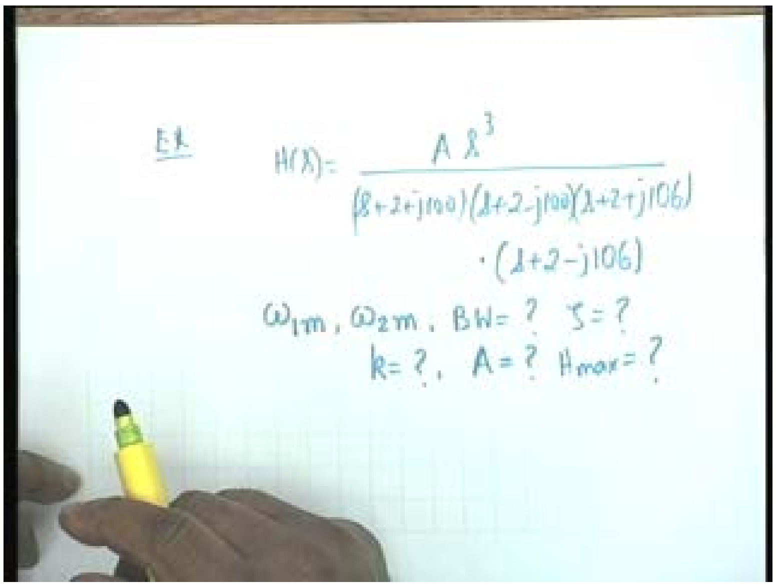
Circuit Theory
Prof. S.C. Dutta Roy
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 19
Double Tuned Circuits (Continued)

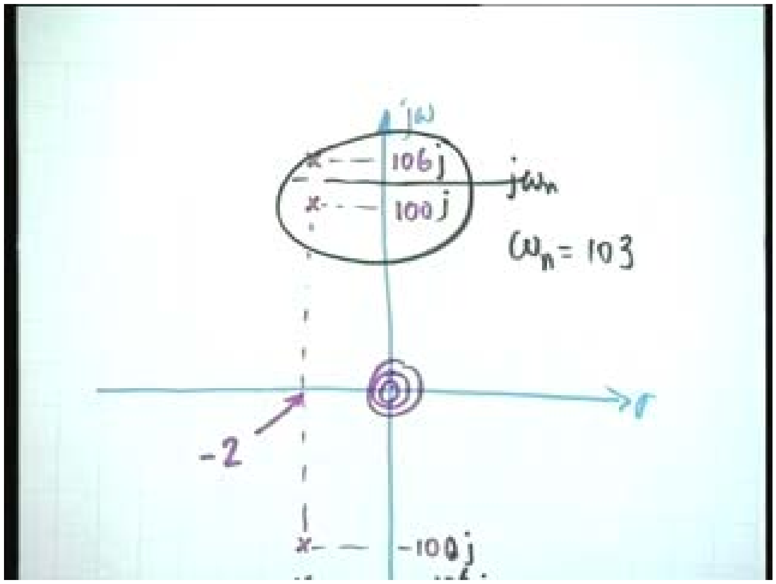
Is the 19th lecture, 3rd February, 1995. We continue our discussions on double tuned circuits. In particular, we consider a couple of examples and then we shall have a general discussion on double tuned circuits. We had started the general discussion, the previous day, that means, transfer functions of the type, that is obtained in double tuned circuits can also be obtained otherwise. And one of the examples I gave was, electrostatic coupling through a capacitor. It could also be a resistive coupling. It could also be some other kind of coupling, which we shall discuss at the end of this class.

(Refer Slide Time: 1:43)



Now the example that we had taken was, a transfer function which was given as A s cubed divided by s plus 2 plus j 100 s plus 2 minus j 100. Then s plus 2 plus j 106 multiplied by s plus 2 minus j 106. This was the transfer function and we wanted to find out the frequencies of maxima, omega 1 m omega 2 m. Where do the, does the transfer function attain a maximum value? We wanted to find out the bandwidth. For bandwidth, we have to find out omega c 2 and omega c 1, then zeta k, the coefficient of coupling, the constant A and the maximum value of the response. These are the things to be found out and if we look at the pole 0 diagram.

(Refer Slide Time: 2:53)



There are 3 zeros at the origin, as in the tuned circuit. 3 zeros at the origin and if we exaggerate a little and distort the scale a little, there are poles here and here, there are poles here and here, where this distance is minus 2, this is 100 and this is 106. This is minus 106, minus 100. Of course, they will have to the multiplied by j.

Student: (…)

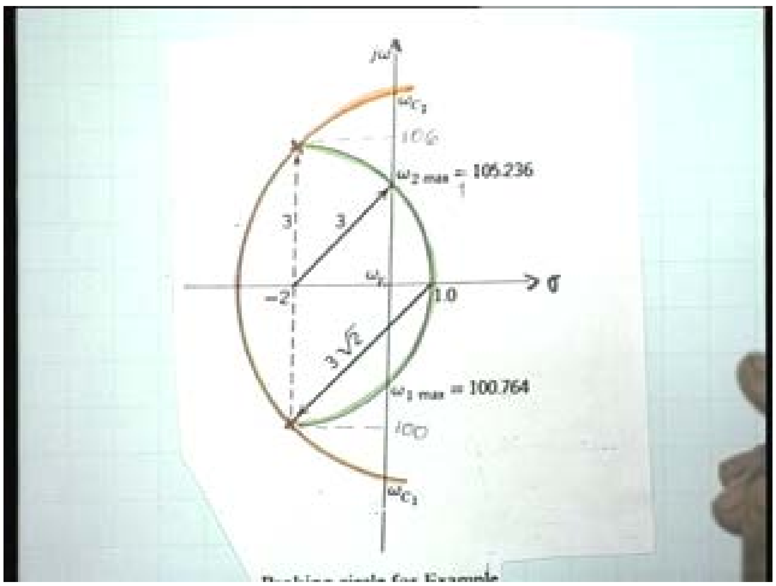
Sir: Pardon me.

Student: (…)

Sir: Thank you. That is correct. 100 would be up and 106 would be down. Now, obviously omega n well, the poles, the distance from the origin along the vertical axis is much larger than the distance from the, I beg your pardon, the distance from the vertical axis, that is, this distance is much smaller as compared to the distance from the horizontal axis and therefore, zeta would be a small quantity.

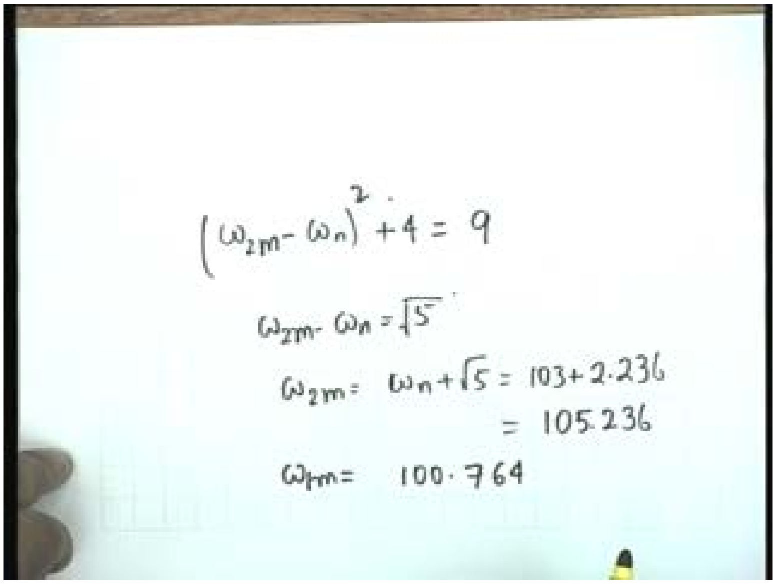
We also assume that the coefficient of coupling is sufficiently small, which is suggested by the symmetry of, well, the closeness of these 2 poles and therefore, our omega n, if you recall, this would be j omega n, midway between the two. So omega n is 1 0 3, that is obvious. If we want to find out the 2 frequencies of maxima, we will have to draw the peaking circle. Now the peaking circle has been drawn here. The green circle here is the peaking circle, let me explain.

