Analog Electronic Circuits.
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Lecture-45.
Problem Session-11 on Minor 3 Problems and Widebanding by Compound Devices.

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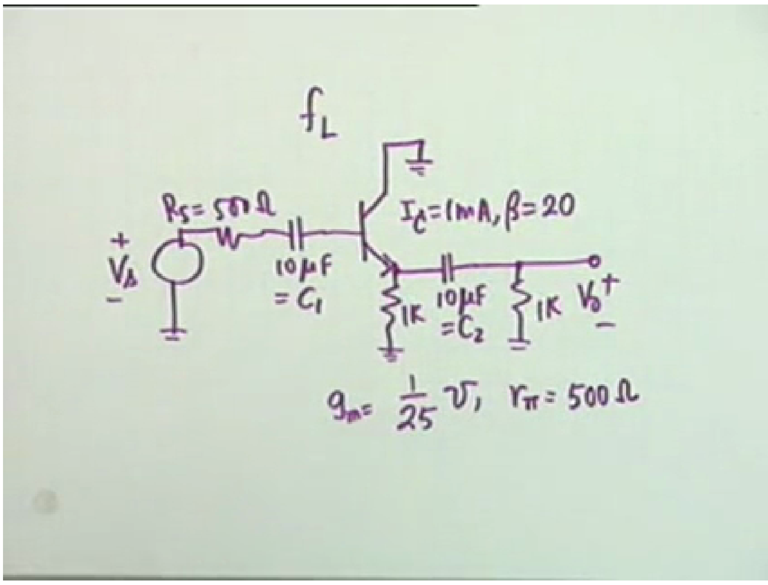

45th lecture, this is our problem session 11 and we shall solve minor 3 problems and a couple of problems on Widebanding by compound devices if time permits. The 1st problem in minor 3 was to determine the low-frequency 3 dB cut-off, FL and the circuit given is this, 500 ohms, 10 microfarads, let us call this as C1, identify this as C1, this we identify as RS, we give a name, the current I sub C is given as 1 million and the beta is given as 20 intentionally. I was asked a few questions, whether this was a printing mistake or not and also someone asked me how do I find GM, you have not given GM, you have not given R pi, I smiled.

10 microfarad, we call this as C2 and 1K, this is my output voltage V0. Now biasing details are omitted, but only this current is given. If this current is given, now I think as far as funding the parameters is constant, that is very simple. GM would be 1 by 25 mhos and R pi would be 500 ohms, 20 divided by 1 by 25, so 500 ohms. See I chose these numbers intentionally so that the answer comes as a very nice figure, so that you do not have to spend time on cranky figures, numbers. Then the question is you have to decide what matter you shall apply.

Now if you draw the equivalent circuit, the choice should be obvious, whether you do an exact analysis or the method of short-circuit, short-circuit or open circuit here? Short-circuit, short-circuit time constant. This decision will be based on how complicated the equivalent circuit is. Equivalent circuit is complicated, then you take a shortcut to the short-circuit to the short-circuited time constant method. If it is not, then you better to wait exact analysis. Now it turns out that exact analysis is involved in this case. If you draw the equivalent circuit, well I did not draw it and if we try to solve, then immediately, it should be obvious.

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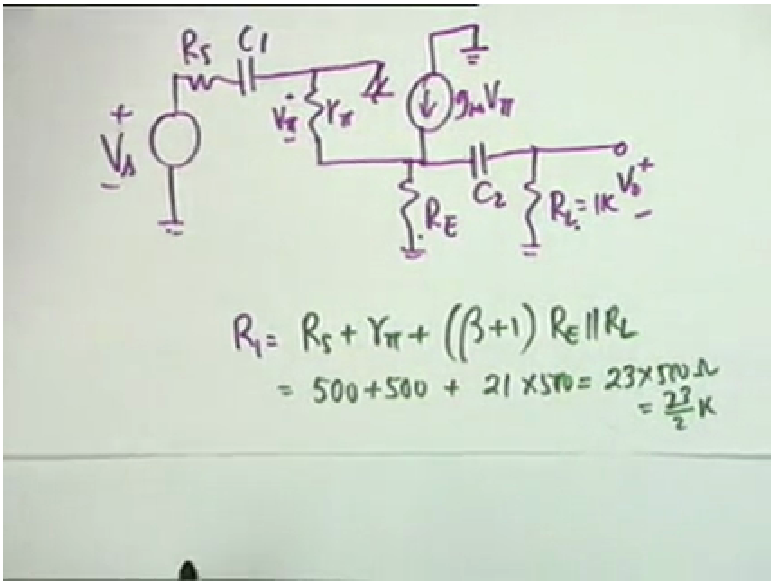

Well, we can draw it as well. This is C1, then R pi, no C pi because we are doing the low-frequency, okay. So this is V by, this is C1, RS, VS, then this goes to RE which is 1K and there is GM V pi, this goes to ground and then you have the C2 and RL let us say which is 1K, this is V0. Now obviously it is not a very simple analysis, you cannot do that, it can be done by Inspection but the equation that you will get will have zeros as well as poles. Not only that, Inspection also requires little bit of ingenuity because the equivalent impedance here is not simply RE parallel RL, it is RE parallel 1 by SC2 plus RL.

And that is how you will be able to point out V pi and then find V0 as potential division between the 2. Not that it cannot be done, whatever will require detailed calculations and it will require time, so we will offer the short-circuit, we offer a short-circuit through short-circuit time constant as I said. We 1st find out, no, as far as, as far as the equivalent impedance seen by C1 is concerned, R1 would be simply, this would be grounded, you can do it by

Inspection, this will be grounded, this is R pi and the equivalent impedance here would be beta +1 RE parallel RL.

So it can be written down by Inspection, RS plus R pi like beta +1 RE parallel RL. Now you see how I chose the numbers. Both of these are 500, this is 500, this is 21 times 500, closes 23 times 500 homes which is equal to 23 by 2K, okay, 23 by 2K, okay. Now let us look at the, look at what C2 sees.

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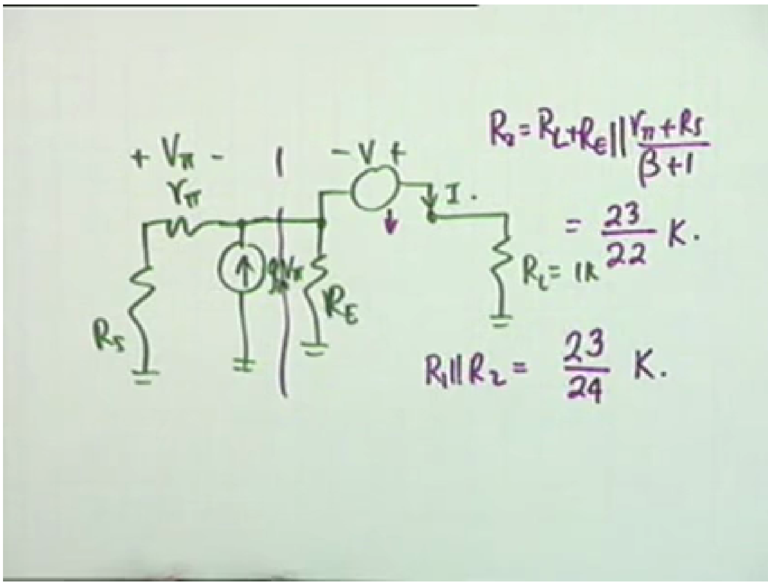

C2 sees some tricks of the trade, this can also be done by Inspection. C2 sees as the circuit, there is an RL here which is one case, then it says R pi, no RE, RE, do not drop GM V pi share, draw GM V pi like this, do not draw it upstairs, draw it as GM V pi, is the directions correct? Then you have R pi, in series RS, that goes to ground, and then there is V pi voltage here, with this polarity plus minus, okay. And this is the impedance, well, you connect a voltage source V here, any polarity does not matter and this is the current I.

