Analog Electronic Circuits.
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Lecture-41.
Problem Session-10 on Tuned Amplifiers.

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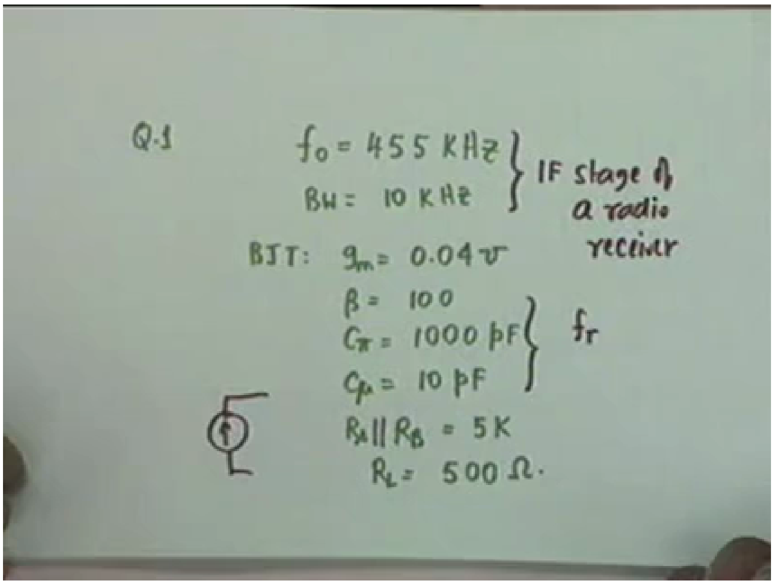

41st lecture problem session 10 on tuned amplifiers. The 1st problem is to design a single tuned amplifier which has the following specifications. F0, the centre frequency is for 45 kilos hertz, the bandwidth is 10 kilo hertz and as i have mentioned this is a typical if stage of a radio receiver. The transistor that is to be used has the following specs. Gm is 0.04 mho, beta 100, c pi 1000 picofarads, c mu 10 picofarads. Now these may be given like this or you may have been given an ft. If you know ft then you can calculate c pi, provided c mu is given, c mu has to be given.

Then the bias network r sub b, the bias that was r1 parallel r2 and the source resistance with a current source, the source resistance, they are in parallel, they combined to make 5k. Rl is 500 ohms, in addition as a matter of practical specification it is stated that a coil which is to resonate at 455 kilos hertz, at 455 kilos hertz coils with q between 10 and 150 are available, coils between 10 and 150 are available. Which means that you cannot assume the inductor to be perfect, which means the inductor has a series resistance. Is the point clear?

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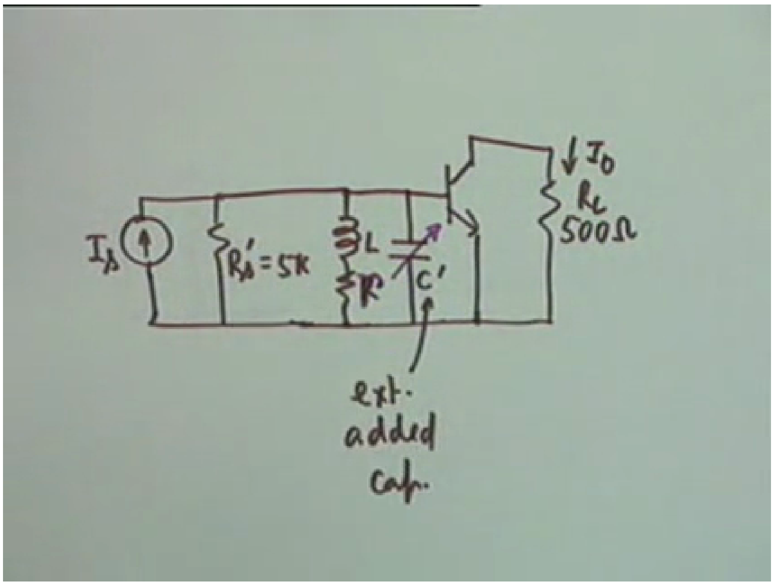

If it is not specified, then you take the inductor to be infinite q, that is its series resistance approximately equal to 0, if it is not specified. If it is specified then you have no alternative. So this is a fairly practical problem, let us see how to solve this problem. The circuit that we plan on, it is almost given, everything is given, it is given that this resistance, we call this rs prime, okay, rs parallel rp, we call this as rs prime, this is given as 5k, 5k, then you have, you connect the tuned circuit here, it is l in series with resistance r, okay, disease resistance.

We have to use r because q is specified to lie between 10 and 150, that means you have a choice of q. Let us see what q we shall choose. Then there is a capacitance which we call c prime, which is not the total capacitors because the transistor reflects a capacitance, so c prime the externally added capacitance, externally added capacitance. And as we shall see this will dominate, at 455 kilos hertz c prime dominates over what is reflected by the transistor. The transistor of course is a common emitter connection, we have not shown the biasing network, that will be taken care of here.

And the load is 500 ohms, this is rl and this is the current i 0 or il and this is the input current is, okay. This is the circuit that we plan on. Of course for tuning you have to keep c prime as part of it at least variable, okay. As you know air variable capacitors with the range of few picofarads to what is the maximum, 500 picofarads, actually 478 or something. A few picofarads to 400, a few picofarads to 500 picofarads, this is the air variable capacitor. So if this lies within that, you can use an air variable capacitor and tune it. If it lies outside, if it is more than that, then you can use a fixed capacitor in parallel with an air variable capacitor.