(Refer Slide Time: 5:21)



This is the sigma axis, this is the j omega axis and the intersection is now at omega n and the 2 poles, that is, what we are doing is, we are zooming on this part and this is omega n this is 1 0 6, this is say 100. You understand why? These are the 2 poles. We are zooming on the 2 poles, on the upper half of the s plane; 100 and 106 and this is omega n 103. So the poles are here. This is, this point is minus 2, and the peaking circle is drawn with minus 2, this point as the centre and the distance from this point to the pole as the radius. So this is the green circle which cuts the j omega axis at 2 points, omega 2 max and omega 1 max.

(Refer Slide Time: 6:30)



And if you notice, the omega 2 max all right. Omega 2 m minus omega n whole squared, that is, consider this right angle triangle. This squared plus base squared, base is 2 and therefore, plus 4 would be equal to the hypotenuse squared, which is equal to 3, therefore, it is 9. Therefore, omega 2 m minus omega n is equal to 5. Therefore, omega 2 m is equal to?

Student: Root 5

Sir: I beg your pardon, root 5, that is, 9 minus 4. Well, therefore, omega 2 m is equal to omega n plus root 5, that is equal to 103 plus root 5 is 2 point 2 3 6. So this is 100 and 5 point 2 3 6. Omega 1 m can be obtained by inspection. It is to be symmetrical; number 1. Number 2, if you take this as minus root 5, I think the answer is obvious, and therefore, this would be 100 and 3 minus 2 point 2 3 6, so this would be 100 point 7 6 4. These are the 2 frequencies of maximum.

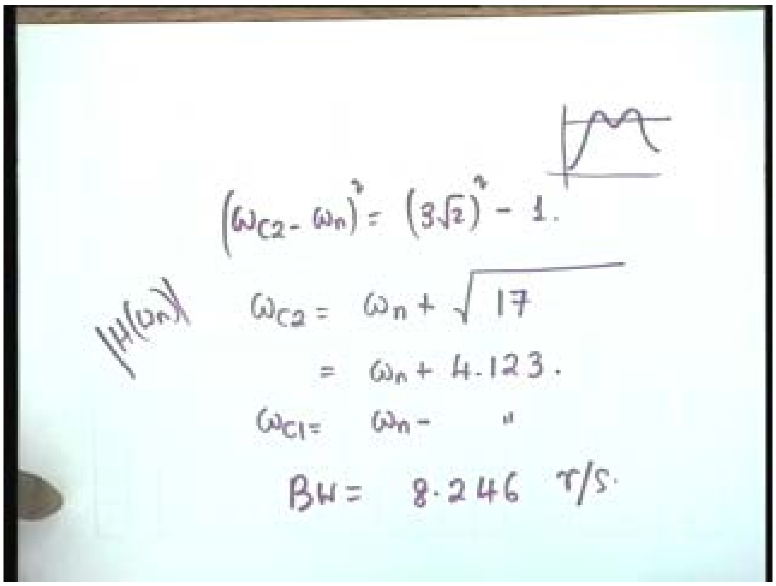
Now we go back to the peaking circle. We have found out omega 1 and omega 2, then we look for the bandwidth. For the bandwidth, you see, the peaking circle intersects at 2 points, omega 2 and omega 1 and it intersects the sigma axis at this point which, whose coordinate obviously, is 1 because the radius is 3, this is 2, so this is 1.

Now from this point, as the centre and the distance from this point to the pole as the radius, you draw the peaking circle, which is the orange circle. It cuts at 2 points omega c 2 and omega c 1 and what we have to find out is omega c 2 and if you find omega c 2 by symmetry, omega c 1 shall also be found. You notice that omega c 2, if I draw this, let me use a light colour. If I draw this line, then right angle triangle, this line is equal to, what is the length of this line?

Student: 3 root 2.

Sir: 3 root 2, because this is, it is the same as this. This is 3 and this is 3, so this is 3 root 2, 3 root 2 squared would be equal to omega c 2 minus omega n whole squared plus 1, plus 1 squared. Therefore, what I get is the following.

(Refer Slide Time: 9:32)



Omega c 2 minus omega n whole squared would be equal to 3 root 2 squared minus 1 and therefore, omega c 2 is equal to omega n plus square root of, how much is this? 18 minus this, 17. So this is equal to omega n plus, square root of 17 is 4 point 1 2 3. Therefore, omega c 1, by symmetry, would be omega n minus the same quantity. Therefore, the bandwidth is the difference between the two. It would be 8 point 2 4 6. You must put the appropriate unit, what is the unit for bandwidth?

Student: Frequency.

Sir: Frequency, radiance per second. We do not have to have absolutely find out what is omega c 2 and omega c 1, because we only want the bandwidth, but we had to determine this. Next,

Student: Excuse me, sir.

Sir: Yeah.

Student: Sir, these bandwidths are same, about the bandwidth, so we should, we need not find the centre point of that between, to gauge that how much is the depth.

Sir: Very interesting question, yes.

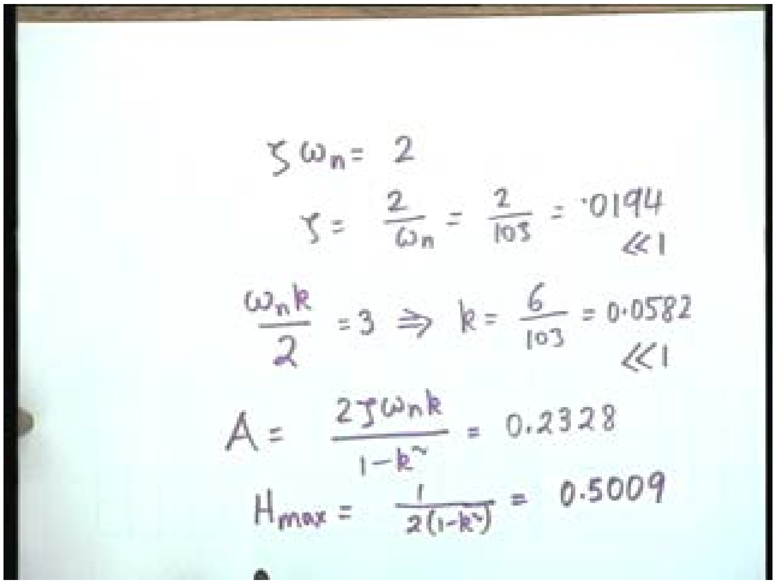
Student: So that will be just the H omega naught?

Sir: That is correct. You will have to find that out. You see, all they are asking is the bandwidth. Now, bandwidth will not have a meaning if this is the situation, for example, if the dip dips below 3 db, it will not be useful. In this case, you shall have to check. I did not check this.

Student: Sir, actually, we have to write H of omega naught is less than 2 root or not?

Sir: That is right. So you have find out H of omega and magnitude and see whether it is less than 1 by root 2 times this or not. If it is not, then this is, this bandwidth is meaningful. Good question.

