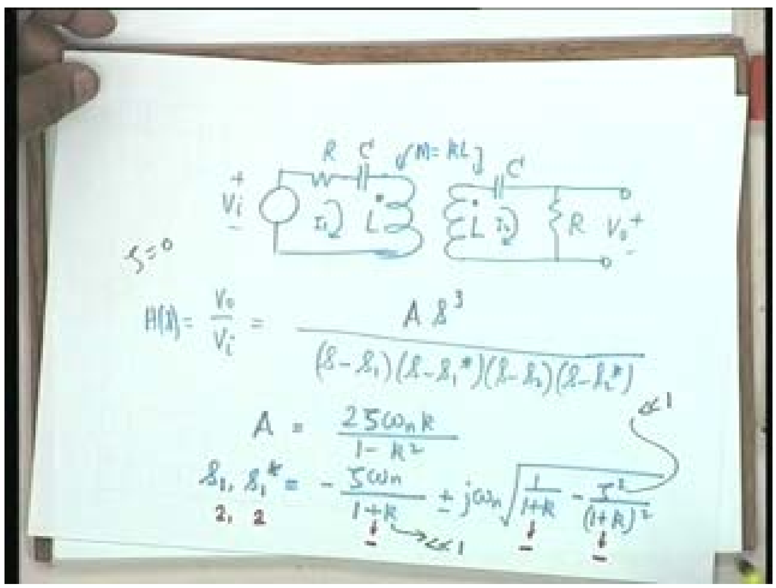
Circuit Theory
Prof. S. C. Dutta Roy
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture -17
Double Tuned Circuit (Contd.)

Seventeenth lecture today, on the second of February and we continue our discussion on double tuned circuits. I first briefly recall what we did the last time.

(Refer Slide Time: 1:13)



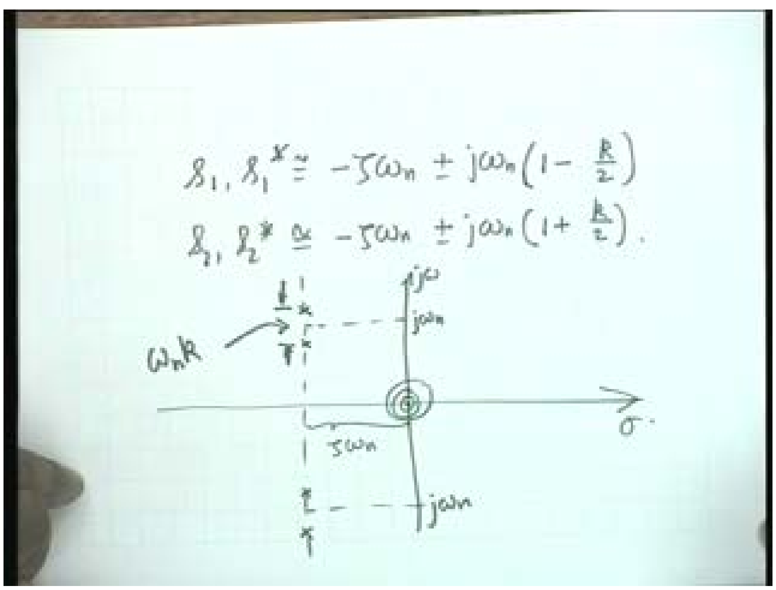
We had a double tune circuit like this, we had a V I, a resistance, a capacitance C and an inductance L. The secondary was an identical tuned circuit L C and the output was taken across R. This was V 0. Identical tune circuit with dots like this, M equals to k L between these two and we had assumed two currents I 1 and I 2, wrote the loop equations and found out the transfer function V 0 by V i H of s as equal to A s cubed divided by s minus s 1, s minus s 1 star, s minus s 2, s minus s 2 star where capital A was expressed in terms of the damping coefficient and the natural frequency as twice zeta omega n k divided by 1 minus k squared and s 1 s 1 star was equal to minus zeta omega n divided by 1 minus or 1 plus k plus minus j omega n.

It really does not matter, s 1, s 1 star because s 2, s 2 star also comes, j omega n square root of 1 by 1 plus k minus zeta squared divided by 1 minus 1 plus k whole squared. It will be plus throughout and if we had s 2, s 2 star. The only change is, this sign changes to minus, this sign changes to minus and this sign changes to minus. So these were the poles and then at this point of discussion, we made a certain approximation. We said that zeta squared is much less than 1. That means it is and under damped case, zeta squared is much less than 1. We also assumed that the coefficient of coupling k is also much less than 1, that is the two coils are loosely coupled to each other. Under this assumption, the poles

Student: (..)