Now what you should do before writing any loop equation and node equation, you should observe that RL is in series with the source, therefore whatever impedance it sees R2 shall have RL in series, is not that right. So you can ignore, you can ignore this now, you can find out the impedance of the rest. The impedance of the rest obviously has RE in parallel with something, okay. So plus RE parallel, therefore all that you have to find out is the impedance looking back here, GM V by KV pi and RS, agreed. And that we have found out again and again and again, this is obviously R pi less RS divided by beta +1, agreed. And this K calculation, I do not know what yourself, it comes out as 23 by 22K, both of them have 23, I chose this intentionally.

Therefore R1 parallel R2 which we shall get later, can you tell me how much is this? 23 by, is it 23 by 24 of 24 by 23? 23 by 24. 22 by 23… 22 by…, Okay, so much of K, we will require this later.

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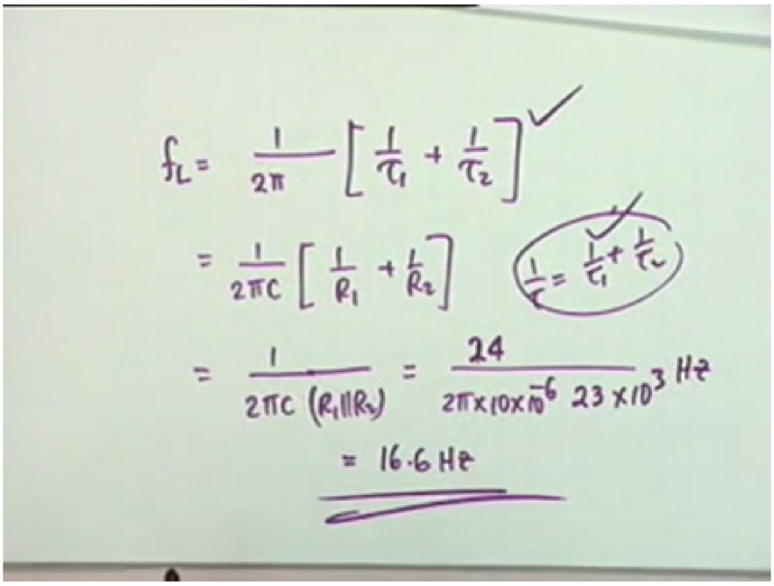

You cannot anticipate this right away but you can as well because FL is 1 over 2 pi, 1 by Tao 1+1 by Tao 2, is not that right? Have done it correctly? Because 1 by Tao is equal to 1 by Tao 1 +1 by Tao 2 and 1 by Tao is 2 pi, this is correct, this is also correct, this is also correct, I have not made a mistake so far. And since the capacitors are equal you get 2 pi C1 by R1 +1 by R2 and that is how you get 1 by 2 pi C R1 parallel R2, this is what I said, you require this. If we substitute these values and do the numerical calculations, you will get 2 pi, C is 10 microfarads, 10 times 102 the -6 and R1 parallel R2 is 23 by 24, so let us say 24K and therefore this should be multiplied by 102 the 3, so many hertz.

And this finally you will have to employ your calculator because of division by pi, otherwise I can do it almost mentally. It is 16.6 hertz, that is the value. Let us look at the next problem, problem number 2. Any question on this, any question?

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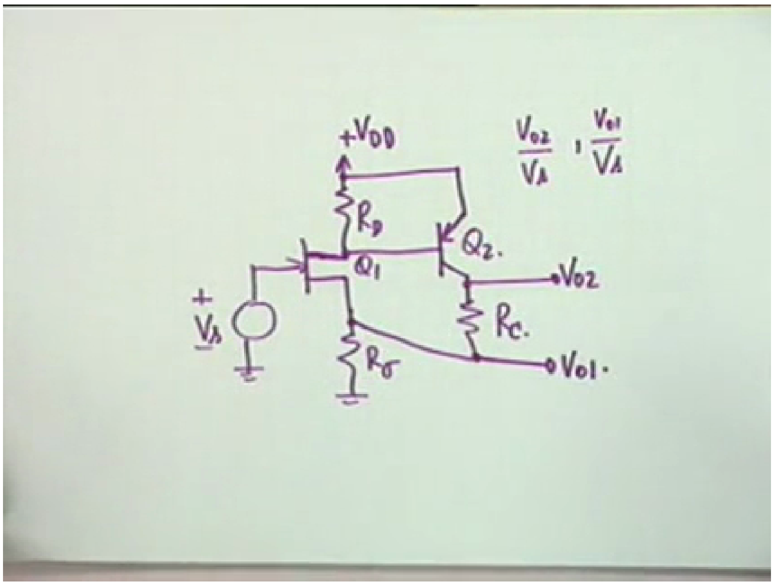

Okay, problem 2 is a feedback circuit, with a Bi-FET, a Bi-FET feedback circuit. Bi-FET means BJT and FCT combination, okay. This is quite common, by CMOS technology for example, is a very popular technology. And for different reasons this is used, for example if you have a source which is not too low in impedance, a microphone for example, it is better to put it at the input of FET or because FET has very high impedance, input impedance. On the other hand the high-frequency response of a BJT in the common base connections for example is much higher than that of, then that of an FET and therefore one makes combination to get the best of both worlds.

This is one such circuit, however I did not give numerical values so that you do not lose your patience in numerical calculations. This is my Q1 and there is a resistance R Sigma through which there is feedback, this is brought to a PNP transistors which the emitter is connected to the positive supply plus V DD or V CC or V EE, whatever you call, then you have R sub C and this is connected here. There are 2 voltages which are taken, one is your V02 and the other is here, V01, okay. The 1st thing, this is Q2 and the question was to apply feedback method, to find out V02 by VS and V01 by Vs, both of them, okay.

Now obviously several people asked me, suppose I find one of them and then apply potential division, obviously that is not correct, because potential division shall occur only when the same current flows through both the circuits, both the impedances. It does not because what flows through RC also flows through R Sigma, but R Sigma also carries a current from Q1 and therefore potential division is not applicable. And in fact the beta is different for both the circuits, the gain is different and therefore there is no way you can derive one from the other, you have to do it independently.

And the 1st thing, the simpler of the 2 would be to consider that V 01 at the output and it is obvious that it is a voltage sampling, it is a shunt correction at the output and the series connection at the output, so it is a series shunt. That applies to both V01 and V02, both of them.

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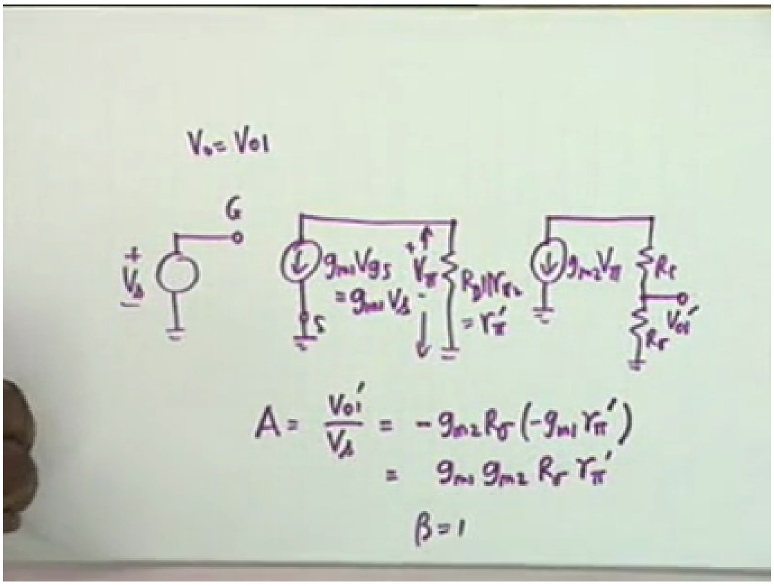

So if we consider V0 as V01, then my equivalent circuit would be VS, that is it, this is the gain, another source, the source, if V01 is short-circuited, obviously this will be shorted and therefore the source is shorted, S is shorted and what you have here is GM 1 V GS and V GS would be equal to VS, intentionally I put the symbol as VS because you might get trapped in the next question whether is a potential at the source, you could call that V Sigma, okay. GM1, do not get confused over these minor confusions, humanly created minor confusions.