(Refer Slide Time: 11:36)



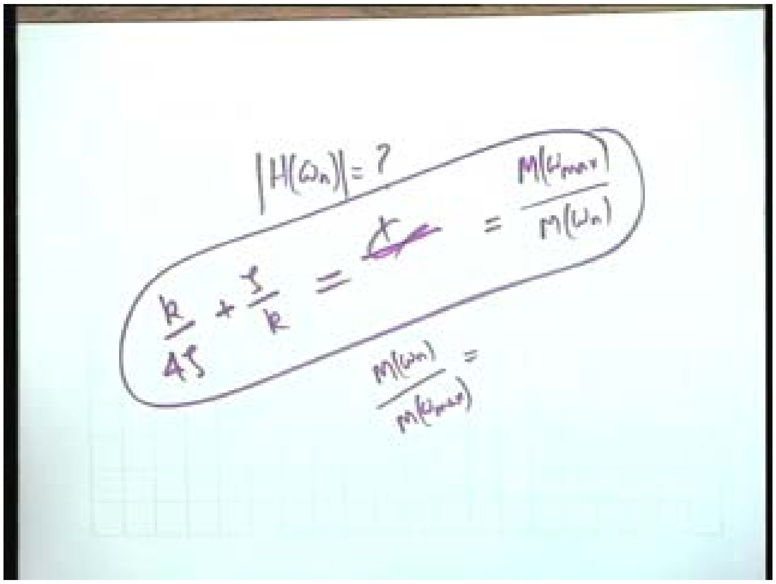
The other things that you have to find out at the, what we can find out zeta, zeta omega n is equal to 2, it is given. Zeta omega n is the distance of the pole from the vertical axis, from the j omega axis. Zeta omega n is 2, therefore, zeta is equal to 2 by omega n which is equal to, and we need the value of zeta to be able to find out the value of the constant, a capital S cube. So 2 by omega n is 2 by 1 0 3 and this is point 0 1 9 4. We also need the value of k. k is specifically asked for, and we know, omega n k by 2 should be this distance, 3. This is equal to 3.

Therefore, k equal to 6 divided by 1 0 3 and this is 0 point 0 5 8 2, which indeed, is much less than 1. This is also much less than 1, 1 by 50. So zeta squared would be much farther less than unity. Finally, you find capital A is twice zeta omega n k divided by 1 minus k squared. You substitute all the values, then you get point 2 3 2 8 and the maximum value of the transfer function H max.

Student: 1 by 2.

Sir: 1 by 2, 1 minus k squared, that is equal to point 5 0 0 9. Finally, did we find out an expression for H of omega n, did we do that earlier? H of omega n, did we or did we not?

(Refer Slide Time: 13:19)



Student: Sir, we did.

Sir: We did find out the ratio in one of the examples, yesterday. We did find out the ratio of M omega max to M omega n, did not we? What was the expression?

Student: 1 by sine psi.

Sir: And what was the value?

Student: (…)

Sir: k by 4 zeta plus?

Student: zeta by k

Sir: Zeta by k. Now let us check this. Compare it to the maximum or we take the other way round that is, M omega n divided by M omega max. Let us, it is now easy to find out, what is the ratio? If this ratio is greater than 1 by root 2, greater than or equal to 1 by root 2, is the point clear? Yes or no? Then the bandwidth that we have found out has meaning, otherwise, it does not have. So this expression must be kept handy also. This is how you check, whether the bandwidth that you have found out is meaningful or not. Let us take another example. Is there any question on this?

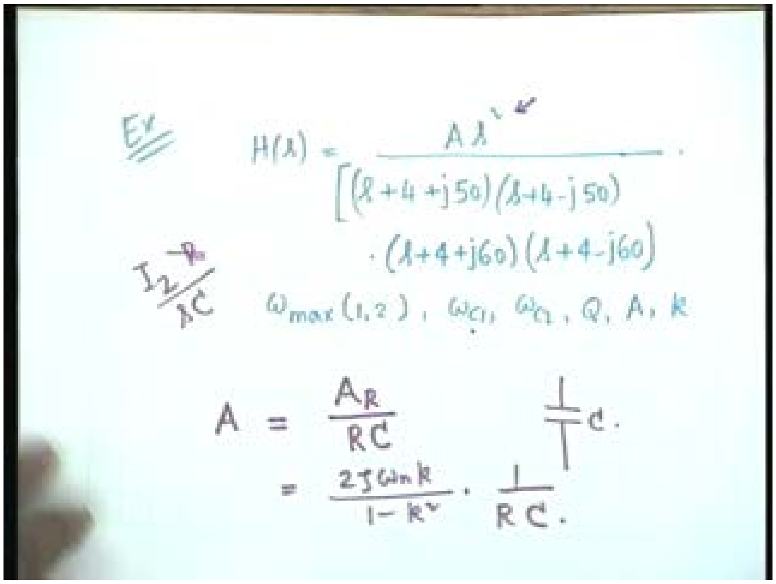
Student: Suppose in the case of the 3 poles or 3 zeros

Sir: In the case of 3 zeros, yes.

Student: As in this case, there were not 3 zeros. Suppose 1 zero or 2 zeros, sir, then there will not be any change.

Sir: We will take that case now. We will take an example with 2 zeros. We take this example.

(Refer Slide Time: 15:10)



H of s is equal to A s squared divided by, this is given, s plus 4 plus j 50 s plus 4 minus j 50, multiplied by s plus 4 plus j 60 multiplied by s plus 4 minus j 60. This is what is given. We have to find out the frequencies of maxima, omega max. If there are 2, both of them, 1, 2, you have to find out omega c 1, omega c 2, this will always exist, whatever the value of k n zeta because it is a band pass. Is it a band pass response, now? You must be careful. There is a power of 2 here.

Student: Band pass.

Sir: It is band pass because at the origin, at s equal to 0, it is 0. s equal to infinity is also 0. Same between, there must be a maximum and therefore, there must occur an omega c 1 as well as omega c 2. You have to find out the value of Q. You remember Q is 1 by 2 zeta. Then the value of A and the value of the coupling coefficient k, these are the things to be found out. The first observation that you make is because the power is s, the power of s is 2 s squared. Obviously, if it is a double tuned circuit, the output has not been taken across the resistor. If it was taken across the resistor, the power could have been 3. So one power has been reduced, what does it mean?

Student: Capacitance.

Sir: Capacitance. So the output has been taken across the capacitance, which means, that the value of A here would be related to the value of A. The previous value of A, which we shall denote by, if the output is taken across R, how will these 2 be related? If you recall, the output is I 2 multiplied by R in the previous case, and in this case, it is I 2 divided s C. This s makes the power of s, 2 here and the constant, therefore, the constant would be, I have to divide by R.

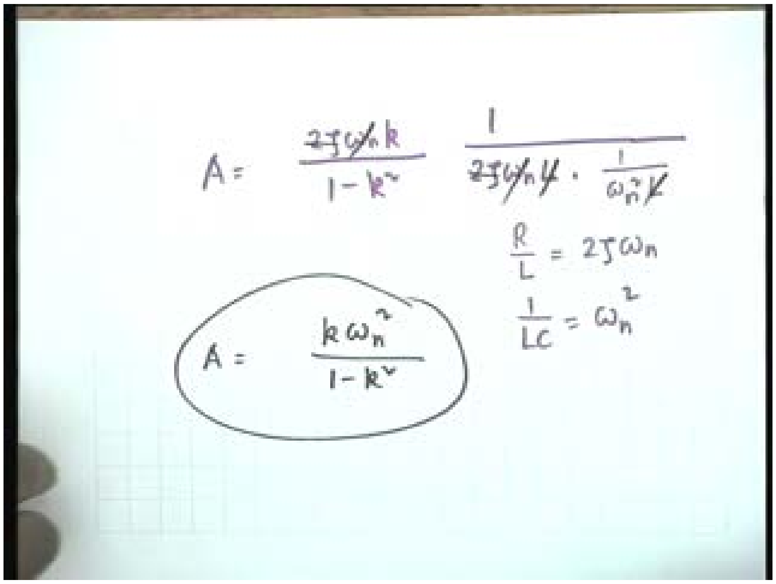
Student: Multiply by C.

