime by R E you can see this immediately right from here okay.

So A vs 01 is the gain of the common emitter amplifier with mid band gain of the common emitter amplifier with unbypassed emitter resistance, is the point clear? Omega tends to 0 means C E is open so R E is not bypassed, this = mid band gain with unbypassed R E. On the other hand, when Omega tends to infinity C E is short, C E is short and therefore A vs 02 should be = what, mid band gain with emitter grounded and this was the real mid band gain that we had calculated, we had assumed that C 1, C 2 and C E are short-circuits and therefore can you guess what this would be? – g m R L prime multiplied by R Pi divided by R Pi + R s, all this we talked about from the expression and from commonsense you can actually show that this is true. All that is required is to manipulate this expression and the ratio Omega 3 by Omega 4, which one is greater? Of these 2 which one is greater?

02 why because Omega 3 is much greater than Omega 4 much greater why because Beta + 1 R E, R E, r Pi and R s prime they will be of the same order or magnitude and therefore this factor shall be approximately half so it is Beta by 2 which is typically 50 so it is 51 times Omega 4 which means that Omega 3 is much greater than Omega 4 is much greater than Omega 4. But it shows that if you plot this expression the magnitude versus Omega what kind of a plot shall we get what kind of a plot shall we get?

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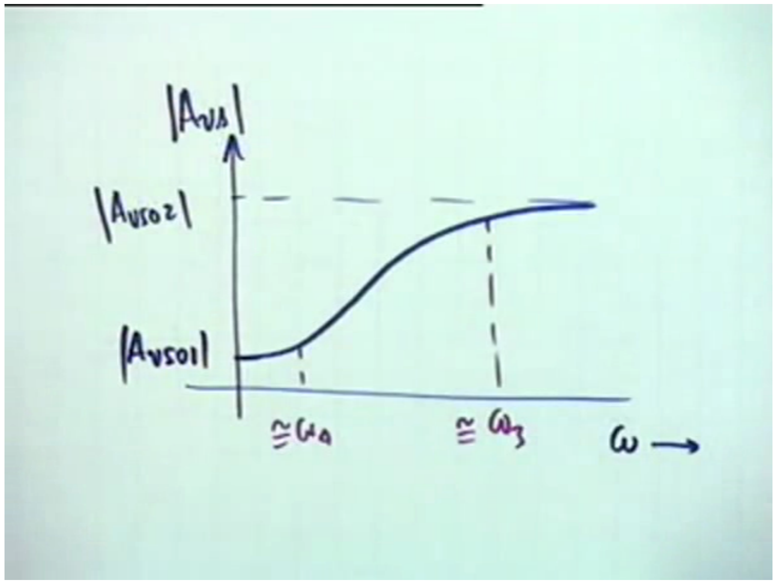


If you plot A vs magnitude versus Omega then at DC it is the gain with unbypassed R E A vs 01 and at infinite frequencies it is greater than A vs 01, it is A vs 02 so you will have something like this, it is a kind of high pass it is a kind of high pass now where will this where will this frequencies Omega 3 and Omega 4 be? Omega 4 obviously would be somewhere here okay Omega 4 would be somewhere here where the curve just starts to rise, this would be approximately Omega 4, and Omega 3 would be somewhere here approximately okay so Omega 3 this is kind of a high pass effect and since Omega 3 is much greater than Omega 4 they are non-interacting which means that if C 1 and C 2 are short circuits, C E has the effect of producing a high frequency 3 dB cut-off at Omega 3 okay.

So our situation is that we have Omega 1 due to C 1, we have Omega 2 due to C 2, we have a 0 at Omega 4 due to C E, we have pole at Omega 3 due to C E so who will determine the low frequency cut-off? Obviously of these 4 frequencies who will determine? How do you know?

“Professor–student conversation starts”

Student: Omega 3.

Student: We will exclude Omega 4

Professor: We shall have to exclude Omega 4 because Omega 3 is much greater than Omega 4 okay so Omega 4 does not determine so will determine?

Student: The highest...

Professor: The highest of these 3 will have the major effect is not it? Suppose Omega 1 occurs here, Omega 2 occurs here these are of no concern what you are concerned with is the mid band gain where does it come 3 dB below okay let us take an example.

"Professor–student conversation ends"

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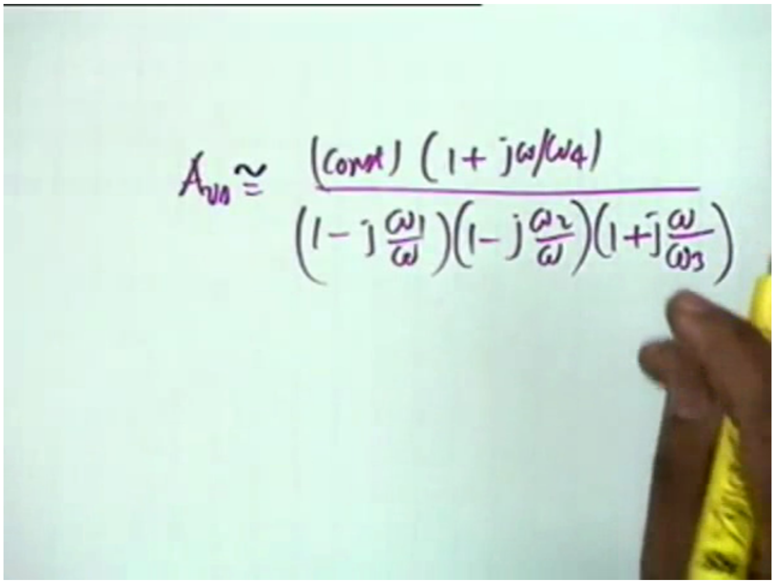