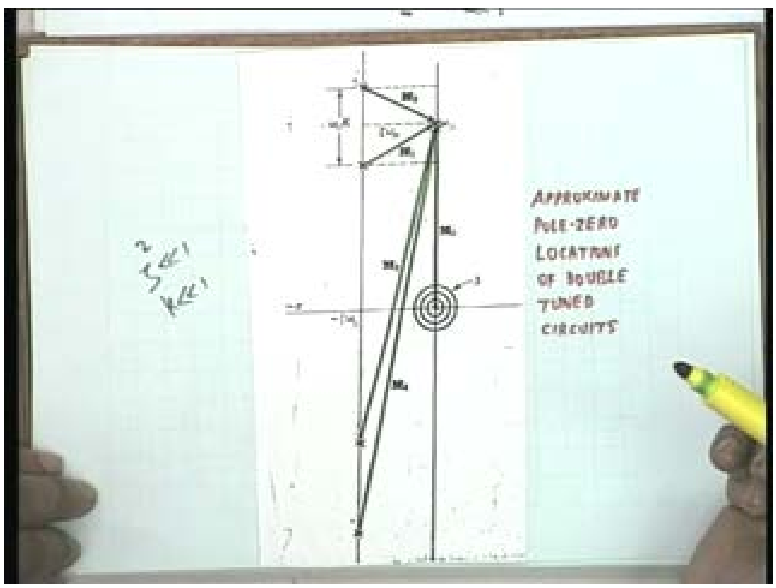
Sir: How can you say this? Zeta equal to 0, of course is under damped, right? Zeta equal to 0 is undamped. Zeta equal to 0 means there is no resistance. So there is no damping. Zeta much less than 1 means zeta tends to 0 and therefore, it must be under damped.

(Refer Slide Time: 4:31)



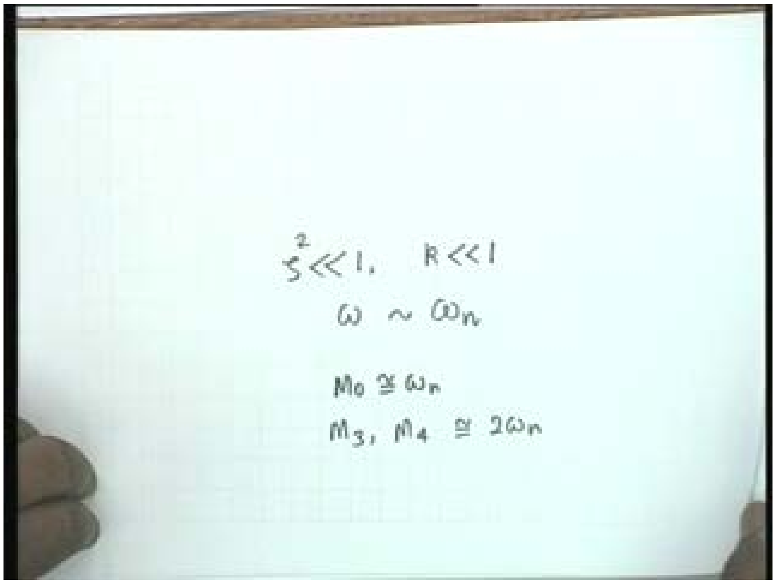
With this assumption, we approximated s 1, s 1 star as minus zeta omega n plus minus j omega n then 1 minus k by 2. You should understand how this minus sign comes. It is 1 plus k to the power minus half and that is why 1 minus k by 2 comes and s 2, s 2 star is approximately equal to minus zeta omega n plus minus j omega n 1 plus k by 2 and we noticed that the pole location are such that they all lie on a line parallel to the j omega axis at a distance of zeta omega n from the origin, and that they are symmetrically located with respect to j omega n one on this side, one on this side, similarly one on this side, one on this side such that the difference, the distance between them is given by omega n times k. One is below omega n, omega n k by 2 and the other is above omega n, omega n k by 2 and therefore, this distance is omega n times k. This is the location of the poles, and this was shown. In addition we have 3 zeros here. This was shown in an enlarged form in this slide.

(Refer Slide Time: 06:12)



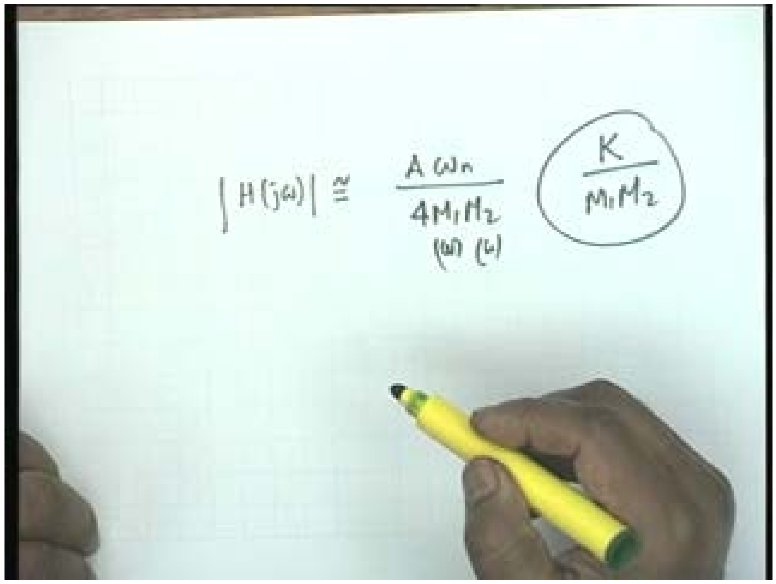
This slide shows the two poles in a slightly enlarged form. Zeta omega n has also been enlarged. Actually, it is very close to the j omega axis enlarged. I want to show you the four vectors which determine the magnitude, five vectors. One is M 0 because there are three zeros, M 0 has to be cubed in the numerator, then in the denominator we shall have M 1, M 2, M 3, M 4.