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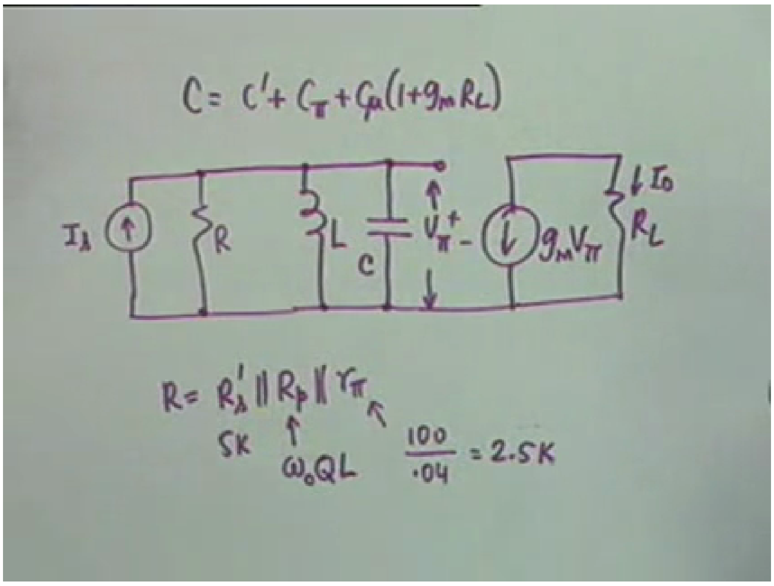

We will see how that the equivalent circuit now is therefore is, then now what other thing that will come in parallel? One of them is of course rs prime, okay, we call, would you allow me to change this to small r, the reason is that this equivalent resistance i want to call capital r, okay. Equivalent resistance that comes in parallel with is, allow me to call this small r, then the resistance capital r that will come here would consist of rs prime which is 5k, then a parallel equivalent of lr which is r p. What is the value of rp? Omega 0 q times l, we have derived this.

The series rl combination has to be converted to a parallel rl combination and then the equivalent resistance is this, is this correct, omega 0 ql, yes, it is correct. What is q0?

Omega 0 l by r.

Omega 0 l by r, okay. Now this parallel, what is the 3rd parameter, r pi. And what is r pi, beta is given as 100 and gm is 0.04, so this is equal to 2.5 k, okay. This is the total resistance that comes in parallel, then the parallel capacitor, parallel inductance is still l, then we have instead of c prime we shall have a c where capital c is equal to c prime plus c pi plus c mu 1+ gm r l, okay, this is the total capacitors that comes in. And this voltage is v pi, then we have the gm v pi and rl, this current i 0 is the output current, all right.

Now the specifications says that the bandwidth, obviously one of the specifications is that parallel, square root of 1 by square root of lc should be equal to omega 0, whatever is given. But you see we cannot find out l or c directly because c involves rl and r, that involves, well r does not come into the picture, okay. Yes.

Why do not you consider effective (())(7:58).

We do not consider because this time, it is usually far away from the resonance frequency. C mu is a small quantity, rl is also a small quantity, so this time constant is very small and therefore it is effective frequency is very large, we do not consider that.

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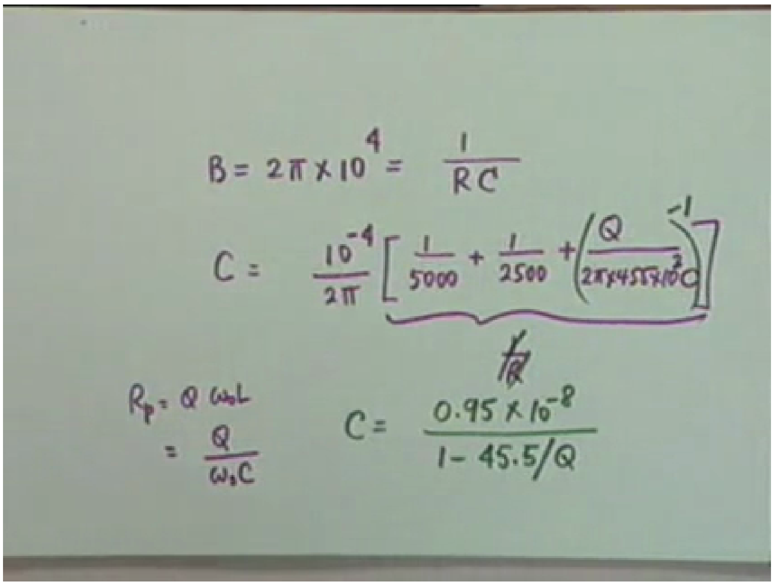

Okay, so we take the 1st specification that is bandwidth which is equal to twice pi, look i am multiplying by 2 pi, multiplied by 10 kilos hertz is 10 to the 4, this should be equal to 1 over rc as we have already found out. All right, therefore c, the capacitance that is required is given by 10 to the minus 4 divided by 2 pi multiplied by 1 by r and 1 by r is 1 by 5k +1 by 2.5 k that is 2500 + rp, 1 by rp and 1 by rp is q0.

Which q you will take?

Oh, the series q, okay. Rp is equal to q omega 0l. Now i want to find out c, can i write this as q divided by omega 0c, agreed. Let us do that, i do not know you yet, q has to be chosen, divided by omega 0 is 2 pi times 455 times 10 to the 3c, is that okay? Is this point clear? Q by omega 0, instead of omega 0l i write omega 0 c, instead of omega 0l i write 1 omega 0c because they have to resonate the omega 0.

It is 1 by rp.

Yes, i require 1 by rp because i am making this is equivalent to 1 by r.

(())(10:15).

Oh, you are right, this should be to the power -1, okay. Now is okay? All right. Now this quantity you see we could have solved for c is the new q, but let us see what are the limitations on q. You will see a very interesting thing. If you find see from here in terms of few after clearing this mess, the result is as follows. 0.95 times 10 to the minus a divided by 1 - 45.5 divided by q, that is what we get. In other words you have to choose a coil whose q is greater than 45.5, is that clear, point clear? And since it is given that you can range between 10 and 150, you choose a convenient value, let us choose q equal to 100.