Well, confusions always are humanly created, nature does not create confusion. Okay, this is the drain and then the drain of the 1st transistor is connected to ground through a parallel combination of RD and R pi 2, if you look at this. RD, that goes to ground and from base to emitter is R pi 2, several people asked me whether the polarity in the equivalent circuit changes, whether it is PNP or NPN transistor. And one of them I scolded, the other one I simply smiled because there is no point in scolding and the smile should be, should clarify the answer, okay. So this should be RD parallel R pi 2, we call this as R pi Prime let say. And this voltage is V pi, then you have gm2 V pi, gm2 V pi, that goes to ground.

And what you have here is, what you have here is RC, then you have to open this because it is a series connection, so RC plus R Sigma, RC plus R Sigma and the voltage is taken from here. Now I had repeatedly told you that please do exercise some discipline, otherwise you will get confused. This should not be called V01, V01 Prime because this is a circuit, this is not the total circuit, this is a circuit. And the gain A can be very easily found out, V01 Prime by VS, this is equal to minus GM 2 Times R Sigma, okay, this current flows through this, so it is independent of RC, minus gm2 R Sigma and then V pi would be minus GM 1 R pi Prime, okay and that is it.

Because this VS is the same as the input VS and therefore this is equal to GM 1 gm2 R Sigma R pi Prime. Now the calculation of beta, the calculation of beta does not require an equivalent circuit because all of you do is apply voltage here, open this and find the voltage here, we have the beta is equal to 1. Therefore beta equal to1, someone asked me whether we should leave it like this or we should find out here.

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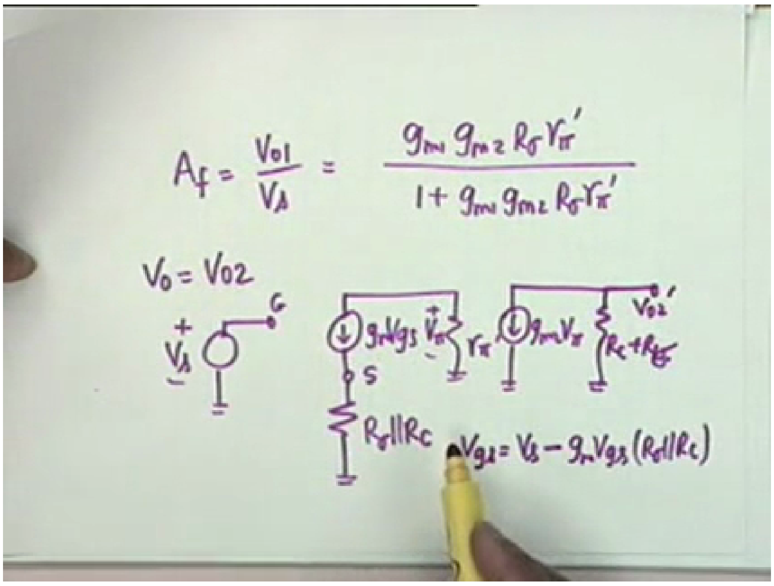

The feedback gain, this is V01 divided by VS where, why this laziness at the last point, if you are, if you have been able to find this out, you can as well find this out. Now does this, does this surprise you that the gain is less than 1? No, I wonder why not, why not. If you look at the circuit, does it surprise you that the gain is less than 1? V01, obviously get the voltage between the source, source voltage divided by the generator voltage, okay. This is like, if the feedback was not there, if this was not there, the gain obviously would be less than 1 because it behaves as a source follower.

Whether there is a resistance here or not, it does not matter, okay, it behaves as source follower, so the gain is indeed less than 1, all right. As far as, if V0 is V02, then the A circuit changes slightly, what you get is VS, G, now S is no longer grounded, okay, S is no longer grounded, S is grounded through a resistance of R Sigma parallel RC. Why this parallel comes? Because V 02 is now to be grounded, okay, V02. If you look at this circuit, it is this point which is to be grounded and therefore R Sigma comes in parallel with RC.

And the rest of the circuit is very similar. GM, now V GS obviously would be, we will have to find that out. Okay, we will have to find out, so let us be content with GM VGS and then you have R pi Prime, V pi and you have gm2 V pi, the rest of the circuit is similar. What shall you have here now? RC plus RL, you do not have to show them separately because V02 Prime is here, this is RC plus RL. And all that you have to do now, pardon, RC plus R Sigma, thank you, RC plus R Sigma.

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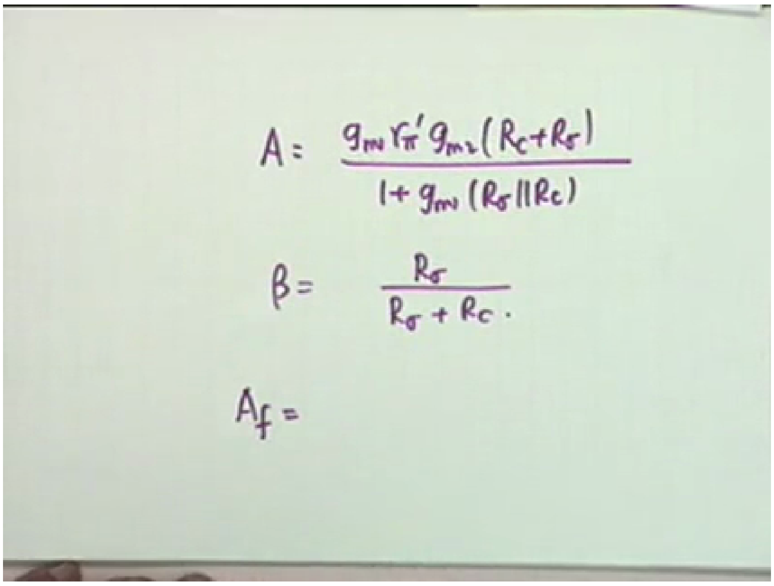

All you have to do now is to show is to see that V GS is equal to VS minus the drop in this which is GM V GS R Sigma parallel RC. And therefore you can find out V GS, if you can find out V GS you can find out A and you can find out A, my result is the following, GM 1 R pi Prime, gm2, instead of RC you have RC plus R Sigma divided by 1 plus GM 1. Where does this factor come from? This factor 1+ GM 1 R Sigma parallel RC, why does it come from, V GS, from the calculation of V GS. Okay, this is A and bit obviously here is a potential division, that is R Sigma divided by R Sigma plus RC. Does that require explanation? The circuit itself shows that.