Sir: And divide by C. There is C, in the denominator here. I 2 by s C, which means that I have to divide by R, divide by C and divide by s. Divide by s, that takes care of s square. That is how we find out the new A. We do not have to derive the whole double tuned circuit again. We can do it by inspection. The only difference is that the output is, has been taken across the capacitor and.

Student: The same can be the thing done in the single tuned circuit?

Sir: Pardon me. Yes, of course, all known results can be utilized. You do not have to derive the same thing. So our A R, if you recall, this is twice zeta omega n k divided by 1 minus k squared multiplied by 1 by R C.

(Refer Slide Time: 18:48)

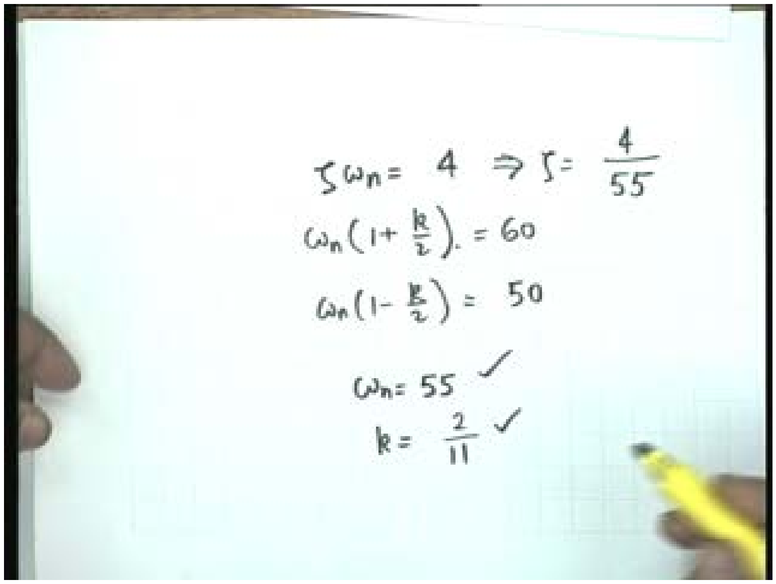


So A, in this case, shall be equal to twice zeta omega n k divided by 1 minus k squared. You also recall that R by L is twice zeta omega n and 1 by L C equals to omega n squared. Therefore, this R and C can be replaced in terms of their equivalent values. R is twice zeta omega n times L and C is 1 by omega n squared L and you will see, jolly well that capital L and L cancel omega n and omega n cancel, 2 zeta cancels with 2 zeta and the expression become simplicity itself. It becomes k.

Student: By 1 minus k squared.

Sir: Omega n square, this omega n squared, divided by 1 minus k square. This is the new value of k, if the output is taken across the capacitor. Now let us proceed, systematically, to derive the numerical values of the other quantities that are wanted. Obviously, we require the value of zeta, we require the value of omega n, we require k and that is about all. Then we shall be able find everything else. Let us see. First thing is, we notice that by comparing the transfer function, by looking at the pole location, the real part is 4 minus 4, for all the poles.

(Refer Slide Time: 20:25)



And therefore, one conclusion that we get is; zeta omega n should be equal to 4, agreed. Then from the high q approximation loose coupling and high q, we get omega n 1 plus k by 2. That is, the upper pole in the upper plane, upper s plane.

Student: 60.

Sir: That is equal to 60 and omega n 1 minus k by 2. The lower pole in the upper half plane is 50 and therefore, omega n is therefore, is equal to 55 radiance per second and by substituting this, you can value, you can get the value of k as

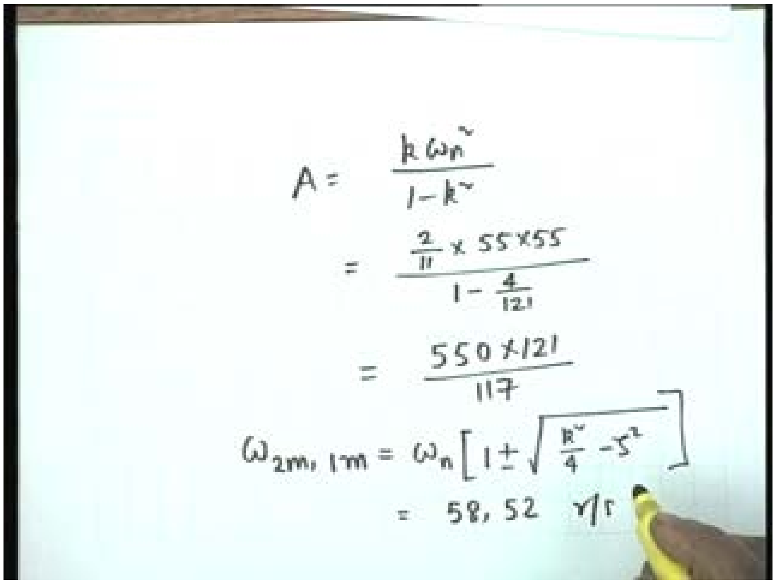
Student: 10 by 55.

Sir: That is, 2 by 11, agreed. 10 by 55, that is correct. Omega n and k and if I know, so I know also zeta, then zeta is 4 divided by

Student: 55.

Sir: 55. I do not require this value for calculating A, but zeta, I should require for other calculation.

(Refer Slide Time: 21:44)

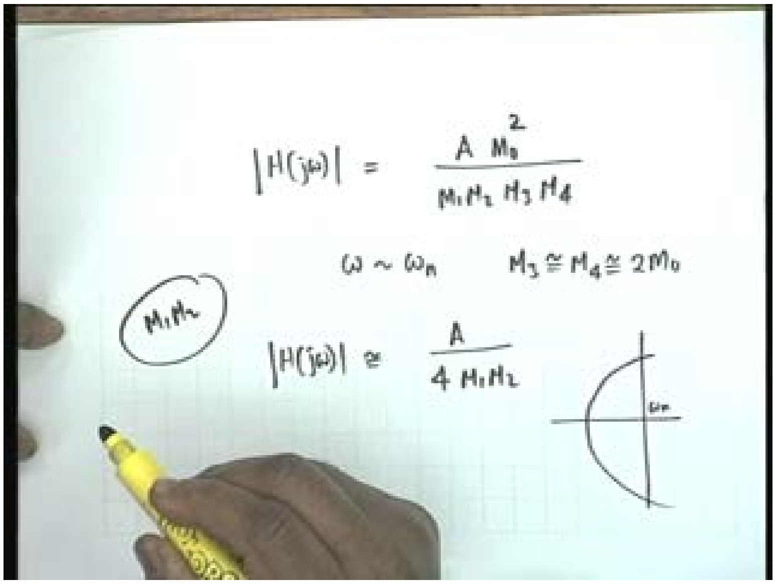


So I can now calculate the value of A, the constant. A is k omega n squared divided by 1 minus k squared. So this is equal to 2 by 11 multiplied by 55 multiplied by 55 divided by 1 minus 4 by 121 and I did not calculate the whole thing. I just left it like this. There is no one, no other cancelation. 550 into 121 divided by 117, 3 is a factor, 9 is a factor, thirteen is a factor, but none of them are factors of the numerator. So I left it as that. You have to use your calculator to get the values.

Then I find out the maxima, the frequencies of maxima, that is, omega 2 m and omega 1 m. I have already derived the values from the triangle and the values are omega n multiplied by 1 plus minus square root of, this I did in the class yesterday, and also, I took help of this in the example. But I did from the figure with numerical values. The general value is k square by 4 minus zeta squared. This, I derived yesterday. So if you substitute the values, my results come as 58 and 52.