Now would you do not agree that our initial gas was A vs would be = some constant multiplied by 1 + j Omega by Omega 4 this was the initial gas, 1 – j Omega 1 by mega, 1 – j Omega 2 by Omega then 1 + j Omega by Omega 3 and remember we did not put this constant = A vs 0 why because it was not A vs 0, it was either A vs 01 or 02 depending on whether you consider Omega tends to 0 or Omega tends to infinity okay so this constant is not the mid band gain alright.

Now if you combine all of them if you combine all of them that is C 1, C 2 and C E then we will get an expression like this but this expression will now be actually an approximate expression, why approximate? Because the input and output circuits are no longer decoupled each other we cannot decouple and therefore this is an approximate expression and as I said Omega 4 can be taken out of consideration, the high frequency 3 dB point shall be no I am sorry low frequency 3 dB point low frequency 3 dB point will be determined by the highest of these 3; Omega 1, Omega 2 and Omega 3 okay. Let us take an example, the same example that we have been considering so far.

Student: Sir why cannot be put this constant = A vs 01?

Professor: Is this constant = A vs 01... Okay, if Omega tends to 0 then what does this corresponds to... 0 I am sorry Infinity so this is not A vs okay there is a problem.

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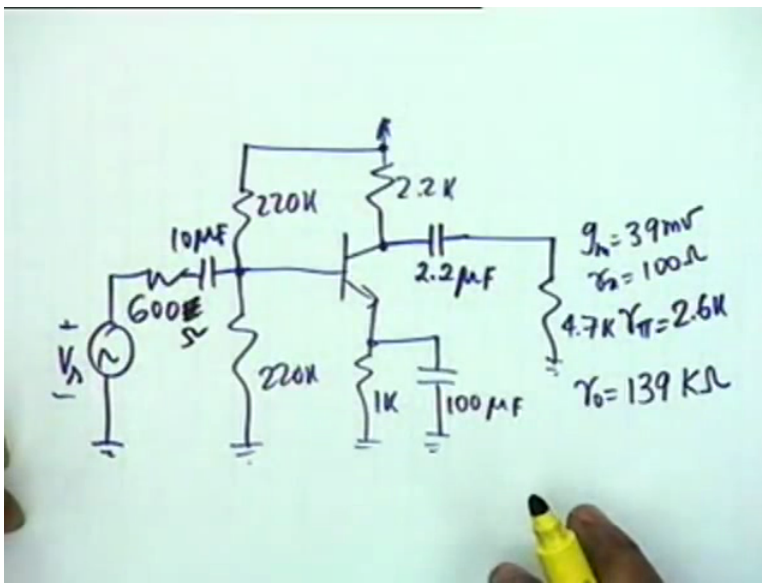


Now we consider the same circuit that is 2.2 K, 1K, let this capacitor be 100 microfarads this also shows some typical values that we have to use in practice then 2.2 microfarads, you see this is about 50 times this is the kind of thing that you will have to use I will tell you why, 4.7 K and you have two resistors 220 K, 220 K then you have a 10 microfarads condenser here, a 600 ohms resistance we had considered this and a V s okay this is the circuit with the numerical values, g m is given as 39 millimho as usual, rx is given as 100 ohms which we have ignored compared to 2.6 K which is r 52.6 K 2600 ohms we can ignore 100 ohms and r 0 poor quantity sometimes is ignored, sometimes is not ignored depending on our convenience but we have to apologize to r 0 because it makes our life difficult so we will keep it out of the door, when it is convenient we will bring it inside when it is not intervene in.

Student: Sir what is R s?

Professor: 600 ohms, if it is 600 kilo ohms nothing will come to the circuit sorry 600 ohms okay.

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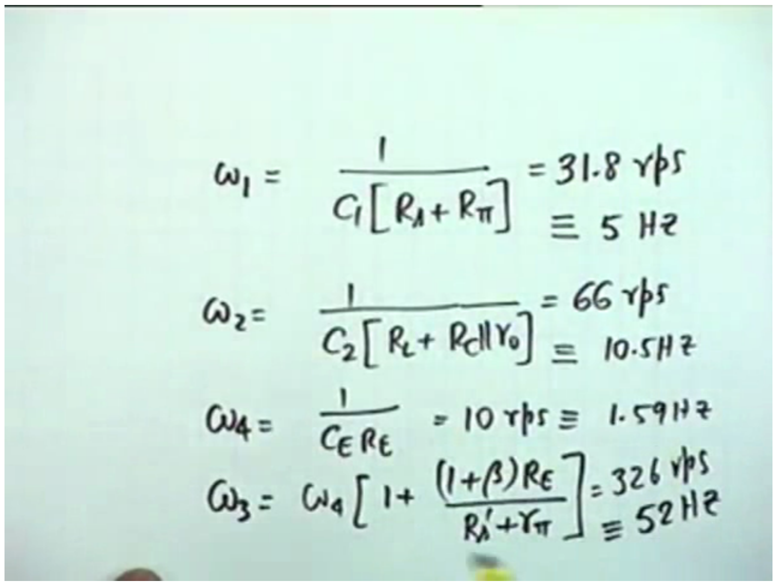