(Refer Slide Time: 06:47)



And we also made the assumption that if zeta is much less than 1, zeta squared much less than 1 and k much less than 1, then and omega is close to omega n, if omega is close to omega n, then it is these two vectors which determine the magnitude response and also the phase response. The other vectors can be approximated, M 0 can be approximated by omega n M 0, M 3 and M 4 being very close to each other and being very close, the j omega axis, the poles being very close to the j omega axis can be approximated by twice omega n and therefore, the approximations that we used were M 0, approximately equal to omega n. M 3 and M 4, both are approximately equal to twice omega n.

(Refer Slide Time: 07:45)



And under this condition, the magnitude function, the magnitude of the transfer function was approximated as A omega n divided by 4 M 1 M 2. Did we come up to this in the last time?

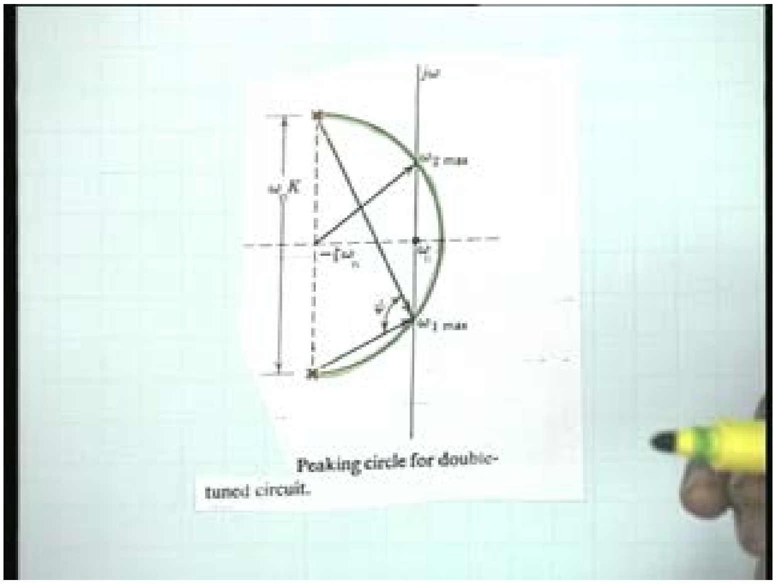
Student: Yes

Sir: Yes we did, which shows that what we have done is, approximating the double tuned response by that of a single tuned circuit. In single tuned also, the amplitude, the magnitude was K by M 1 M 2. Here also it is M 1 M 2. M 1 is a function of omega, M 2 is a function of omega. The only difference is that, instead of the center point at origin here, the center point is at omega n and therefore, all the concepts of peaking circle should be valid here also. Let me show a typical situation.

Student: Won't that psi make any difference?

Sir: Yeah, I will come to this.

(Refer Slide Time: 8:51)



Here, we have assumed, this is a typical situation, omega n is the center frequency, omega n and then I have the two poles, red crossed ones, these 2 poles at a distance of omega n K from each other. This is minus zeta omega n and here we have assumed that zeta omega n is greater than omega n K by 2. In drawing this diagram, we have assumed that, I am sorry, it is the other way round, omega n K by 2, this is the center and this is the radius. Radius is omega n K by 2.

We assume that omega n K by 2 is greater than zeta omega n, so that there are two intersections with the j omega axis. There are two intersections and these intersections are called omega 2 max and omega 1 max. At both of these points, the magnitude will be a maximum because this angle psi, the derivation of which we are coming to in a moment, this angle psi is 90 degrees here. This is a diameter and this is an angle subtended on the circumference or the angle psi, must be pi by 2.