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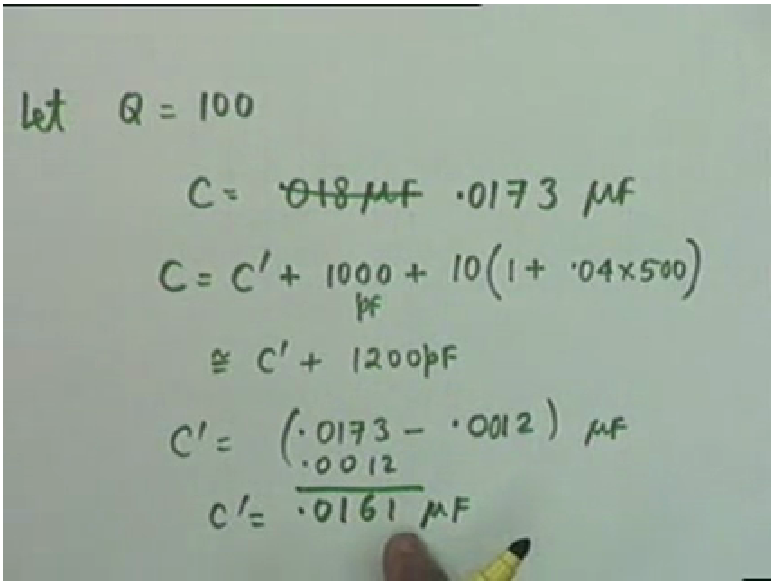

Let us choose a coil with a q of 100, then my c becomes equal to how much? 0.018 microfarads, that is what you get. Pardon me? 0.0181, will someone tell me, i seem to have made a mistake.

It is 1.7 into… yes sir 1.7 into 10 to the power minus 8.

1.7…

1.743 into 10 to the power -8.

Okay, so 0.0173, is that okay? So many microfarads, agreed. Therefore what is c prime then? We require the external capacitance, you see c prime, c as you know c prime plus c pi which is given at 1000+ c mu which is given as 10 multiplied by 1000 picofarads +10 multiplied by 1+ gm rl, that is 0.04 multiplied by 500 which is approximately c prime +1200 picofarads, agreed. Now therefore c prime is c -1200 picofarads, that is 0.0173 minus let us see how much is this, 0.012, is that okay. 10 to the -2, so 0.1…

It is 0.0012.

0012, do not make a mistake. Now 0.0012, you see that this capacitance is negligible compared to 0.0173. Nevertheless the value is 1610, 0.0161 microfarads, this is c prime. And you see that c prime dominates, c prime dominates in c. This is desirable, why? Because if the transistor is replaced by example, it will have a different c pi and c mu. It should not affect the tuning too badly and nevertheless if the transistor is replaced, that variable component of c prime, that will take care of, you tune it again, that is all. So we have found out c prime, we found out c, what remains to be found out is l.

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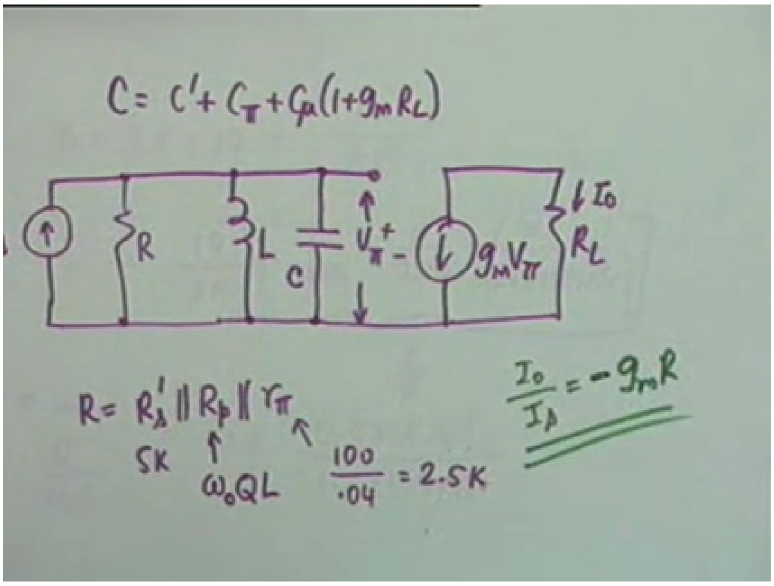

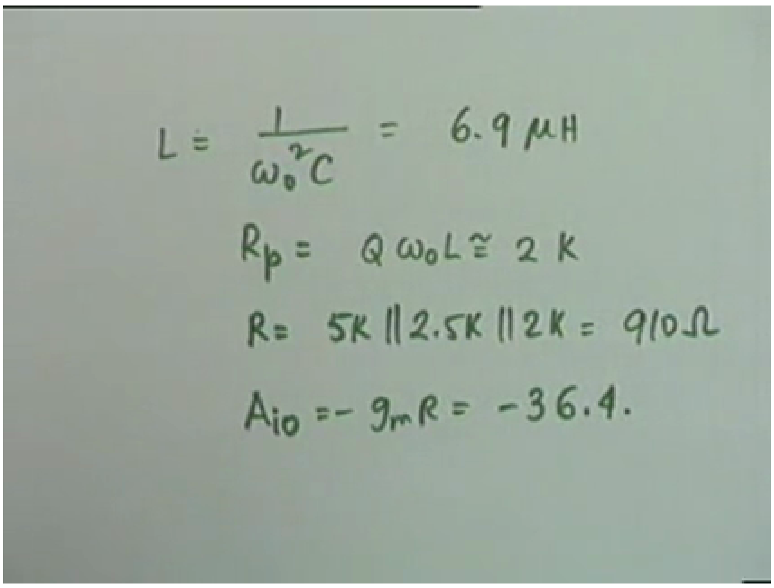

L is 1 omega 0 squared c and since c is 0.0171, was that, 0.0173 and omega 0 is given, 455 kilos hertz, this can be calculated, this comes out as 6.9 micro henry. Now let us also calculate what is rp, rp is q omega or q divided by omega 0c, if you substitute the value, this comes out approximately as 2k. Why is rp needed to be calculated? What did we calculate rp?