Now if I apply if I can consider these effects separately and calculate the various frequencies, I get Omega 1, which is 1 over C 1 you must remember mentally what C 1 sees, what C 1 sees R s + R Pi... No R Pi... okay alright for once I am right mostly I am right, 31.8 radiance per seconds that is what it comes if you put the values. This is equivalent to 5 hertz equivalent to you have to divide by 2 Pi that become 5 hertz okay, that is F1 = 5 hertz then if you calculate Omega 2, Omega 2 is 1 by C 2 multiplied by its Thevenin resistance which is R C parallel r 0 okay, this calculates out to 66 radiance per second, which is equivalent to 10.5 hertz. Omega 4 that 0 which is 1 over C E R E this calculates out to 10 radiance per second which is equivalent to 1.59 hertz and therefore this is really at low frequencies, even Omega 2 is much Omega 2 10.5 is much larger than this so you can ignore this.

And Omega 3 unfortunately even with 100 microfarads condenser what is it, Omega 4 that is this multiplied by 1 + 1 + Beta R E divided by R s prime + R Pi, this comes as 326 rps, you see 31.8, 66, 10 and 326, which is equivalent to 52 hertz and there is no doubt that f L that is the low frequency 3 dB cut-off is dominated by Omega 3 and shall be = 52 hertz okay. This shows that the calculations can be done independently but you can get a fairly good estimate, now suppose

Omega 1, Omega 2 and Omega 3 are comparable if they are comparable let us say 31.8 maybe this is 40 and this is 50 then you are in a problem okay you have to combine all the 3 and find out the actual 3 dB cut-off frequency that is by taking the magnitude and putting the magnitude = mid-band value divided by root 2 solve that for mega, what kind of equation you have got, what order of equation?

Student: Cube.

Professor: Cubic equation in...

Student: Omega.

Professor: No not in Omega that is why I asked you, Omega square because magnitude will contain 1 + Omega 1 square by Omega square.

Now cubic equation can it be analytically solved? It can be solved but the solution procedure is quite complicated and quite disgusting so what you do is do numerical approximation okay Nevertheless it has to be done. Suppose only Omega 1 and Omega 2 are comparable then Omega 3 is much lower than Omega 1 and Omega 2 then obviously you have to solve a quadratic equation but if one of them dominates nothing like it and this is now this is where I am going to now.

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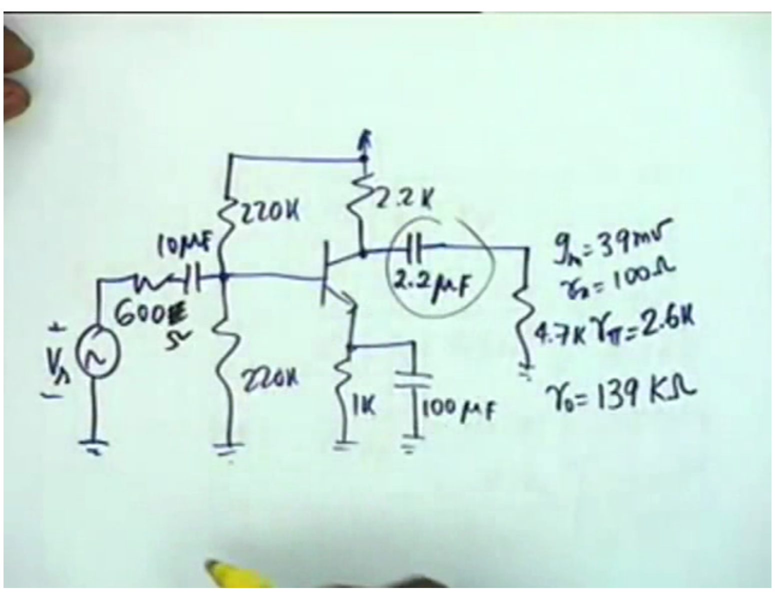

One was expecting in the circuit that perhaps C 2 shall dominate but alas contrary to our expectations it is C 3 which dominates because Omega 3 is the cut-off due to C 3, even with 100 microfarads we could not make it we could not make it non-dominant factor. Now this is usually the case that you can afford to use low value capacitors here but if you want R E to be bypassed then this capacitor has to be substantially larger compared to C 1 and C 2 and 500 microfarads, fortunately R E capacitors can be used because it is a bypass, how many microfarads is a typical value that is used, we will continue this tomorrow.