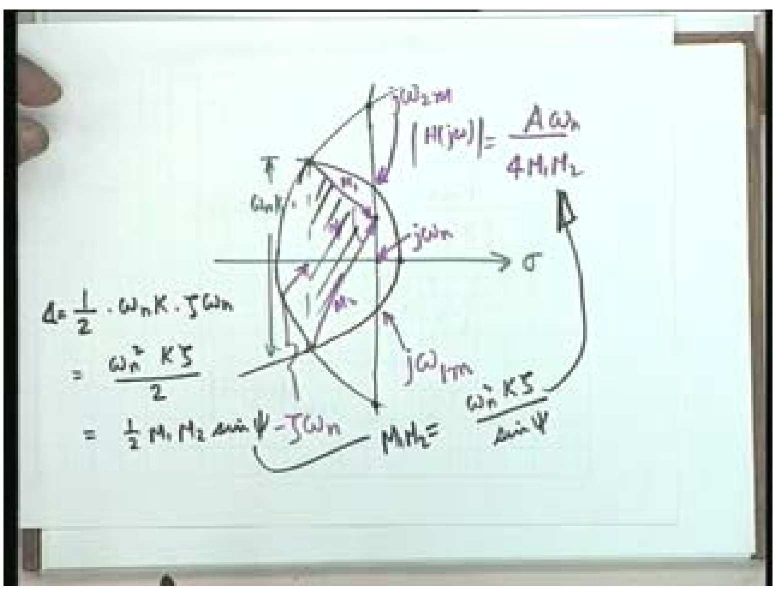
You also realized before passing further that this circle may or may not intersect the j omega axis. Depending on the relative values of K and zeta, this circle may or may not intersect. This situation is when omega n K by 2, that is, K is greater than how much, twice zeta. This is a situation when the coefficient of coupling is greater than twice zeta. Omega n K by 2 is greater than zeta omega n, so K is greater than 2 zeta.

If K is equal to 2 zeta, then this circle shall touch the j omega axis at omega equal to omega n and when K is less than 2 zeta, then the circle will not touch at all; it will cross the real axis at a certain point, but it will not touch the j omega axis. So one is tempted to conclude that if the circle does not intersect or touch the j omega axis, there should be no maximum at there should be no peaking but the situation is slightly different here. I think we left at this point.

Student: Sir, can you explain the second, I mean, what case there will be a maximum?

Sir: I am coming to it in details. I just wanted to mention this briefly here. You see, depending on this radius, this circle may or may not intersect the j omega axis and the three cases that arise, we will come to it a little later but let us do a little derivation.

(Refer Slide Time: 11:54)



Assuming that they do intersect, in other words, our poles are let say somewhere here. This is my sigma axis, this is omega n K and this is the peaking circle. This is a general point at which we draw the vectors, and we call them M 1 and M 2. The angle included is psi, the angle included here is psi and this point is what?

Student: (..)

Sir: Minus zeta omega n and we have already seen that the magnitude H of j omega is equal to capital A, not capital A. A omega n divided by 4 M 1 M 2. Now in a similar manner, as we did in the single tuned circuit,

Student: Sir, horizontal axis will be j omega n

Sir: Yeah, this is j omega n quite so. We will call this intersection as j omega 2 m, 2 max and this intersection as j omega 1 max. The origin here, the crossing that is shown here is j omega quite correct.

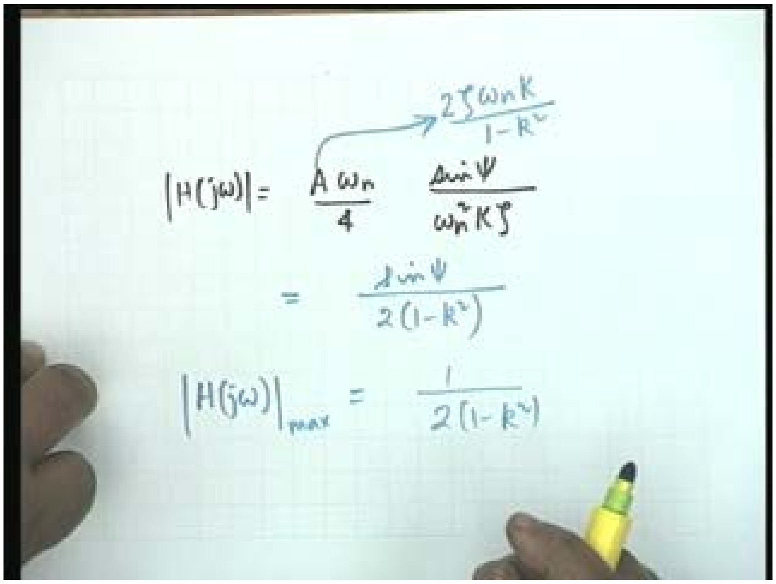
Student: You have labeled that sigma?

Sir: This sigma is okay, I can draw the sigma axis anywhere I like. Sigma is okay, the horizontal line. This point is j omega n. Sigma equal to 0 here, this is perfectly all right but this point is 0 j omega m. Now the area of this triangle, let me show this, we can calculate the area of this triangle in two manners, exactly like in the single tuned circle.

The area is, obviously, half; triangle is equal to half. The base is omega n K and the height is zeta omega n. Therefore, this is equal to omega n squared K zeta divided 2 and it is also equal to a triangle with the two sides given and the included angle. So it is half M 1 M 2 sine of psi. This is simple trigonometry and therefore, I get the value of M 1 M 2 from here. M 1 M 2 becomes equal to how much, omega n squared K zeta divided by sine psi.

Let me substitute this M 1 M 2 in this equation. That is, the equation for H of j omega. If I do that, then I get the following result.