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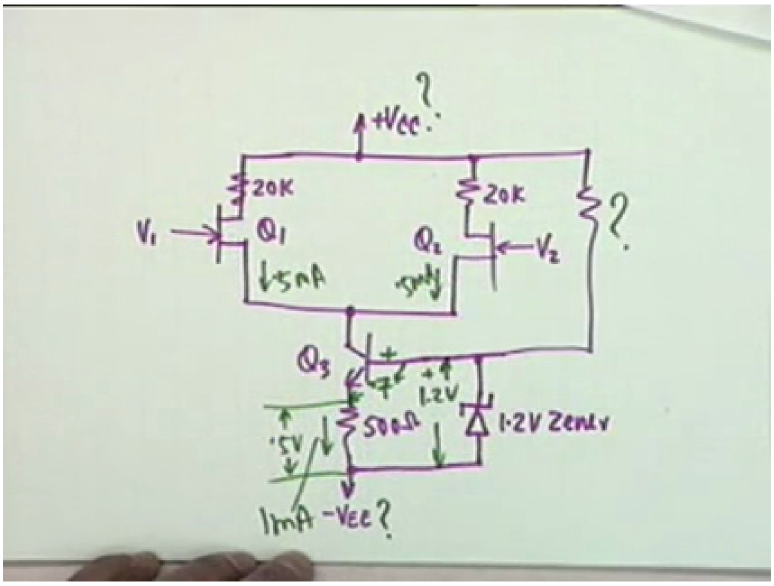

And therefore A f, let me now be as lazy as the person who asked me, whether we should find this out or not, please do. Question number 3. Here I had a barrage of questions in the class. Let me tell you what these questions are. Once again this is a Bi-FET circuit, that is there are FETs and BJT. This is V1, it is a difference, differential amplifier, 20 K, this is also 20 K, absolutely symmetrical, this is Q2, Q1 and this is V2. The 2 sources are brought together and biased through which kind of source is this, current source of the Vidler kind, okay, this is 500 ohms.

And then it goes to minus VEE but these points, the base, well it is connected to, to the power supply through a resistance which is not given and then you have a Zener diode. And it is given that 1.2 volts Zener, okay, this is the circuit. So people ask me what is V CC, what is VCC, what is this resistance, what is VEE. If you, this is called what, seeing not see, observing. If you observe carefully, this 1.2 volts Zener, there is a purpose, a Zener stabilises voltage and therefore the voltage that will and it is in the reverse direction, so Zener breakdown occurs.

There is a plus VCC, this resistance has been chosen such that VCC plus VEE, this voltage is greater than 1.2, agreed and this resistance is chosen such that the breakdown occurs and this voltage is maintained a constant, okay. Which means that this voltage, voltage from here to here is 1.2 with this polarity, if that is so, if that is so, and if this is 1.2, obviously Q3 shall be in the active region, this question was also asked. Why is Q3 in the active region? Well, Q3 requires 0.7 and it is written in 0.7, therefore it must be active and this voltage must be 0.7, plus, minus.

And therefore this voltage, now look at my choice, this voltage must be 0.5 volts and therefore the current through this must be 1 milliamperes. Alright. And this current therefore, since the circuit is symmetrical, this current must be 0.5 milliamperes, this point must be 0.5 milliamperes, everything else is known.

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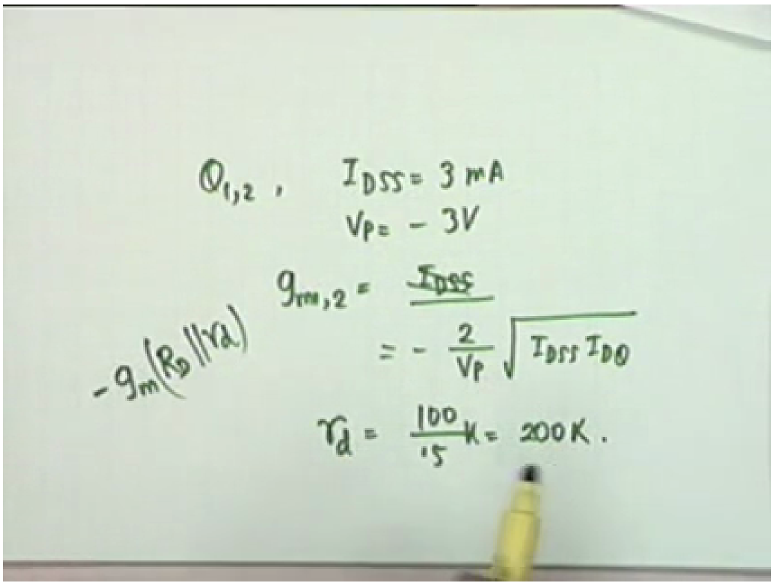

For Q1 and Q2, the more, the further specifications are that IDSS equal to 3 milliamperes, Vp equal to -3 volts. Now why are these given, because we require a calculation of GM. So GM 1 GM 2, now some of you, I have seen a few papers, some of you have 1st calculated VGS and then substituted in the formula of GM but we had, we had made a shortcut. What was it? IDSS divided by, now -2 by VP square root of I DSS ID Q and VB is known, IDSS is known, I DQ is known, I DQ is 0.5 milliamperes and therefore GM can be found out.

What else is required to be found out? RD and I has the venues equivalent VA, I did not want to use the symbol lambda inverse because you may not remember, I mentioned it only once in the class. So equivalent VA is given therefore, it should be 100 divided by 0.5 which is equal to 200k, that is right, so you know GM and RD and if you know, if you know GM and RD, then the differential gain is immediately found out minus GM times RD parallel small RD and this is 20 K and this is 200 K, GM is known and therefore you can find out the gain.

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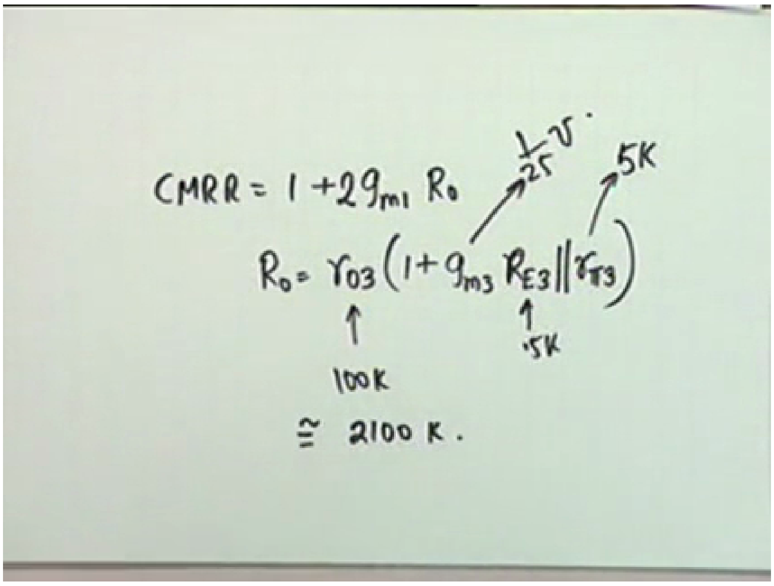

As far as CMR R is concerned, now you have to take help of Q3. CMRR is determined by the equivalent resistance that is presented between these 2 points. If we call this R0, then the CMRR shall be determined by 1 plus GM, 1 or 2 or 3?

2.

2 or 1, does not matter because they are identical, okay. So GM 1 R 0, that is it. Why is GM 1 R 0, okay, that is right, twice GM REE, equivalent resistance, all right. And R 0, this we have done for the Vidler source, it should be R03 1 GM 3, okay RE3 parallel R pi 3, right. This parallel comes, usually R pi 3 is much larger than RE3, in fact this is the case here also. What is R pi 3? Pardon me? 500 ohms.

5K.

Okay, 5K and RE 3 is 0.5 K, so this is 10 times, agreed, this is usually the case. And you can as well ignore R pi 3. At R 03 is how much, again VA is given, 100 K, and GM is, again 1 milliampere is the current and therefore 1 by 25 mhos. Substitute all these and get this as approximately 2100 k.