To see if we require external resistance.

To see if we require external resistance, no. We have already taken care of this, we do not require an external resistance. To find out the mid-band again. Can you tell me what the gain would be? Let us look at the circuit, not midband, the resonant gain, the gain at resonance. Let us look at the surface, what do you think would be the gain at resonance, i 0 by is, look at the circuit and tell me? Yes? Pardon me? Would it be a - sign of + sign?

Minus sign.

Minus sign, because i 0 and gm vpi will not take any. And that resonance you see l and c produce infinite impedance and therefore v pi would be is times r, and that would simply be minus gmr, that is the current gain, okay. In order to calculate this we require the value of theta and therefore we require r2. And therefore r is the parallel combination of 5k, 2.5 k and 2k which is equal to 910 ohms in my calculation. And therefore ai 0, the resonant gain is minus gmr is equal to -36.4 and the design is complete, the design is complete. Any questions before we go to the next one?

Next one would be a little more involved but let me point out that if an inductance, this inductance 6.5 micro henries really a very low inductance. And if an inductance with this value cannot be easily made, maybe it occupis too little space and your standard ferrite core that is available is longer, okay, so it would be beneficial to wind a larger coil, okay. If that is required you do that, you do that and take a tap but the next question is that of designing a tapped inductor or an auto transformer coupled tuned circuit.

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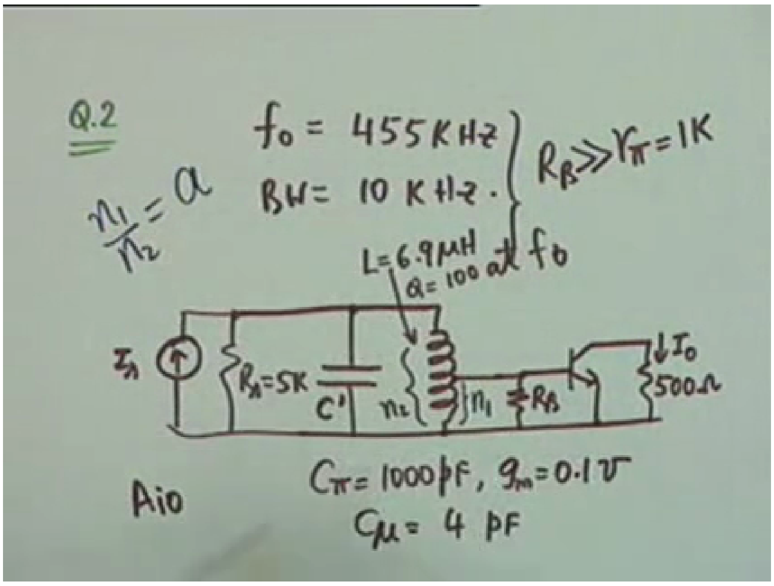

The next question, question 2 is the specifications are the same, almost the same. We will make a slight variation in the transistor, okay. We have, we still have to design a tuned circuit whose f0 is 455 kilos hertz, that is the if stage of a radio receiver, the bandwidth is still 10 kilo hertz and now the circuit is specified, the circuit is specified to be this. Draw the circuit with me. Is and rs is found to be 5k, an external capacitance c prime, external capacitance c prime, then a coil whose inductance is 6.9 micro henry, same as in the previous case, 6.9 micro henry and let say the number of turns here is n2.

Then you take a tap from here and what comes in parallel with this is the biasing resistance rb and it is given that rb is much better than r pi and r pi is given as 1k, right. So rb is shown but its effect need not be considered, rb maybe typically 30 to 40 k and then you have the transistor, emitter, common emitter transistor and the load is the same 500 ohms and this current is i 0. Here r pi is given and the coil q, coil q is given as 100 at f0, that is at 455 kilos hertz, the coil q is given as 100, c pi is given as 1000 picofarads, gm in order that you cannot use all the data of the previous example, gm is changed, 0.1 mhos, rl is given and c mu is also changed to 4 picofarads.

The question is to design this circuit and to find out the mid-band again ai 0, not midband, now it is the resonant gain, centre frequency gain, okay. Now you notice what does the design involve then? All that you have to do now is to find out, let us call this turns ratio as n1, all that is required to be done is to find c prime, the external capacitance that is needed and that turns ratio n2 is to n1 or n1 is to n2, bringing variety into experience, we will call this as a, we will call this as the primary and this as a secondary, okay, n 1 by n2 is equal to a, we will call this either turns ratio.

All that you have to do now is to find out c prime and a, all right, everything else is given. The coil is given to you, you are only allowed to make a tap, now where would you choose the tab, that is the question and what capacitance would be needed. Because the capacitance here would be reflected into the, into the input circuit and therefore c prime that is required shall be different. Let us see how to solve this problem, it is a fairly practical problem and fairly involved problem. The equivalence circuit of this would be the following.