(Refer Slide Time: 15:29)



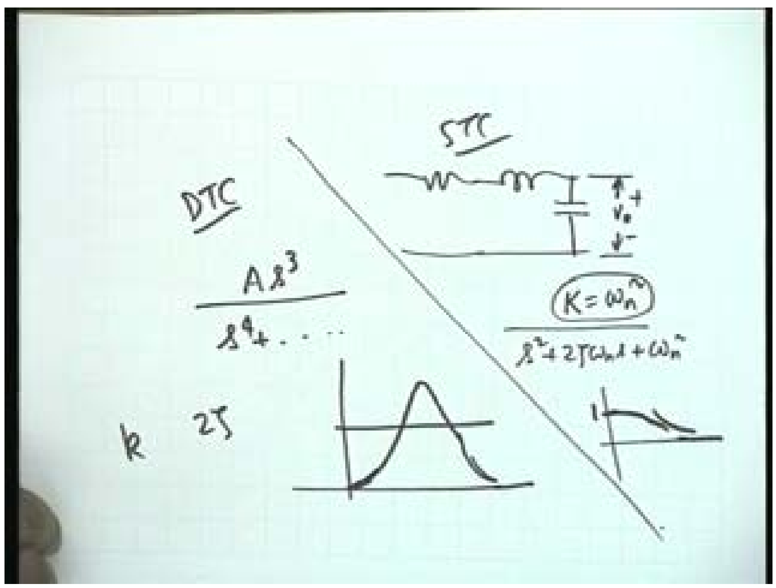
I get magnitude H of j omega as equal to A omega n divided by 4, then 1 by M 1 M 2. So I shall have sine psi divided by omega n squared K zeta. If one recalls that capital A is nothing but twice zeta omega n K divided by 1 minus K squared, substitute this here and makes all the cancellations that are due. Then this simplifies to a very simple expression. It simply becomes sine psi divided by 2 1 minus K squared. It becomes independent of zeta.

We have, of course, assumed that zeta squared is much less than 1. It is only dependent on K and therefore, if you agree, we shall conclude that the magnitude, you must not forget the assumptions, it is not the general magnitude; it is not the magnitude at a general point on the j omega axis. It is a point close to omega n. It is a point close to omega n under the assumptions that zeta squared is much less than 1 and K is much less 1, then the magnitude, is basically determined by a single variable namely psi and of course, the maximum H of j omega max occurs when psi is pi by 2.

So this is 2 1 minus K squared and the half power points shall occur when psi is pi by 4 and you can draw the half power points, half power circle, in exactly the same manner as we did earlier, namely, what we do is, we take this as the radius, the intersection on the sigma axis as the radius and, I am sorry, as the center. This as the center and this as the radius distance from here to here and then draw the circle. These two will be the half power points. If the peaking circle intersects the j omega axis at two points then these two shall be the half power points.

The K is slightly different from single tuned circuits because of the fact that 0 has been transferred to omega n 0 has been lifted to omega n and because of another fact, let me highlight that fact.

(Refer Slide Time: 18:38)



In the single tuned circuit, you recall if the voltage, if the output voltage was taken across the capacitor in the single tuned circuit, then the transfer function was of the form some constant divided by s squared plus twice zeta omega n s plus omega n squared. K was equal to omega n squared and therefore, the DC response was equal to unit A. On the other hand, here we are taking the output across the resistance and the transfer function is of form A s cubed divided by a fourth order polynomial and therefore, the DC response is 0. Therefore, the conclusion is the DC response is 0, infinite frequency response is 0. So whatever are the values of K and zeta starts from 0; magnitude cannot be negative. It goes to 0 at infinity. So in between, there must a maximum. Is that clear?

Student: No

Sir: No. Okay. The difference between single tuned circuit and double tuned circuit is that the transfer function, in the doubled circuit, has an s cubed in the numerator and in the denominator has an s to the 4. Whereas in a single tuned circuit, the case that we considered, we took the voltage across the capacitor; V 0 was here and the transfer function had a constant in the numerator. So the DC response, that is, put s equal to 0, this value is 0. In the double tuned circuit, the double tuned circuit DC response is 0. So it starts from 0.

At infinite frequency, when s goes to infinity the highest power term in the denominator dominates, so we get s cubed over s to the 4. So as s goes to infinity, the magnitude must go to 0. So it goes to, it starts from 0, it goes to 0 therefore, in between, it must show a maximum; there is no other way, at least, one maximum. There can be other maxima also as you will see in the peaking circle. Whereas in the single tuned circuit, the response starts from unity, now it goes to 0 at infinity. In between, it may either show a maximum or may not show a maximum whereas in the double tuned circuit, there must be a maximum.

It cannot be otherwise and therefore, in the double tuned circuit, irrespective of the values of K and psi, K and zeta, irrespective of the value of K and zeta and the relations between them whether K is greater than equal to or less than 2 zeta, whether the peaking circle intersects the j omega axis at two points or not, whether it touches at one point or it does not touch or intersect at all, it does not matter. There shall always be a maximum.