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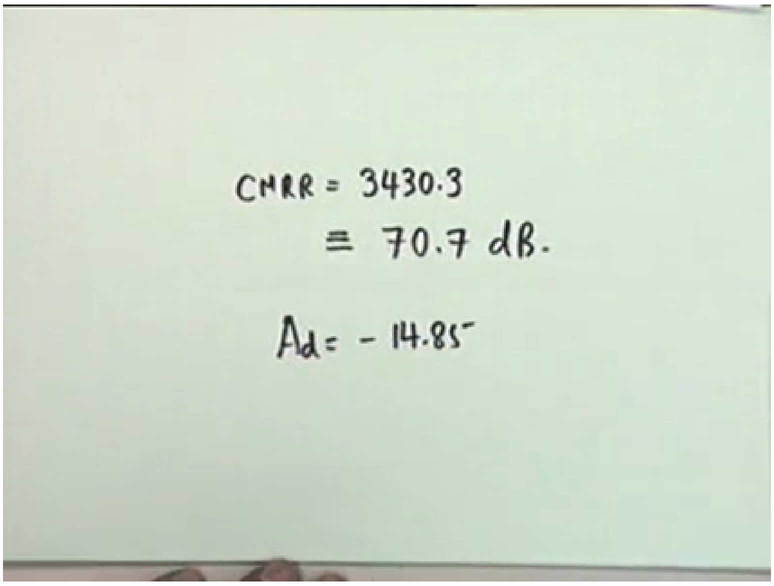

And therefore the CMRR, if you substitute the numerical values, CMRR is equal to 3430.3 and it is always a practice for engineers to specify this in DB. If you specify this in DB, what you have to do, you they log 10, 20 or 10? 20. Why? Because it is a ratio of 2 voltages, okay. This my calculation says, this is 70.7 dB as the differential gain is equal to -14.85. Would you also like to express this in DB? Why not? It is very low, 14.85, not only that, if you express in DB, then you must take care of the negative sign. How do you do that?

You see in DB you cannot take log of negative quantity. You take a model, you either express Ad as mod so many DB, or you say Ad equal to so many DB and angle pi, okay. Do not say minus so many DBs, no, that does not make sense. Okay. Minus so many DBs means what, that means attenuation, we always -3 DB frequency, all right, the attenuation is 3 DB. Okay, these are the things that an engineer should remember. Now in the rest of the times we will work out 2 examples of broadbanding compound devices.

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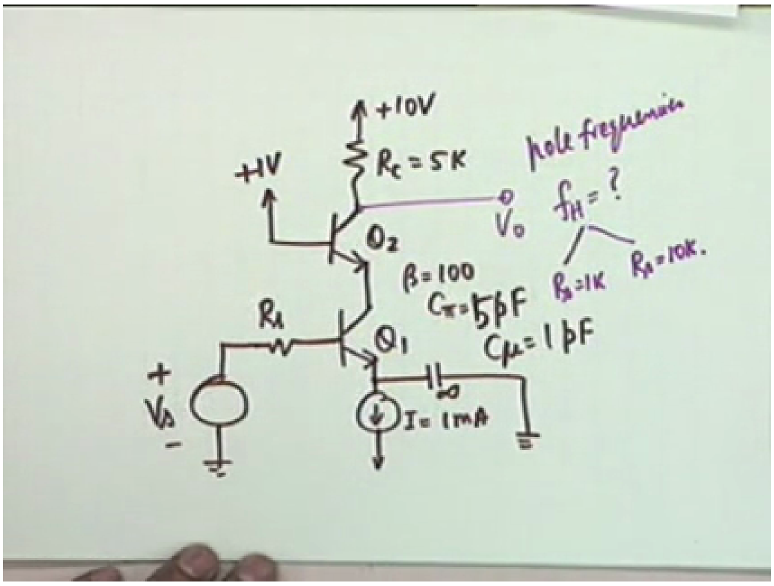

The 1st example is that of a cascode. This page is not sufficient, so let us draw it on a separate page. The circuit, draw with me, +10 volts, R sub C is equal to 5K, you have the transistor Q2, the base is maintained at a constant voltage of 1 volt, okay, the base biasing is not true, it is maintained at the voltage of 1 volt. Perhaps, perhaps 7.2 volts zener and then a potential division. Perhaps of that type, we do not get a 1 volt Zener. 7 is perhaps the minimum, now there are smaller voltages also. Pardon me? Three-point…

We used 5.6 in the lab.

5.6 is there, yes. 5.6, 6.2, do you know the logic of these fractions? By 4.7, why not 4.8? You better find out. The processing, the processing facilitates manufacture of such values and this has become almost standard. Look at any components Handbook in the library, I do not want to give you the answer, you will find out for yourself by these specific values. 3.3 microfarads, not 3.2 or 1 or 3 microfarads, no… Q2, then you have Q1, and the biasing here is that a constant current source I equal to1 milliamperes, that means another transistor, either a Vidler source or an ordinary source, which can be approximated by an ideal current source.

We do not consider, we consider the equivalent resistance to infinity. But then my AC, for AC it would behave as open and therefore I make an AC short by connecting a capacitor to ground where this capacitor is very large. You understand the meaning of this, why this is done? Ideal current source but I want Q1 emitter to be grounded as far as AC is concern. If I do not use this capacitor, then it will be open, it will not be grounded and therefore AC will not be able to flow, therefore I provide a short circuit for AC here. This does not affect the DC, and the source is applied here, RS, this is my Vs.

The transistors, both of them have beta equal to 100, obviously they carry the same collector currents, the same collector current, so GM 1 and GM 2 or equal, that is what gives the cascode its basic property, namely that it can extend the high-frequency range. Beta is 100, C pi is given as 5 picofarads, 5 picofarads and C mu is given as 1 picofarads. The question is to find out, let us see if there is anything else, no, C what is here, V0 as usual it is a cascode. The question is to find out the pole frequencies, the pole frequencies and estimate FH for 2 conditions.

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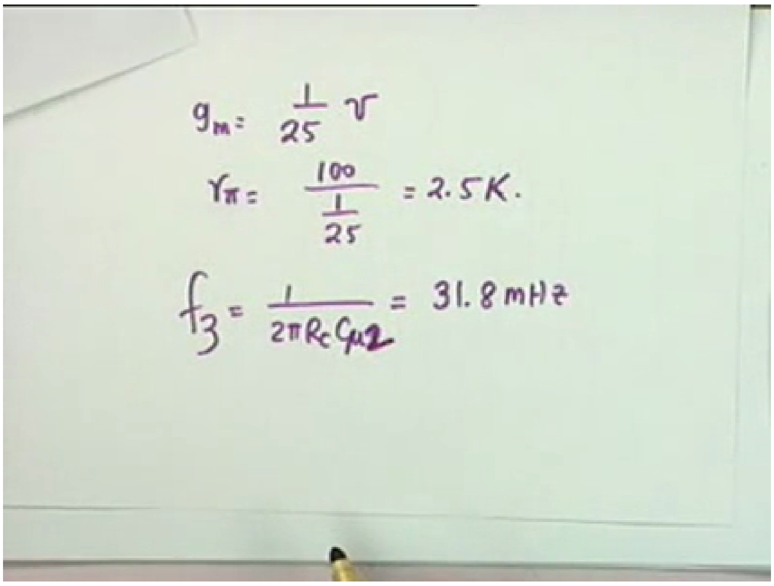

RF equal to1 K and the other is RS equal to 10 K. There must be difference, there must be a difference, that is what… Alright, have you been able to note, okay. Says that it is given as 1 milliamperes, our GMs are obvious, GM would be equal to 1 by 25 mhos and therefore R pi would be equal to beta divided by 1 by 25, that is equal to 2.5 K, 2.5 K, then instead of drawing the equivalent circuit, let us see if we can do it by Inspection, okay. The equivalent circuit if you remember is fairly complicated and then there was a current generator which has to be taken care of in 2 parts, through a resistance 1 by gm2 and a current generator gm2 V pi 2.