I did not have to calculate the other one because symmetry says, 55 plus 3. So 55 minus 3 is 52, so many radiance per second. Of course, the major deviation of working of this example shall come in calculating the value of the maxima.

(Refer Slide Time: 23:36)



Here, H of j omega, magnitude, shall be A multiplied by the 0 vectors. Vectors drawn from the zeros and there are 2 of them now, not 3. Therefore, it would be M 0 squared divided by all the 4 M 1, M 2, M 3, M 4, agreed. Not Q and therefore, it will make a difference. Now, obviously, if omega is of the order of omega n, then M 3 would be, approximately, equal to M 4, would be approximately equal to?

Student: Twice M naught.

Sir: Twice M naught. The same as this and therefore, we substitute this. If I substitute this here, instead of putting omega n, this will be approximately equal to A divided by 4.

Student: M 1, M 2.

Sir: M 1, M 2. Also from that pole 0, from that pole diagram, this is omega n, this is my peaking circle.

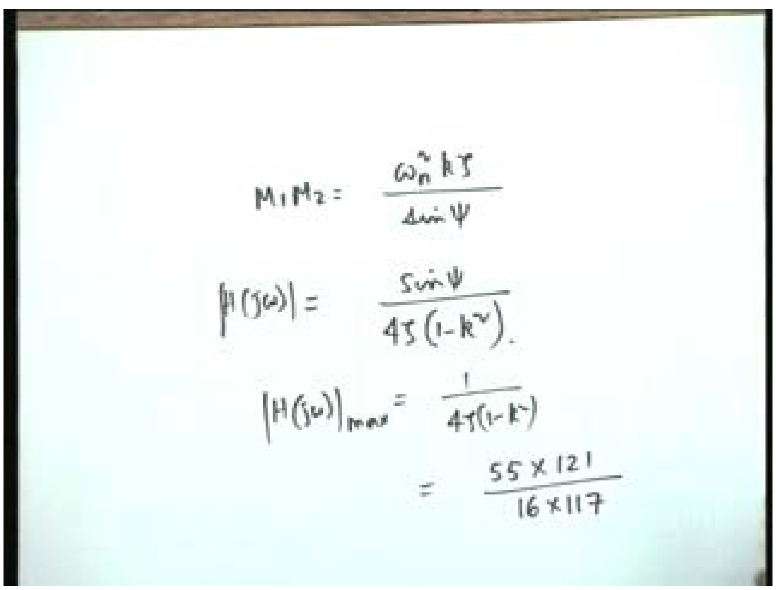
Student: Sir, the other way round, the circle.

Sir: Anyway, from the triangle, I have already done this derivation, so I do not. Does the product M 1, M 2 change?

Student: No sir.

Sir: In terms of psi, it will remain the same, because the same triangle that we are evaluating in 2 ways. One is in terms of its base and the height, and the other in terms of M 1, M 2 and the included angle. Therefore, let me not derive this again.

(Refer Slide Time: 25:22)



Sir: M 1, M 2 is equal to omega n squared k zeta divided by sine psi. Was this the result derived by, earlier?

Student: Yes, sir.

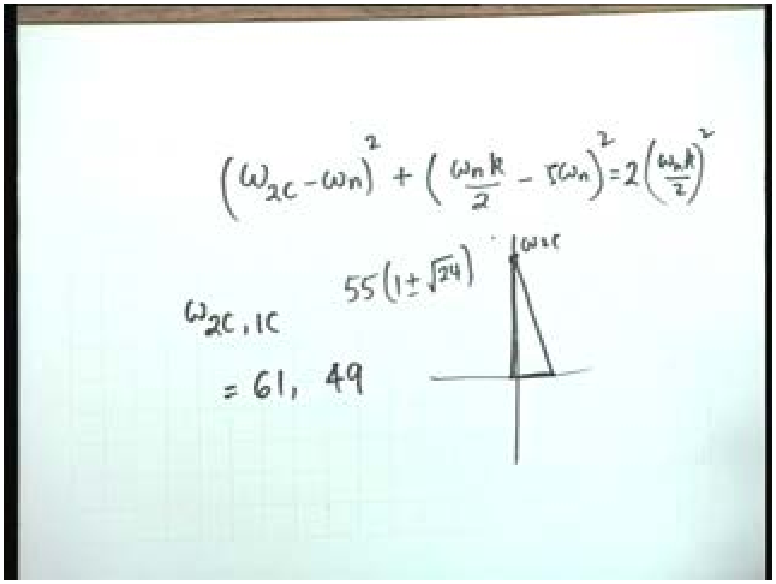
Sir: Therefore, magnitude H of J omega, if you substitute, you shall get sine psi divided by 4 zeta 1 minus k square. What is the difference? Difference is the factor of 2 zeta in the denominator. Previously, it was sine psi by 2 1 minus k squared. Now it is 4 zeta. Is that clear? What does this mean? That the maximum value here would be much higher than the maximum value in the previous case, is that clear, because of the occurrence of zeta.

Student: (…)

Sir: psi is a very small quantity. It is increased by a factor of 2, but decreased may be by a factor of 100 and therefore, you will get much higher value. So the maximum value H j omega max would occur when psi is phi by 2 and therefore, this is 1 by 4 zeta, 1 minus k squared and by substituting the values, I get 55 multiplied by 121, divided by 16 into 117, it is not too high. It is about 3 times or 4 times, at the most. The value is approximately 4. You can find that out.

Student: The zeta is also different?

(Refer Slide Time: 27:16)



Sir: Zeta is also different, of course. Finally, finding out the cut of frequencies, omega 2 c minus omega n whole squared plus.

If you recall the triangle, we have done this twice plus omega n k by 2 minus zeta omega n whole squared. This triangle, if this is, this is omega 2 c, this triangle, should be equal to what?

Student: Root 2 into omega n k.

Sir: Omega n k by 2 was the radius.

Student: Into root 2.

Sir: Squared, no, I am taking this square. So this multiplied by 2. From which, we can find out omega 2 c and omega 1 c. The 2 roots of this, it is a quadratic.

Student: 55 plus minus.

Sir: Plus, minus and therefore, pardon me.

Student: 55 plus minus root 24.

Sir: 55 plus minus root 24. 1 plus minus root 24, I do not know what that is. Well, my calculations, perhaps you are right, my calculations give omega 2 c and 1 c as 61 and 49. I suspect this because root 24 is not a whole number. I did get a whole number, perhaps, I made an approximation. I do not know. I have just noted the results. My rough calculations are elsewhere.

Student: Not multiplied by 55. Instead, whole product, it is simply 55 plus minus.

Sir: Oh, 55 plus minus, even then.

Student: (…)

Sir: Well, anyway, if this is your base equation. You can calculate that out. Now, that completes the example. Now, if I had taken the output across the inductor, could I have taken the output across the inductor?

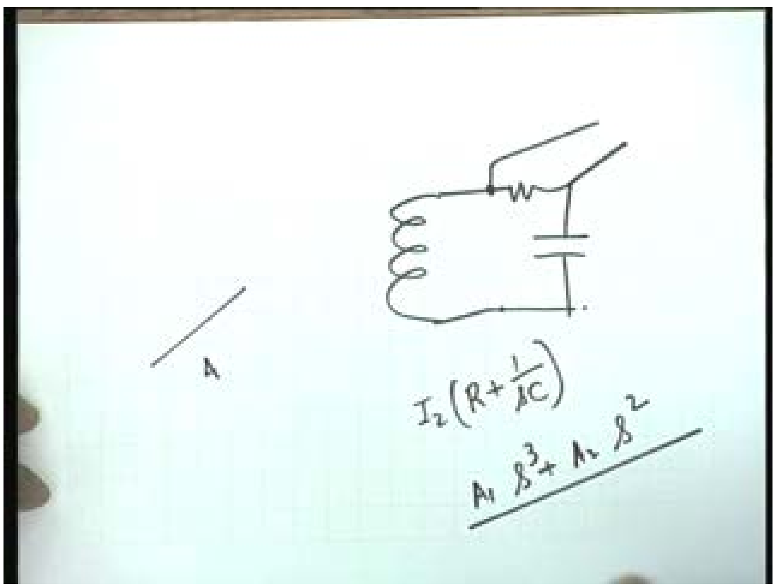
Student: Yes sir.