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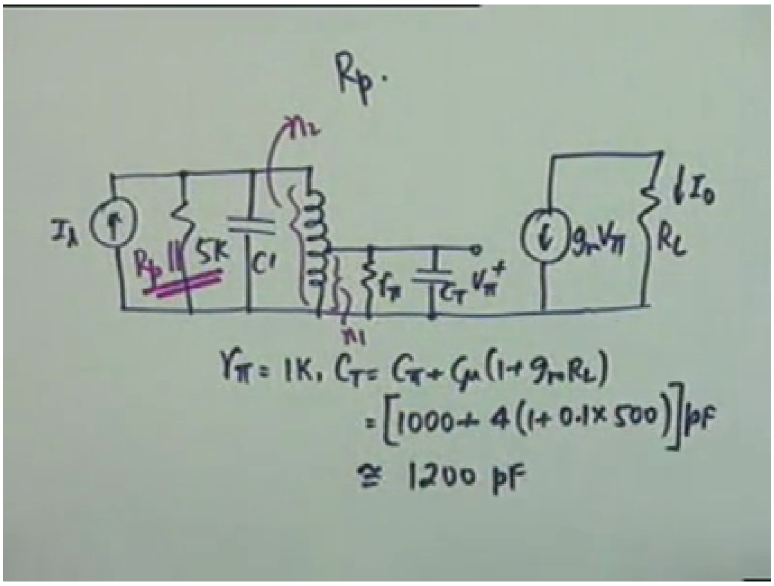

You can draw this very quickly, 5k, then c prime, then the inductance l which is 6.9, then tap, what comes across the tap, 1st is r pi and then a ct, this voltage is v pi, where r pi, r pi is given by 1k and ct would be c pi plus c mu 1+ gm rl, this is equal to 1+ 4 picofarads, 1 + 0.1 multiplied by 500, so it is approximately 1200 picofarads, 1200 picofarads. Then you have gm v pi and rl and this current is i0, which is the equivalent circuit. And i know everything, pardon me, rp, oh, the parallel, where would that come, yes, that is a very good point, it should come in parallel with, okay this is, i beg your pardon, the inductance, the inductance is 6.9 micro henry and q of 100, so this is not a pure inductance.

If it is to be reduced to pure inductance, its equivalent parallel resistance at resonance must be reflected and combined with rs, very good. So you have to include rp here, rp parallel with 5k.

(())(23:32).

No because it is in this, it is above the total and therefore the total inductance has to be here. It is r pi and ct which will be reflected into the input circuit by, r pi would come as r pi multiplied by, that said, no, no, no, that is wrong, this is n 2, this as i said i will bring variety into experience so that you are, okay r pi by… ct would come as a square times ct, okay.

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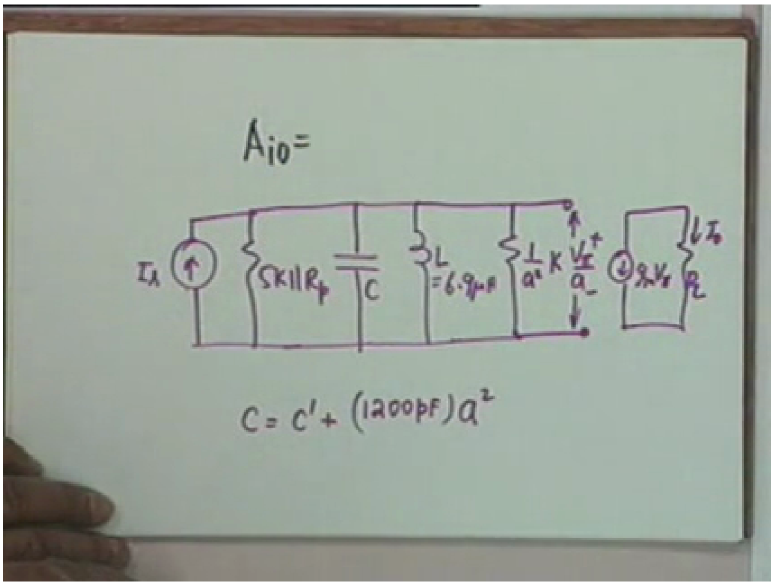

So let us look at the input circuit now, equivalent circuit by reflecting r pi including into the input circuit, we have 5k parallel rp, we have a c now, where c is c prime +1200 picofarads multiplied by a square, is that okay? The capacitance ct, that would be multiplied by a square, that is how it is reflected. This is c, then you have the inductance l which is 6.9 micro henry as given and the resistance would be reflected as r pi divided by h square, so it is 1 by a square kilos, is that okay? What would this voltage be now?

V pi into a.

Not into a, do not make the mistake again and again, that is why i chose n 1 by n2 equal to a, it would be v pi by a, then you have gm v pi rl i0. Before i go further, can you tell me what would be the centre frequency gain ai 0? This is not v pi, if it was v pi, then this would have been minus gm times the equivalent resistance here. This is v pi by a and therefore there should be a factor of multiplication or division?

Multiplication.

So it will be minus a gm r where capital r is equal to 5k parallel rp parallel 1 by a square k, agreed. Now let us take the, what is rp, rp also we know, 6.9 micro henry, omega 0 we know and we know q and therefore it would be same as in the previous case, it would be to k. Agreed , the only thing we do not know is 1 by s, what is a, that turns ratio, okay.

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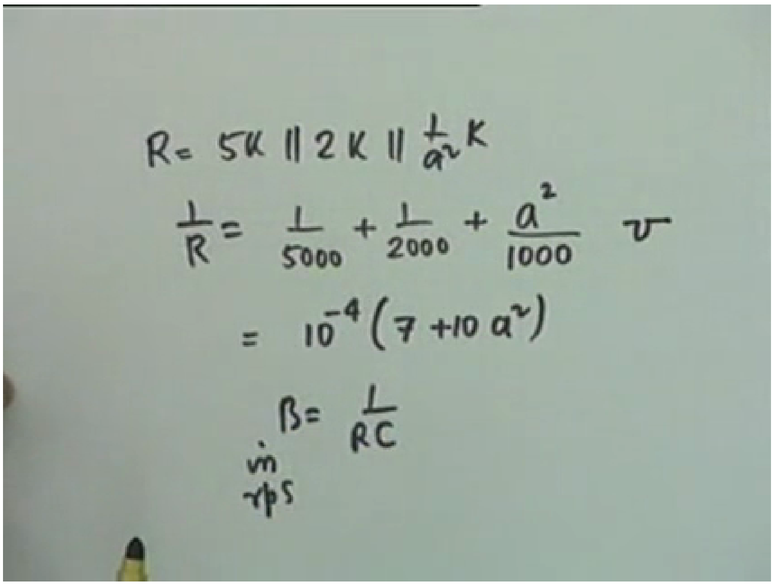