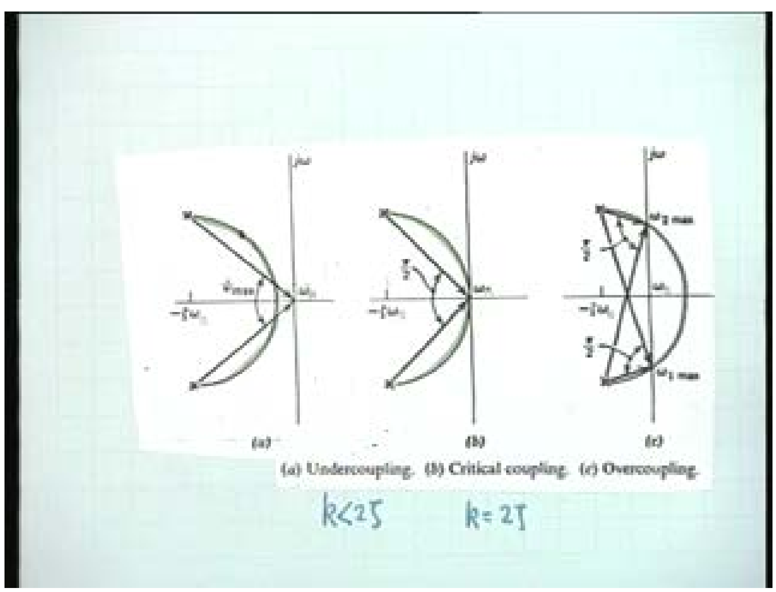
If there is a maximum, there must also occur two half power points, two. In the case of a single tuned circuit with output taken, I am repeating this, output taken across a capacitor, if the output was taken across the resistor, situation would have been quite similar to here. If the output is taken across the resistor, you would have got a band-pass response, truly band-pass response and there would have a maximum. If the output is taken across a capacitor, there may be a peak, there may not be a peak. If there is no peak, then obviously, only 1 half power point. Even if there is a peak and if peak is less than root 2, then also there shall be only one half power point. Whereas, in a double tuned circuit, irrespective of what you do, there shall always be at least 1 maximum.

Student: At least 2.

Sir: At least 1 maximum, 2 half power points.

Student: 4. Yes, there can be 4. We will come to this. There can be 4 also. We will come to this. Now let us go back, after this qualitative explanation, of why there should be a maximum and why there should be at least two half power points and the difference between STC and DTC. Let us look at the actually situation depending on the values of K and zeta.

(Refer Slide Time: 23:36)



You see, in the first figure, the peaking circle does not touch or intersect the j omega axis, which means that for this, K is less than 2 zeta. Is that clear? Omega K omega n by 2 is less than zeta omega n. So K is less than 2 zeta, which is called the over.

Student: (..)

Sir: No more damping. We are assuming the damping is small because we have got complex conjugate pairs of poles. This discussion is all based on the assumption that there are complex conjugate poles. So we take damping away from our consideration. We now only depend on K, why? You saw the magnitude has been expressed now as 2, I am sorry, sine psi divided by 2 times 1 minus K square. So zeta has been dropped out of the picture. Zeta is low, that is assumed low enough to produce complex conjugate pairs of poles and approximation of the poles by the expressions that we have all ready indicated zeta is low enough. Zeta is now out of the picture.

Now we have to talk about K. Zeta is fixed quantity now for all these, zeta does not vary. What varies is K. Now if K is such, if K is less than 2 zeta, then this is called, there is no peaking. No, I am sorry, I should modify this statement. The peaking circle does not touch or intersect the j omega axis. Obviously, K is less than 2 zeta in this case and this is called the under coupled case. This is under coupling. Under coupling means that K is less than 2 zeta.

Physically, there are two coils which are brought close to each other to interact with each other. Suppose they are taken far part so that K is 0. Obviously, each tuned circuit will behave, will show its own behavior and therefore, there shall be only one maximum and two half power points, agreed? So this is called under coupling and the extremum value of under coupling is obviously K equal to 0. No coupling, both tuned circuit behave in their original manner. They do not interact with each other.

Now the situation changes when the peaking circle just touches the j omega axis and this touching must be at omega n. Oh, one more point.

Student: Sir, is there a maximum (..)

Sir: One more point, you can easily show by geometry construction that the angle psi between the two vectors, M 1 and M 2, this angle is highest at omega equal to omega n. As you go this way the angle goes on decreasing and therefore, the maximum as is justified by commonsense, when K equal to 0, obviously, maximum shall occur at the natural resonance frequency or between circuit. That is, at omega n.

So the maximum still occurs at omega n. As long as K is less than 2 zeta, the maximum occurs at omega n. Now if you go here, the maximum, obviously, now here psi max cannot be, cannot reach pi by 2 and therefore, the maximum is less than what would have occurred otherwise. We will show this by picture later. So there would be a maximum but this maximum value would not reach the highest possible value. Highest possible value is reached here when K is exactly equal to 2 zeta.