Sir: Which means?

Student: (…)

Sir: Hold it, there is a problem. Across the inductor, could I take the output from here?

(Refer Slide Time: 29:36)



Student: Yes sir.

Sir: Then should I simply multiply I 2 by s L? No.

Student: No sir.

Sir: Because there is a defective mutual inductance also. The simpler thing would be?

Students: (…)

Sir: That is right. Your simpler thing would be, take the output as I 2 R plus 1 over s and then you calculate, and therefore, in the numerator, you would have an s cubed term and also an s squared term. You will have A 1 s cube plus A 2 s squared divided by those quadratic, that quadratic polynomial, because of the 4 complex conjugate poles. Now, what can you say about this equation? Would it also be a band pass?

Student: Yes sir. It will be.

Sir: Sure, surely it will be band pass.

Sir: Is there a, is there a way I can get a high pass from here? Is there a way I can get a high pass from the double tuned circuit? You see, I have, there are only 3 possibilities.

Student: Sir inductor will not be needed?

Sir: There are only 3 possibilities. I can take the output across resistance, I can take it across capacitor or I can take it across the secondary and in all the 3 cases, it is band pass, in all the 3 cases, because the number of poles here is 4. You cannot create more than 3 zeros and therefore, there is no way that you can get a high pass response. You cannot get a low pass response either. There is no way that you can reduce the numerator to a constant and therefore, it is truly a band pass case. Now, let us, a small

Student: Excuse me sir. Then why cannot we create, more than 3 zeros?

Sir: More than 3 zeros, tell me how to?

Student: Theoretically, sir.

Sir: This is a, this is the degree of the, well we have to enter into a bit of complicated discussion, but let me put this to you that the number of energy storage elements, that determines the number of poles in the circuit and the number of zeros is determined by the way you take the output. The number of poles here is 4. It cannot be more than 4, because even with, without those approximations, you have only 4 poles, and you cannot create more than 3 zeros because you have exhausted all the possibilities of taking output and therefore, there is no way you can introduce another pole.

Student: Sir, what will be the equivalent A for this case? (…)

Sir: Oh, you have find out A 1 and A 2 we have already found that out. There is no equivalent A

Student: Individual.

Sir: There are two As. One is A 1 and the other is A 2.

Student: Sir, but each will give different frequency response, because each individually is a double tuned circuit.

Sir: Correct. You will have to find out the total frequency response from here.

Student: Then it will be a superposition?

Sir: A combination superposition of the two. Yes, you can do the two and then, but that does not give you the maxima and minima frequencies. That investigation has to be done independently.

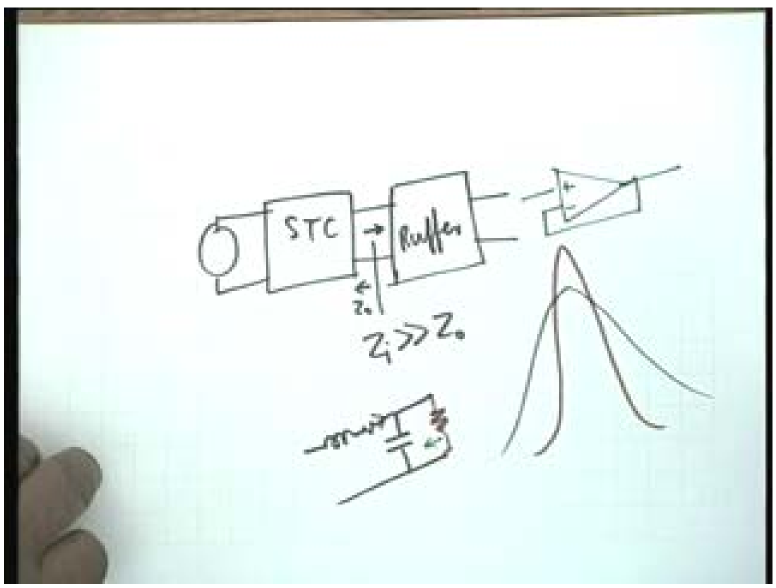
Student: Sir, how can we do that?

Sir: You find out your way, that is your problem, not mine. It is not difficult. I can assure.

Student: Sir, same thing.

Sir: It is not difficult. You have to go a little bit deeper into it. Think about it, get the solution and come up. Now, last, yesterday, I had indicated to you that there are many ways of obtaining such responses. Double tune equivalent of double tune responses, I mentioned resistive coupling, I mentioned capacitive coupling. The other way could be that you take the output from a single tuned circuit, this is your input and this output, you apply through a buffer. Do you know what a buffer is? Buffer is?

(Refer Slide Time: 33:42)



Student: Interface.

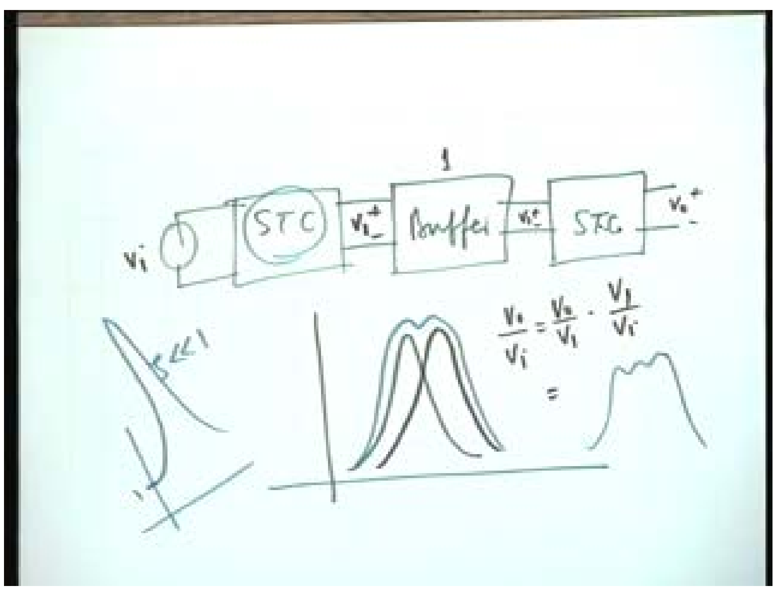
An interface, interface between 2 stages. The buffer virtually decouples. The buffer has 2 functions. One is coupling and the other is decoupling. The buffer, decouples, the response of the previous stage and the succeeding stage. In other words, these 2 stages are decoupled from each other. They work independently. Which simply means that the input impedance here, of the buffer, must be very large compared to the output impedance here, agreed.

Then the buffer will not load the single tuned circuit. For example, if your single tuned circuit, you are taking the output across the capacitor and you connect anything here. You connect any other impedance here, that is going to affect the tuned circuit response. For example, if this is a resistance, if there is a resistance here, obviously, if the single tuned circuit response was like this, with the resistance, well, this is what you expect. Usually, it will become flatter, the queue shall be destroyed.