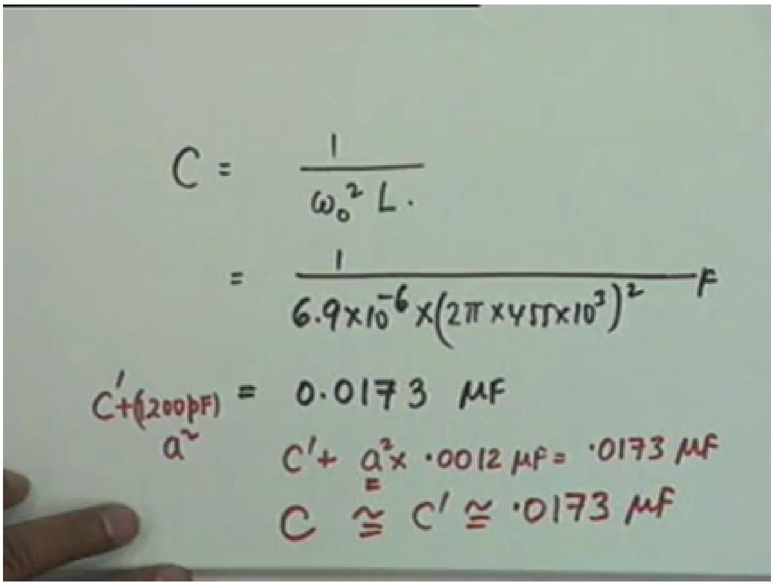

So the 1st thing we find out is from the bandwidth, from the bandwidth , no, our r is 5k parallel to k parallel 1 by a square k and therefore 1 by r is equal to 1 by 5000, i will require this in the calculation of bandwidth, in the calculation of c, we will see, +1 by 2000 + a square. Divide by thousand or multiplied by thousand?

Divided by.

Okay, wonderful. So many mhos, so many mhos and this comes out as 10 to the - 4, 7 + then a square. So a is the quantity we found out, this can be found out from the bandwidth specifications. But before we do the bandwidth specification, bandwidth specification as you know is b is equal to 1 over rc, we in radians per second, we require c. Since we know l, therefore you can find out c, the required capacitance c is 1 omega 0 square l and that is equal to 1 by 6.9 micro henry, okay, 6.9 micro henry multiplied by 2 pi times 455 times 10 to the 3 whole squared. And this comes out as 0.017, it would come out exactly as 0.0173, exactly as in the previous case, is not it, 0.0173 microfarads, so many farads, so many microfarads.

And c as you know, it should come out to be the same, okay and c as you know is c prime plus, did we find that out, 1200 picofarads multiplied by a square. Now that is, you look at now the designer's common sense. C prime plus a squared reply by 1200 picofarads means how many microfarads, 0.0012 microfarads is equal to 0.0173 microfarads. Now the designer comes into effect, a is less than 1, is not that right, a is n1 by n2 and therefore this quantity will be very small compared to the right-hand side. And therefore c prime is equal to c prime is approximately equal to 0.173 microfarads, that is approximately equal to c, agreed.

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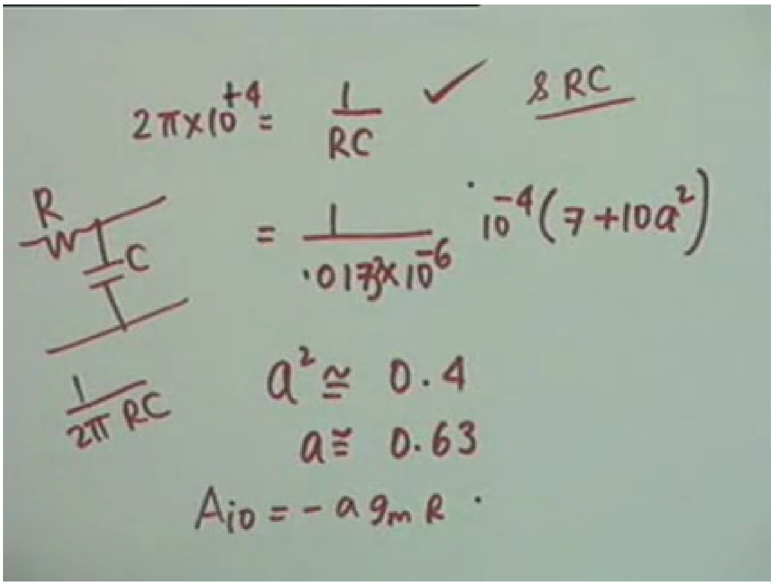

Now we can go and find out from the bandwidth specifications turns ratio. The bandwidth specification is 2 pi times 10 to the minus4 would be equal to 1 by rc, that is 1 by 0.017 multiplied by 10 to the -6, that is c, 173, okay, 1 by c, then 1 by r, 1 by r we have already found out to be 10 to the -4 times 7+10 a square, right, which has now to be cramped up for finding out the value of a. And a square comes out approximately as 0.4, so that a is equal to 0.63, a is equal to 0.63. Which means that if the original one is 10 turns, this should be 6.3 turns, n1 should be 6.3 turns, okay. And the centre frequency gain which was minus a gm r…

Excuse me sir.

Yes?