So the peaking circle touches the j omega axis at just one point omega n and this angle, obviously, is pi by 2 because it is an angle subtended by diameter on the circumference. This angle is pi by 2 and therefore, there shall be one maximum. There shall still be two half power points; here also. There is a maximum, there should be two half power points and these half power points, if you exact a little, can again be found by geometrical means, but I am not, I will not discuss that. I will leave that to you as a problem, exactly like the single tuned circuits.

Student: Sir, if we draw by taking that omega n as the centre then the?

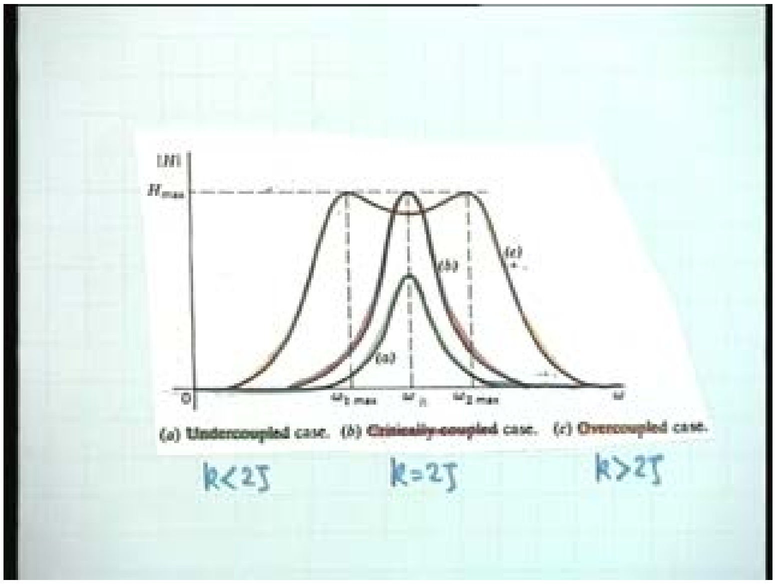
Sir: I will leave that to you. Unfortunately only two people responded to my earlier challenge. I want more responses. Otherwise, it becomes a dull class. Unless you come out with my expected answers or counter to my answers, I maybe wrong and if you can prove that I am wrong, that gives me the greatest pleasure rather than verifying what I said is true. No, that I know it is true. So what is so big about it?

Come back here. I leave that to you as problems. Finding out the, by geometrical constructions, perhaps without going into the mathematical derivation. The other two answers that I got, they were suggested by the mathematical derivation. Perhaps one could be it otherwise also, because all it amount it towards findings another point psi, where the angle is pi by 4. So by geometrical construction, you should be able to do that. Now coming here, the maximum occurs at omega n. Here also, maximum occurs at omega n but this maximum is greater because sine psi reaches its highest value, that is, unity. Here it cannot because this angle cannot be pi by 2.

On the other hand, if the peaking circle does intersect the j omega axis at two, points omega 2 max and omega 1 max, at each point, the angle is pi by 2 and therefore, there will be two maximum and if there are two maximums, in between there must be a minimum and therefore here is a situation where instead of 2, you may or may not have 4 half power points.

Now the minimum, by symmetry, obviously, shall occur at omega n. If you go on drawing the angles, it is very easy to show that this angle psi shall reach the minimum value at omega equal to omega n. If this minimum is less than, mark my words, if this minimum is less than 1 by root 2 times the maximum value, then obviously, then there shall be how many? 4 half power point. If it does not, there will be 2. There shall be in between. Now let us see what, let us see by means of the diagram.

(Refer Slide Time: 31:16)



The green here is the under coupled case. Under couple means K, what is under coupled? K less than 2 zeta? It reaches a maximum but this maximum is not quite H max which can be achieved. On the other hand, when K equal to 2 zeta, that is the critically coupled case, there is the maximum value occurs again at omega n but it reaches the highest possible value. Highest possible value is 1 by 2 multiplied by 1 minus K squared.

When it is over coupled, when the coils are brought close to each other, that is, K is greater than 2 zeta, this is the over coupled case. This single resonance curve now flattens in the middle to make way for two maximum and obviously, as you can see here there shall be only two half power points. This is less than, this is not 70 point 7 percent. There should be only two half power points and irrespective of the value of K, irrespective of whether it is an under coupled case or critically coupled case or over coupled case, we shall have two half power, at least two half power points and if we have two half power points, naturally, we can determine.

Student: Sir, for over coupled case?

Sir: For over coupled case, there can be 4 half power points.

Student: Sir, the omega max are symmetrical

Sir: Omega max are symmetrical. This happens, yes, omega. Can anybody answer this?

Student: Because (..) k by 2

Sir: That is right, because the poles have been made symmetrical by that approximation.

Student: Omega n k by 2.

Sir: That is right. So everything would be symmetrical, this would be, this curve shall have arithmetic symmetry. You see, the resistance between omega n and omega 1 max, omega 2 max omega will be the same. Let us find that out. Let us take, that is a good question. Is there any question about this curve? It can be physically observed. It takes very little hardware to actually carry out the experiment.