Let us see if we can remember little bit of the equivalent circuit, whether we can do it by Inspection. Let us look at this. 1st let us consider the output circuit. The output circuit time constant or the pole frequency, which let us call F3, who determines this? Obviously RC, does RC come in parallel to anything? No. And the capacitor is from here to ground, that is C mu 3, anything else? Anything else, no, so F3 is simply 1 over 2 pi RC C mu 3 and if you substitute the values, this comes as 31.8 megahertz, without drawing any equivalent circuit, okay.

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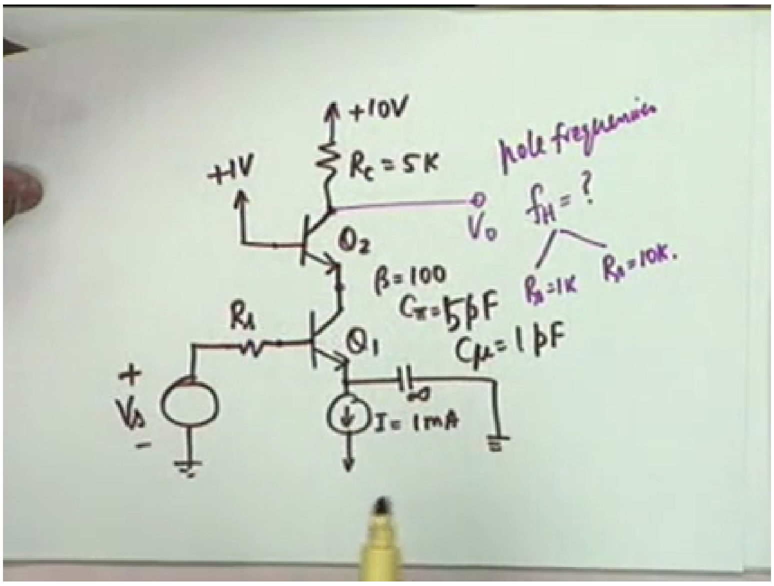

All right, then the 2nd one, that is F2, F2 would be at this point, F2 would be determined by the time constant such this point, that is E2. Pardon me? C mu 2, I beg your pardon, C mu 2, which is 1 picofarads, 1 picofarads, okay. Now let us see F2. Tell me what is the equivalent resistance at the emitter of Q2? And since beta is large, this is approximately 1 by gm2, agreed. This is what gave the Widebanding property because the load is 1 by GM 2, the gain is equal to -1, GM 1 multiplied by 1 by gm2.

If you remember this property of 1 by cascode, then you do not have to draw the equivalent circuit. So what we have is 2 pi, let say this is approximate, I will tell you how good is this approximation is in a moment. 2 by 1 by GM 2 and what is the total capacitance? C pi 2 plus, note plus twice C mu 1 because the gain was equal to minus1. This is C mu 1 multiplied by 1 minus gain divided by gain magnitude. So 1 minus minus1, all right. And if you substitute the values, that this comes out as 0.97 gigahertz. How many megahertz it is, 970 megahertz, 970 megahertz.

Now let us see how approximate this is. You see actually this resistance should be R01 parallel R pi 2 parallel one by GM 2. R01, VA is not given, so we assume this is infinity, R pi 2 is 2.5 K and what is gm2? 1 by gm2? 25 ohms which is 0.025K, do not you see that this dominates, 1 by GM2 dominates? So this results, I can as well remove this hesitation, okay, it is almost exact, right. Now finally our F1, we call that frequency F1 pole frequency F1. This is due to input circuit, let us look at the input circuit.

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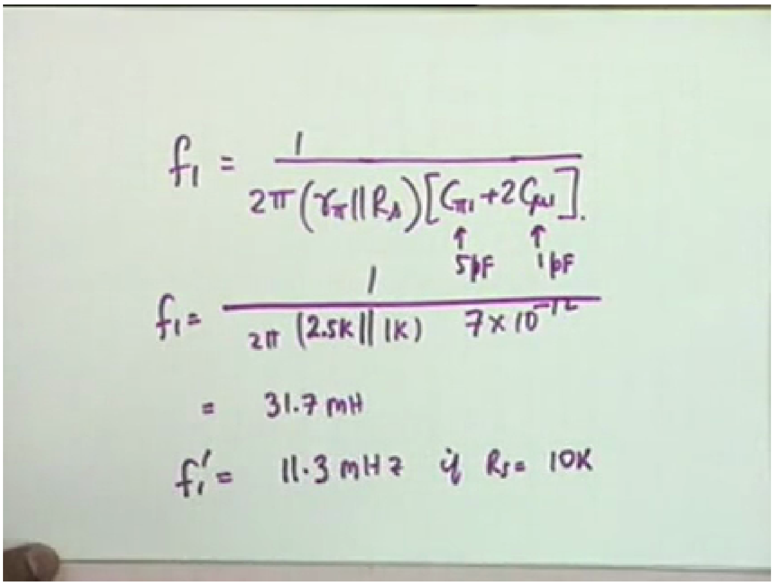

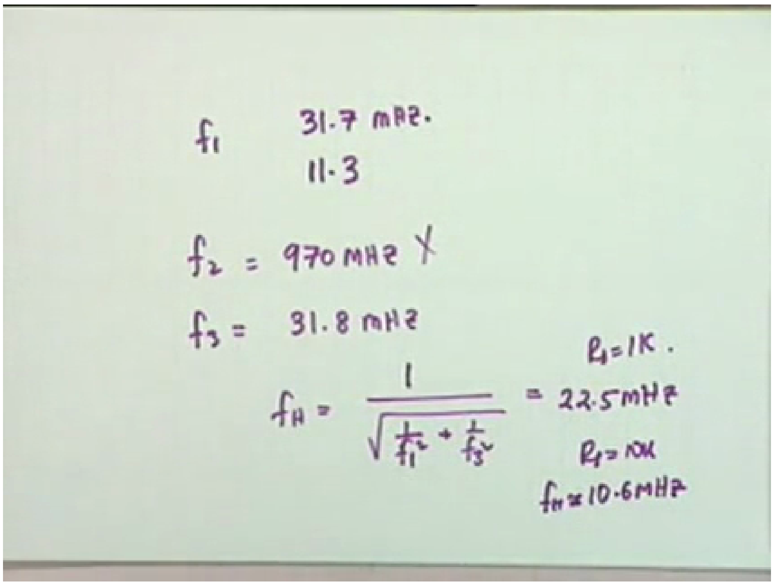

Input circuit, what is the equivalent capacitance from here to ground? C pi 1 would not have been unless this, okay, so C pi 1, only C pi 1, no. Plus twice C mu 1, whatever is reflected and what is the equivalent resistance, RS parallel R pi, that is correct. And therefore I did not have to draw any equivalent circuit, F1 is 1 over 2 pi R pi parallel RS multiplied by C pi 1+ twice C mu 1. This is 5 picofarads, this is 1 picofarads, so 5+ 2 is 7, 7 times 10 to the -12 and R pi parallel RS, R pi is 2.5 K, RS is 1K multiplied by 2 pi. So this is what I get, F1.