The unit of 1 by rc is hertz (())(31:54).

One by rc is hertz…? Okay, 1 by rc is radians per second, yes. You see s rc is a dimensionless quantity and s is in radians per second and therefore rc must be inverse of radians per second, which is okay, do not make a mistake. You see if i have, if i have a simple lowpass filter, whereas the cut-off frequency, 1 by 2 pi rc, this is in radians per second.

What is 2 pi into 10 raised to power minus4… (())(32:46).

Oh, what mistake did i make?

Minus sign.

It should be plus, i am sorry about that, it should be plus, otherwise everything goes wrong. Okay, the final problem of today, is there any question on this? You have to do this very carefully, what is required to be done must be very clear to you. Your aim is to find c prime and a, these are the 2 quantities and these are interlinked with each other. You see there was a point when, when we were we were absolutely at a loss to understand what should be done. Suppose that we did not ignore this, then we had to have an equation which contains both c prime and a square, only one equation. You could not solve for both but this commonsense that a is less than 1 has helped us to solve the problem.

This is how a designer comes into application of this commonsense. The final problem is that of a synchronously tuned amplifier and we shall assume that we have only 2 stages of synchronous tuning, in other words we have to resonant circuits which resonate at the same frequency and their bandwidths are the same.

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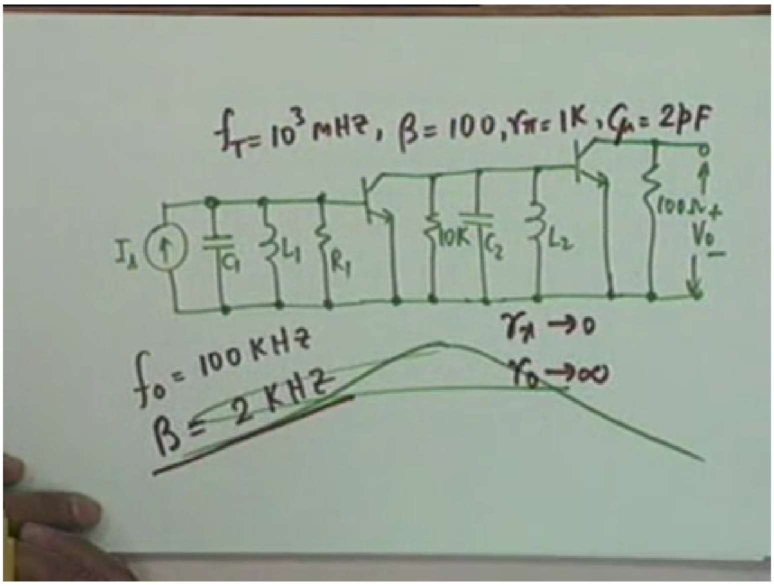

And one of these very simple way of making this is to have 2 transistors, yes, you have for simplicity let us assume that perfect coils are available, if they are not, then you have to convert them into l in parallel with rp, okay. So let us assume that we have perfect coils like this or coils whose resistance has been taken into account in, we will introduce a resistance r1 here, okay, in r1. Then you have, this is one of the tuned circuits, the other tuned circuits comes in the load or in the collector circuit of this transistor and for some reasons, for biasing and other considerations, this resistance is 10 k.

For biasing this transistor, this resistance is 10 k, then you have a capacitance c2, and inductance l2, once again we assume that the pile of resistance of l2 has been observed in 10 k, all right. And then you have a 2nd transistor load is 100 ohms and this is the output, for variety in the experience we assume that the output is the voltage. A question that could be asked at this stage is, well, why do not you take the output from here, from here itself? Why did you take the output from here itself? The condition of the problems says you could not, why?

Pardon me? Because the load is specified, it has very low resistance, 100 ohms, agreed. If you put 100 ohms here, all this tuning, not tuning, the bandwidth, that goes absolutely haywire, the bandwidth becomes very very large. In other words the tuned circuit becomes a flat tuned circuit like this, okay. So you need, you do require a buffer, okay. Now let us see how to solve this problem. The equivalent circuit if we draw, oh the specifications are as follows. Now again to bring variety into experience, again to bring variety into experience, the specifications are that ft is given, 10 to the 3 megahertz, okay, ft is given and the bandwidth, well it is required to resonate at 100 kilos hertz and the overall bandwidth b is required to be 2 kilos hertz, overall bandwidth is required to be 2 kilos hertz, that is it.

The transistors that are used have ft equal to 10 to the 3 megahertz, beta equal to 100 for both of them, r pi is 1k, in other words both have the same gm, okay, r pi is 1k. What else do you need? What else you need? C mu is given as 2 picofarads and it is said that rx tends to 0 and r 0 tends to infinity, all right. This is the specification of the problem, you have to find out. What are the things to be found out here? This capacitance c1, the inductance l1 and we do not know what this resistance is, we have to find r1, then we have to find c2, l2, that is all?

Gain.

Gain, okay, that of course, that also. Can we write the expression for this, gain at the centre frequency, can we write an expression, write by looking at it? Can you do that? For the last stage without doing the equivalent circuit, for the last stage it is minus gm times 100, okay. And for the 2^{nd} stage, minus gm times 10 k parallel r pi, 1k, that is right. Then for the 1^{st} stage… yah? For the input circuit. V pi over is, that is the gain now. So that will be r1 parallel r pi, absolutely wonderful.

We can write this by inspection and therefore if you know gm, you can find out gm, all that you need to find out to find the centre frequency, find the centre frequency gain is to find r1, that is the only thing that is unknown, all right. And the equations, now let me draw the equivalent circuit, then the equation should be clear.