So what we want is that, this capacitance should not be loaded and the way to ensure that is that, if you see the Thevenin equivalent impedance of the single tuned circuit, this should be much less, compared to the input impedance, in other words, the current after coming here should only flow through c. Very little current should flow through the connecting stage through the next stage. Is that clear? And the usual thing to do is, we use an (..) in the unity gain connection.

If you know what is an (..) this gives an almost infinite input impedance, now after the buffer you connect this, let me draw this diagram again.

(Refer Slide Time: 36:18)



You have a single tuned circuit connected to a source. Then you have buffer and you connect to another single tuned circuit, take the output here. Now, if the single tuned circuit, the 2 single tuned circuits may have slightly different resonance frequency. They are close together, but slightly different resonance frequency. Suppose, one is this and the other is this, then the overall response V 0 by V I, the magnitude shall be the product of the two, is not that right? If the buffer has gained, let us say, one, unity gain, then the transfer function, let us say, this is V 1 and this is V 0, so this will also be V 1.

Therefore V 0 by V i shall be V 0 by V 1 multiplied by V 1 by V i, which is equal to the product of the two and therefore, the overall response may be somewhat like this, which is, indeed which indeed looks like?

Student: Double tuned.

Sir: A double tuned response. So you can couple, you can combine 2 single tuned circuits without magnetic coupling or without resistive coupling, without capacitive coupling to form a double tuned circuit response, to form a wide band selective response by simply doing this. You require an active stage, a buffer in between. Suppose, yeah.

Student: Sir, the last stage is also similar?

Sir: May not be. It is not similar, if resonance frequencies are different.

Student: No sir, the capacitor, if you took the output in a double tuned circuit across the resistor and capacitor

Sir: It will either be a low pass, high pass or band pass. But zeta should be much less compared to 1. So that, even if it is low pass, even if it starts from 1, there is a high peak.

Student: Sir, but if individual was, if individual or both was at a low pass?

Student: Yeah double, 2 maximum for the

Sir: 2 maximum?

Student: A dip in between.

Sir: No. This is a single tuned circuit not a double tuned.

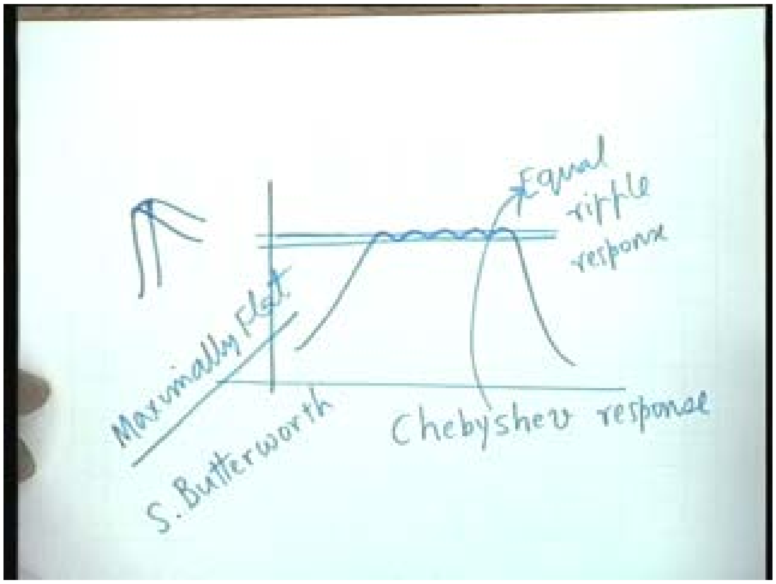
Student: Sir, in the last case, R plus 1 by C.

Sir: That is also single. Oh no, I am not talking of that at all. What I am talking about is, single 2 single tuned circuits being coupled, and decoupled like this. They will produce a response which is similar to the response in the double tuned circuit. Now, what is your question? These are not double tuned circuit. If both of them are double tuned circuit, they are slightly different tuned circuits.

Student: Yeah, that is right.

Sir: Then I shall have the response like this. Let us say, 1 2 dips and so on or may be 4 maxima, I do not know. 3. There can be 4 maximas. If there are slightly separated.

(Refer Slide Time: 39:52)



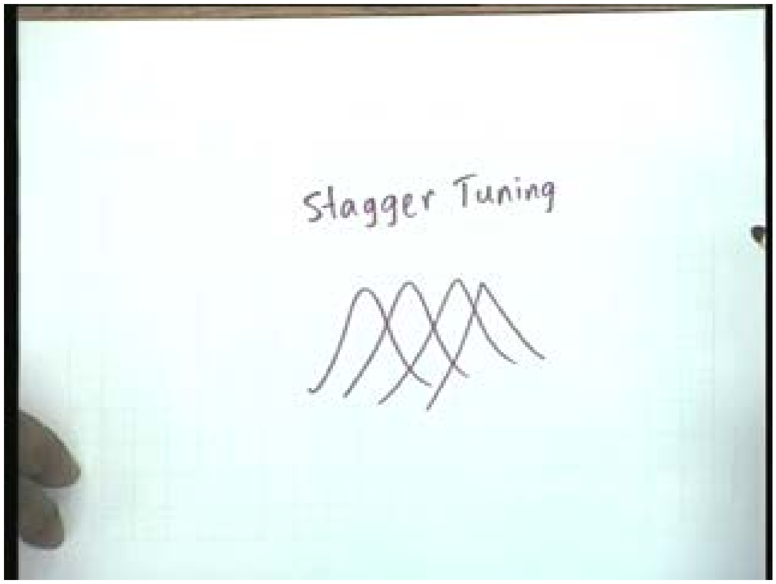
Now in general, I can couple many single tuned circuits like this. I can also couple 2 double tuned circuits or 3 double tuned circuits and I can get a response like this, as many ripples as you want. If these are, if the ripples are equal, that is, if they fluctuate between same maxima and same minima, then obviously, this is called an equal ripple response. Equal ripple response or what goes in the literature by the name of Chevbyshev response. C h e v b y s h e v, Chevbyshev response, the name is derived from the name of the mathematician Chevbyshev, who first gave a polynomial named after him, Chevbyshev polynomials, which are equal ripple in nature. And this is why such filters are also called such circuits are also called Chevbyshev band pass filters.

Mind you, Chevbyshev is associated with equal ripple, ripple should be equal. I can also have design circuits in which there are no ripples. There is flat pass band by coupling several such circuits. I can show a range that each is critically coupled and the juxtaposition of the 2 is such that the fall due to one is taken care of by the rise of the other due to other and therefore, I can get something like this. Such responses are called, obviously, flat responses and one special kind of flat response is the so called maximally flat response, that is, at these frequencies as many differential coefficients of the function, as possible values.

We will come to such responses at the end of the course, but let it be known to you that maximally flat is associated with the name of an English mathematician, by the name Butterworth and these 2 kinds of responses are very popular to electrical engineers. That is, Butterworth filters and Chevbyshev filters, and I wanted to introduce to you, right at this stage. Now, if a band pass filter of the type that we have been discussing is named by coupling to single tuned circuits, whose resonance frequencies are slightly different from each other.

Then this arrangement goes in the literature by the name of stagger tuning, that is, the tuning of the circuits individual circuits are staggered. The resonance frequencies are staggered. Omega 1, omega 2, omega 3 and so on, they are staggered, one after another. This is called staggering, but they are close to each other. On the other hand, you can also get a circuit in which each tuned circuit is tuned to the same frequency. Let us say identical tuned circuits.