And by calculation I get this as, oh, is RS is 1K, then I get this as 31.7 megahertz. Whereas if RS is 10 K, I have to calculate for 2 situations. RS is 10 K, then this is 11.3 megahertz, if RS is 10 K, it is very tempting to divide this by 10, that is not correct, because there is a parallel combination. Okay, let us consolidate the results. My F1 is either 31.7 or 11.3 megahertz. F2, what was the value, 970 megahertz and F3 is 31.8 megahertz. Now if I want to calculate exactly, obviously you see the effect of F2 would be negligible, because it is about 30 times the higher values, 30 times, approximately, so this effect would be negligible.

Therefore FH would be mostly determined by F1 and F2. In the 1st case, that is when RS is 1K, 31.7 and 31.8, they are comparable and therefore FH should be determined as 1 by square root of, can you tell me what should this value be? F1 square plus F2 square, no. 1 upon F1 square, you must remember the Taos as, okay. So one by F1 square +1 by F3 square, you can as well ignore this. And in the 1st case, that is when RS is 1K, when RS is 1K, they are comparable and the result is 22.5 megahertz. Whereas if RS is 10 K, RF is 10 K, then it should be approximately 11.3 because this is also 3 times time now, okay. And we exact value is 10.6 megahertz, slightly less than this, slightly less than 11.3. Okay, any question?

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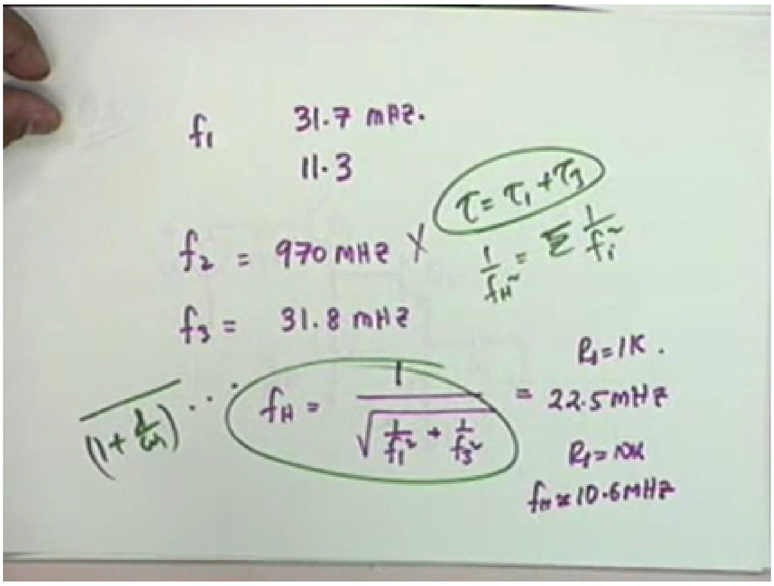

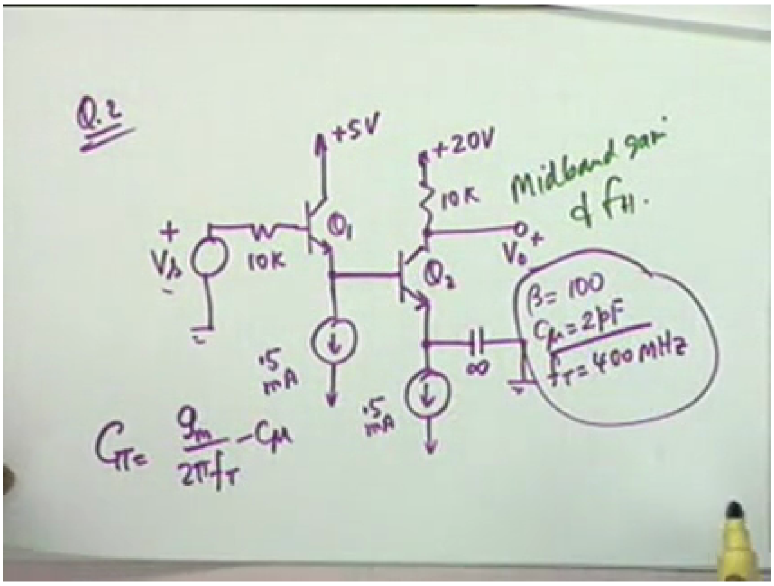

The 2nd problem, the 2nd problem is that of CE, I am sorry CC CE combination, draw the circuit with me. VS, 10 K, Q1, all transistors are biased by a current generator, this is biased by a current generator and this goes to the next page, that is Q2, this is also biased by a current generator, 0.5 milliamperes. And then you have come in order that this is not floating, you apply a capacitance, a short-circuit, a bypass capacitance.

Excuse me Sir.

Yes?

Please show the (())(44:26).

Previous, okay…

In this we have added the reciprocals of the squares, then divided (())(44:36), then the time constant add and the universal time concept is that is also low frequency.

Very good question. You see what we have is Tao equal to Tao 1+ Tao 3, how would it would be this 1 by F1 square, why did we take the square? This is more exact because one by FH square is equal to summation 1 by F I square. If I take the expression as 1+ S by omega 1, 1 by S by omega 2 and so on, I showed is that in the magnitude square, the, if you ignore omega H to the 4 and other terms, only keep the square terms, then this is a better formula than summation of the time constants. This is not the method of short-circuit time constant, it is a better formula. Okay.

But even if you do it by this, it will not be much difference, the estimates are fairly close to each other, good question. Now in this circuit, question number-one, I have not finished it but let me, let me raise some queries. Question number-one if both are biased by 2 constant current sources, why could not we have a single constant current source of 1 milliamperes and connect them? Pardon me?

One is grounded.

That is right, one is grounded and the other is open. This emitter current, AC emitter current has to go to the base current of Q2 and therefore you could not make them, you could not short them. Alright, then Q2 is connected to a 10k resistance and the voltage is +20 volts, the voltage is +5 volt. Why is there a difference? This is V0, why is there a difference? Come on? The question is why is there a difference of power supply? I sub C are the same…

(())(47:15).

One at a time.

(())(47:22).

The VC here does not matter, almost does not matter, whereas it matters here.

Ic of Q2 will be greater than ic of Q1 by a factor of beta, beta is large, beta is 100, so that can be ignored. Think about it, I have given the answer, think while this answer is correct, if it is not correct then counter me. The other specifications are these, beta is equal to 100, C mu equal to 2 picofarads and Ft instead of giving that V, now you smart can, you can calculate C pi, right. Tell me how you calculate C pi? It is equal to GM, pardon me? GM by 2 pi FT minus C mu, therefore C mu is given and therefore we can calculate C pi, all right.

The question is to find out the mid-band gain and FH, these are the things we found out. Midband gain and FH, we could do that without drawing the equivalent circuit also, if we recall bit of the equivalent circuit. But let us do it because we have to calculate the mid-band gain also.

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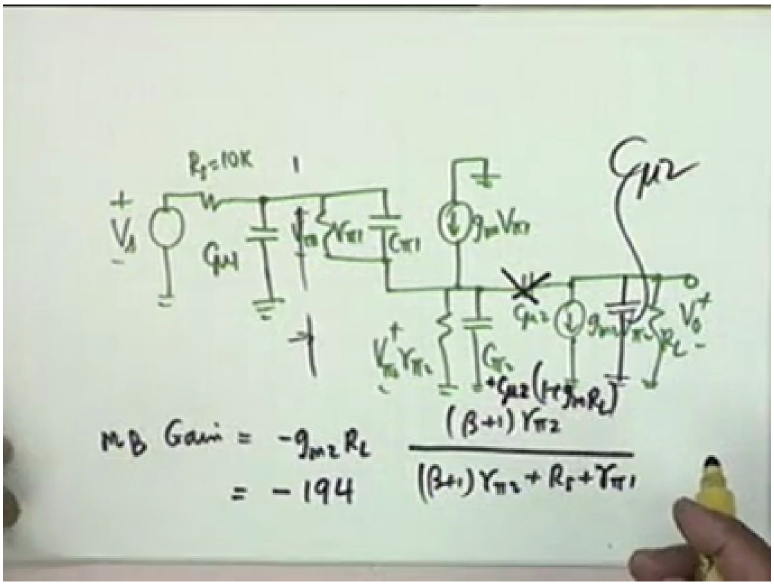

Let us draw the equivalent circuit, it does not take much time. VS, RS which is 10k, then what do you have from here to ground, from here to ground what do you have? If you look at the equivalent circuit, R pi, not to ground, to ground I am asking, to ground is there any element?