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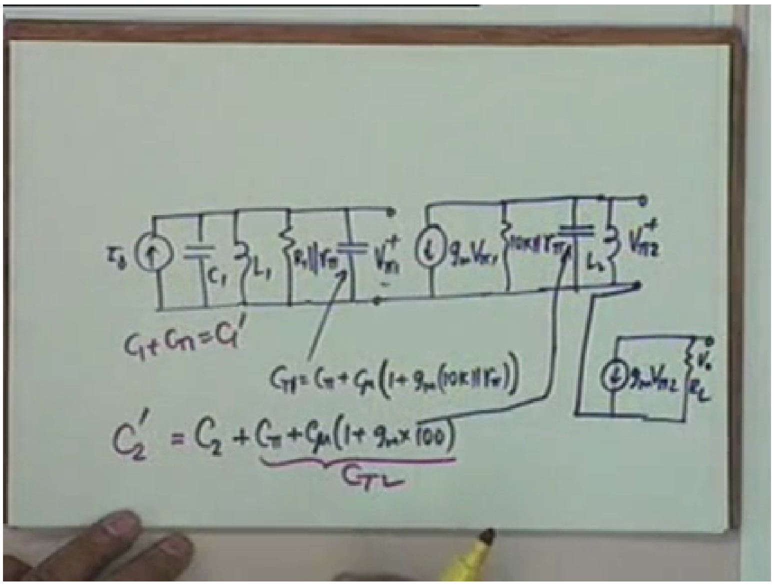

What i have is is parallel c1, l1…

Excuse me sir one question.

Yah?

This ai 0 is the ratio between what and what, v 0 by is?

That is right because our output is v0 and input is is. It has a dimension of, look at it, it has a dimension of…? Resistance, this is dimensionless, this is dimensionless, so this has dimension of resistance. It has to be v0 by is, okay. C1, l1, then you have the parallel combination of r1 and r pi, agreed, the 1st transistor. And you have the capacitance as, actually this capacitance, okay, since we have drawn it separately, this is ct1 which is equal to c pi plus c mu 1+ gm times 10 k parallel r pi. Okay. This is v pi 1, then you have gm v pi 1, this resistance should be 10 k parallel r pi, agreed, 10 k parallel r pi, then you have, what would be this resistance?

C2 plus, what shall be reflected? C pi plus c mu + 1 + gm multiplied by 100, that is correct, this is the total capacitance. And then you have l2, of course that has to be there and this voltage is v by 2 and finally, finally we shall have gm v pi 2 and in parallel with rl, this voltage is v0. All right, i could not find place here so i have brought it down, is it okay? Or have i made a mistake? Do not be too sure, i can make a mistake. I shall call this as, what shall i call it, c2 crime let us say , ct2, well, i did not want to use that because i had used this ct1 here, this is ct 2, okay. And i will call c1 plus ct 1 as c1 prime, that is the total capacitance here. Then i have 1, 2, 3, 4 equations, what are these equations?

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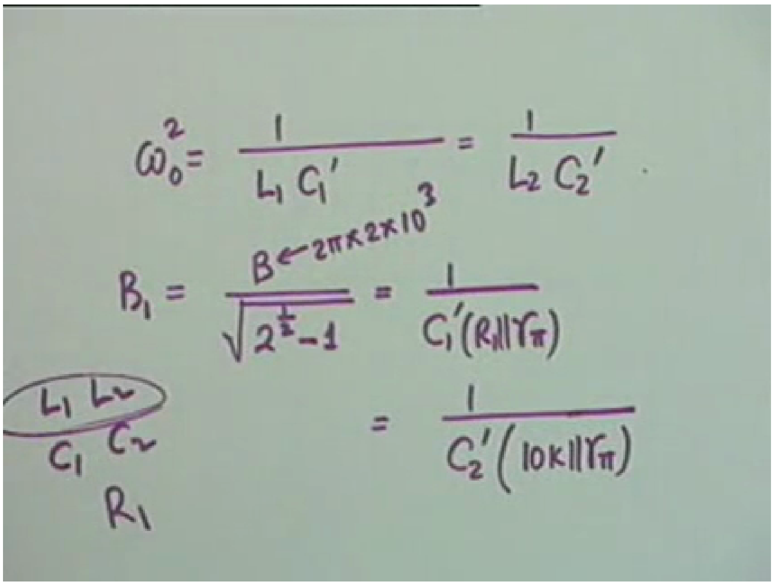

Mind you it is synchronous tuning, therefore the equations are omega 0 squared equal to1 by l1 c1 prime, it should be same as 1 by l 2 c2 prime, this gives me how many question, 2? 2. And the other one is the bandwidth equation, now there comes the question. What bandwidth should be used? The overall bandwidth is required to be 2 kilos hertz, so what is the individual bandwidth b1? How do you know?

Synchronously tuned.

Synchronously tuned, so the bandwidth shall shrink. That shrinkage factor you must take into account. It should be the overall bandwidth divided by, obviously the single stage bandwidth has to be larger than the overall bandwidth, so you divide by square root 2 to the power half -1, this you have to find out. And this is given as 2 kilos hertz, so this is 2 pi multiplied by 2 multiplied by 10 to the 3, is a the clear? You might for career, if you use a 2 kilos hertz, then your calculations will go wrong. This should be equal to 1 by, 1 by c1 prime and the total resistance, total resistance is r1 parallel r pi, it should also be equal to 1 by c2 prime multiplied by what?

10 k parallel r pi, how many questions will we get here? 2. So you have 4 equations. What are the things you have to find out? L1, l2, c1, c2, what else and r1, these are the 5 things we have to find out. So to have 4 equations, so one of them you can choose this at your (()) (45:04). You would normally like, you would normally like l1 and l2 to be equal because this

is the problem point. Winding an inductance of a specified value is a problem. So if you have wound it once, then you know exactly how many turns you have to use. So normally you choose l1 equal to l2, that constraints you to 4 equations, okay because you have made one choice, then the rest can be calculated, more on monday.