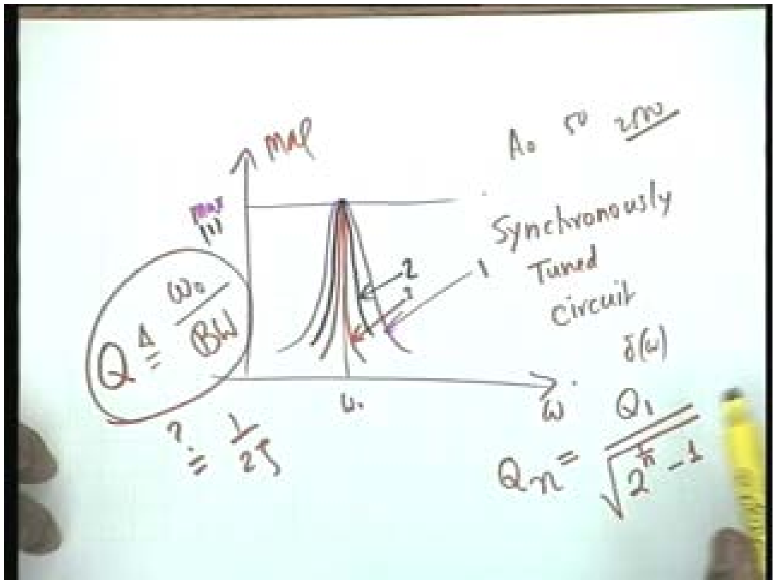
(Refer Slide Time: 43:03)



Suppose this is the response of, let us say, one tuned circuit. If I connect 2 such tuned circuits in cascade, exactly identical tuned circuits, same resonance, frequency, well, what will be the response? Suppose, the maximum is normalized to 1, I can always do that, that is, the maximum does not change but at any other frequency away from the maximum point 9 squared is point 8 1 and therefore, it becomes sharper. So with 2 such circuits, I shall get a sharper response and if I connect another circuit, now I will get still sharper.

So this is a way of getting sharper selective responses or narrower or bandwidths is it? A bandwidth goes on decreasing, is not that right? The bandwidth goes on decreasing, narrower bandwidth or sharper frequency responses and such circuits are called synchronously tuned circuits. So you know now the meanings of single tuned circuits, double tuned circuits, stagger tuned circuits, synchronously tuned circuits, resistively coupled circuits, inductively coupled circuits, capacitively coupled circuits and so on. Now,

(Refer Slide Time: 43:38)



Student: Sir, in this case, we can also get delta response circuits?

Sir: Delta response, delta in was which domain? This is a frequency, this is a frequency response. Yes, you can get a delta omega, in the frequency response. Is that what you are meaning? Not quite, even if you couple infinite number of such circuits, you cannot get a delta because of the same kind of problem that you have and we do not want it either. Who wants?

Student: Who wants sir?

Sir: Who wants? If nobody wants, why should an engineer be interested in he should not make it, life miserable.

Student: Sir, cannot we normalize the maximum (…)?

Sir: Well, I am, I do not really care. You see, if the maximum is A 0, it becomes A 0 square. But, what I wanted to show you is that, off the resonance, the magnitude comes down point 9 square. Suppose, A 0 was 50, 50 squared is 2500, 40 squared is 1600. The ratio of increase is much higher for the maximum, then for the, off resonance frequency. One interesting exercise that one can do at this point is to see how the selectivity increases.

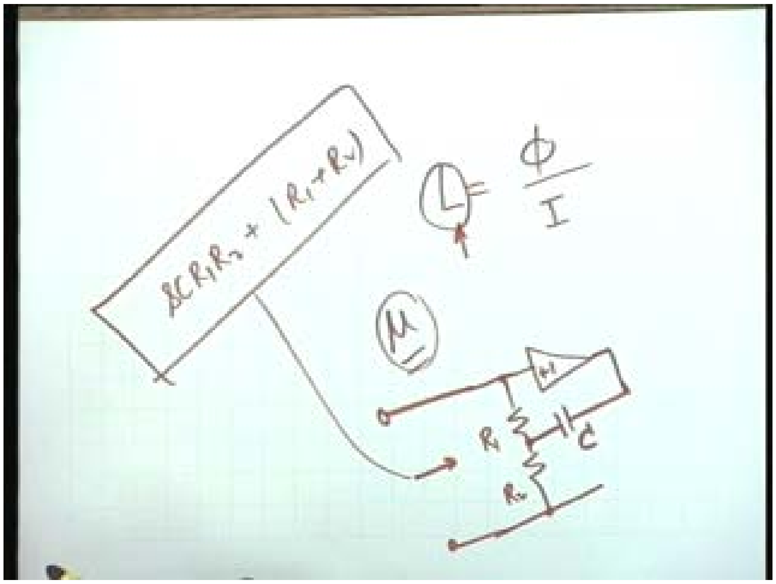
In other words, how do the bandwidths change, or how does Q of the circuit, Q of such a response is defined as the resonance frequency omega 0, if this is omega 0 divided by the bandwidth and you can show, that in a high tuned circuit, single tuned circuit, this Q is the same as 1 by 2 zeta. Let me set to you, set for you two problems. One is to show that, in a high Q single tuned circuit, if you define Q like this, it is the same as equal to 1 over 2 zeta, first question. Second question, if n numbers of such circuits are synchronously tuned and cascaded, that is, they are the same resonance frequency, identical tuned circuits, if they are cascaded together, what is the resulting Q? Would it increase or decrease? It would?

Student: Increase.

Sir: Increase, I do not want to take a vote here. It would increase because bandwidth decreases. Obviously, the Q must increase and you can show that this is Q 1 divided by, I am giving you the final result, it is your responsibility to show this, that this is 2 to the power 1 by n minus 1. Is that higher, even it is greater than Q, yes. Q 1 is the Q for a single tuned circuit. Then Q n is the Q for n number of such tuned circuits put in cascade.

The reason for this elaborate discussion is that these circuits are extremely useful at radio frequencies. They are also useful at frequencies higher than radio frequencies, but the way inductances and capacitances are used, there are quite different. They are also in integrated form, capacitance in integrated form is no problem but inductance is a problem. So in integrated circuits, you see, inductance by definition, listen to me carefully. What is the definition of an inductance?

(Refer Slide Time: 49:32)



Student: phi upon I

Sir: phi upon?

Student: Number of (…)

Sir: Inductance is the reflux per unit current. This is definition of inductance flux for unit current and generation of a flux, a reasonable amount to flux. You see, if you want make L high, then you should make the flux high. For the same current, you can make, you should make the flux high. Now if the medium, if not changed, that is, medium permeability remains the same. For generating a large amount of flux unit for a large volume, which is not available in integrated circuits. Integrated circuit, this phase is at a premium.

The other thing you can do is to make u high, that is, the permeability high. Now the highest permeability that is attainable is limited. You cannot make it infinite and therefore, the value of inductance that you can obtain in an integrated circuit is typically of the order of peak O and restraint to the minus 12 or even less, which are useless and therefore, what one does in practice at in integrated circuits is to stimulate an inductor.

Then let me give you this exercise. If you have a unity gain amplifier, a unity again amplifier obtained by (..) and you have 2 resistances R 1 ,R 2 at its input and a capacitor comes from the output, then you can show that this impedance, input impedance, you have done 1 1 0, so you know how to analyze such circuits. You can show that this impedance is S C R 1 R 2 plus R 1 plus R 2. It behaves like a real world inductance with a resistance with it.

So the Q is finite, it is not an ideal inductor. In theory, it is also possible to use { } (51:51) to make idle inductance, but that we will, we shall not discuss here. That will be the subject in some other course, I do not know but whatever we do, however, in whatever way we produce an inductor, the basic principle remains the same.

To produce a high selectivity, we shall have to stimulate or actually use a physically physical single tuned circuit. If you want a wide band, then we use stagger tuning or double tuned circuits. If you want a narrower band, then obtain from a single resonance, then we use synchronous tuning. These are the 3 points that you have to remember and you cannot afford to forget for the rest of your life.