(())(49:22).

C mu 1, that is correct, C mu 1 and then you have R pi 1 parallel C pi 1, which is V Pi 1, this goes to R pi 2 parallel C pi 2 and there would be a current source here GM 1 V Pi 1 coming from ground to here and then from here you get a C mu 2, this voltage is V pi 2, C mu 2, then what? gm2 V pi 2 and RL, this is V0. This is the equivalent circuit, you should not spend much time in drawing the equivalent circuit. It should be, looking at the circuit it should be obvious. Now the easiest thing to find is the mid-band gain, mid-band gain, mid-band gain, okay. Obviously this would be minus gm2 RL for this stage, then V pi 2 divided by Vs, agreed.

This voltage is minus gm2 B by 2 RL, ignore all the capacitances, mid-band and then you have to find V pi 2 in terms of VS. Therefore it would be minus gm2 RL, what is V pi 2 by VS? Beta +1 R pi 2 divided by beta plus 1 R pi 2 plus RS R pi. Very good, by Inspection, no analysis, nothing. And if I substituted the values and I find the result as -194. Obviously because I sub Cs are the same, GMs are the same, that is why did not make the difference between beta 1, beta-2, R pi 1 and R pi 2, they are all, they are all identical because I sub Cs are equal.

Okay, now about the time constant. Again now we do not look at the, since we have taken the trouble of drawing the equivalent circuit, let us look at the equivalent circuit. And find out the equivalent resistances. But before that shall we take help of Miller in getting rid of this? So this shall be multiplied by, this should be added to C mu 2, 1 plus GM RL and instead of RL we shall have here a capacitance of C mu 2, agreed. Then how many capacitance we have, 1, 2, 3 and 4, 4 capacitances. So we have to find the equivalent 4 resistances, let us see if we can do it by Inspection.

Okay, what does C mu 1 C see, it sees a parallel combination of RS are in, not R pi 1. R pi 1+ beta plus 1R pi 2, so you can find out R mu 1. What about CD, CD2? What about CD2? Well, what about RT 2, what does this see? Obviously it will be parallel combination of R pi 2…

(())(53:15).

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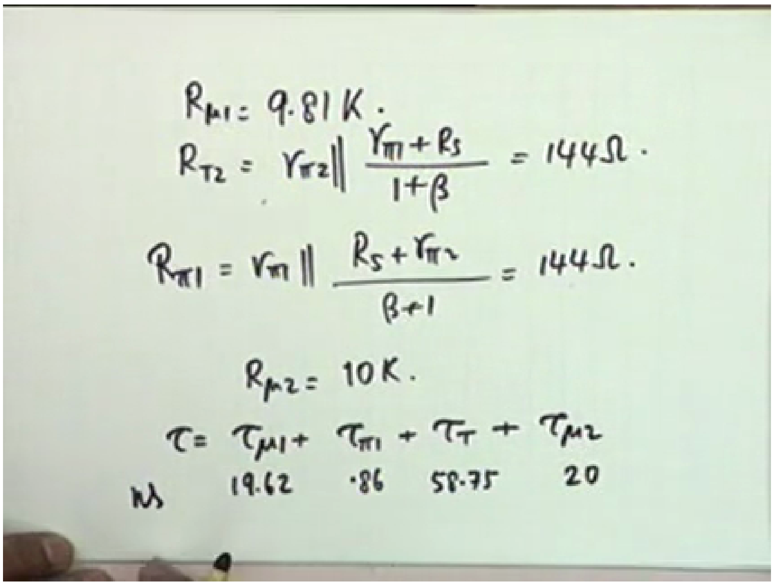

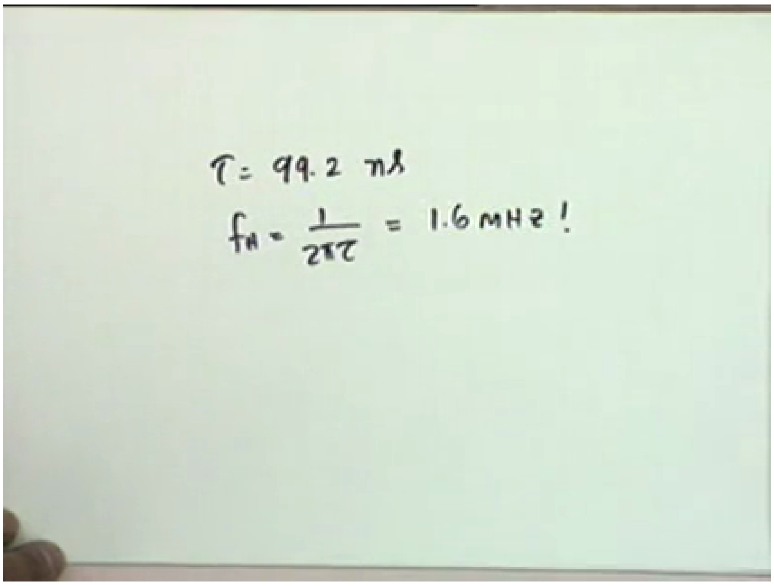

Wonderful, so R pi 2 parallel R pi 1+ RF divided by 1+ beta. And this comes out as 144 ohms, my calculation. R pi 1, we jump from here, now R pi 1, that is C pi 1, what does it see, R pi one parallel, parallel RS is your and R by 2 is here, okay. This would be R pi one parallel, not with a plus and, yes, correct. RS plus R by 2 divided by beta +1, agreed. This also comes as 144 ohms, why? Because they are identical, R pi 2 R pi 1, R pi 2 R pi 1, they are identical. So this is also the same and finally R mu 2 is simply…

(())(54:43).

No, RS plus R pi 2. Why? You see what does C pi 1 see? R pi 1, there is R S here and there is R pi 2 here.

So beta (())(54:37) current is only flowing through R pi 2?

Actually it is one plus GM times R pi 2, 1 GM time, we will calculate it out, it comes out as this. R mu 2 is obviously equal to 10k. And my time constants tao…

Pardon me?

(())(55:02).

1+ R mu 1.

What was R mu 1?

What was R mu 1, did we not calculate this? R mu 0, yes I had calculated, I will give you the value. R mu 1 is 9.8 1K and Tao is equal to Tao mu 1 plus Tao pi 1+ Tao T plus Tao mu 2 and my calculation says this is 19.62, all in nanoseconds, nanoseconds, 0.86, 58.75 and 20. Usually none of them are really dominant, these 2 are comparable, this is approximately 3 times, so you can say this is dominant but the 2 together makes this dominance disappear, is not that right. So I cannot say 58.75 is dominant but 0.86 perhaps we can safely ignore.

You see it is the time constant due to C pi 1, C pi 1 otherwise creates havoc because of Miller effect. But because Miller effect only reflects 2 C mu 1, nothing more, this has become very negligible. And my calculation is that Tao, total Tao is 99.2 nanoseconds and fh which is 1 by 2 pi tao, now we did not apply this squared formula, okay. We could happen that was, we could have done that, now we found to be more convenient so we say this is equal to 1.6 megahertz. Okay, that is all for today.