There are coils in the laboratory. You go to the electronics lab, ask for two coils. Bring them close together, put the identical capacitors in the circuit. Do not use any external resistance because the coil resistance is enough to take care of that capital R and then you can actually observe this double peaking.

Student: Excuse me, Sir. (..) because they are intersecting G O at different points.

Sir: Well, this starts from the origin. I do not have all the three colors, but let us see. The green one, for example, it goes like this.

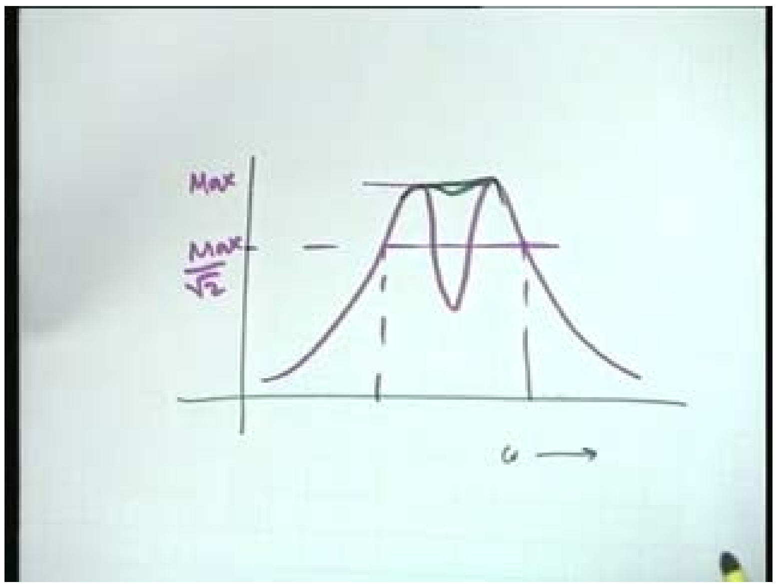
Student: Sir, that means it is too small.

Sir: Too small, so it has not been plotted. There will all go to 0 at origin and also at infinity. Any other questions?

Student: Sir, is it possible to have three half power points, at a point exactly where it is 1 by root 2?

Sir: Very good, yes, it is possible. If the dip is exactly 1 by root 2 times, maximum 3 half powers. That is correct but in every case where, at usually one does not want. Let me now talk about a bit of practical sense.

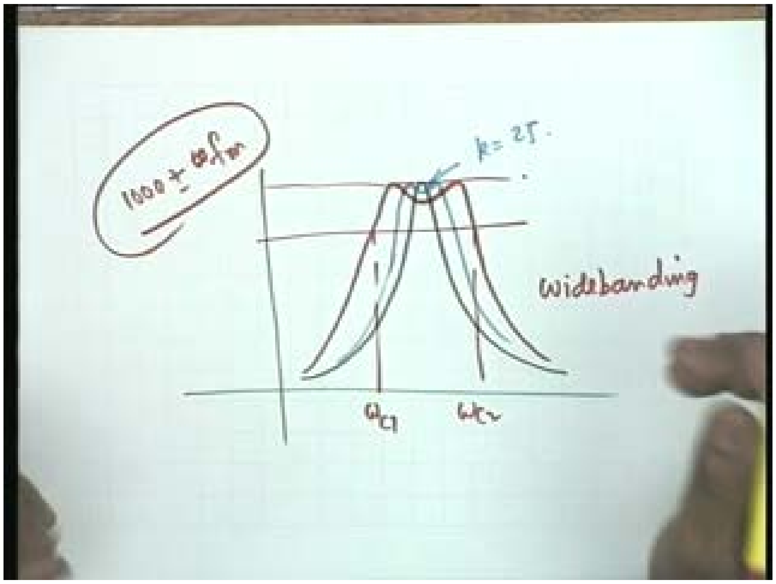
(Refer Slide Time: 34:55)



You see, with a double tuned response with a double humped response, this is called double hump. Omega and let us say, we have the response like this. Suppose, the hump is like this, this is the maximum and 1 by root 2 is somewhere here. This is max and this is max by root 2. Well, such a response is hardly of any utility because you cannot say this is the bandwidth. We gain this band, there is a band which falls bellow 3 db. Is not that right? And therefore, the group of frequencies situated between these are not passed almost equal.

However the response, that is of greatest interest is when this is almost flat; cannot be achieved in practice, but you can achieve something like this, a small width and the curve will follow like this.

(Refer Slide Time: 36:07)



Once again, look at this. This is the case when critically coupled, when it is critically coupled. When K, this is K, equal to 2 zeta and K becomes slightly greater than 2 zeta well, may be the curve goes like this. When K goes higher than this value, the blue curve, perhaps it goes like this, maxima is the same but the dip is higher and then it goes on, this phenomenon goes on. As we make more and more tightly coupled, as we bring the coils closer and closer together, the dip in between and the separation between the dips between the peaks increases, separation increases.

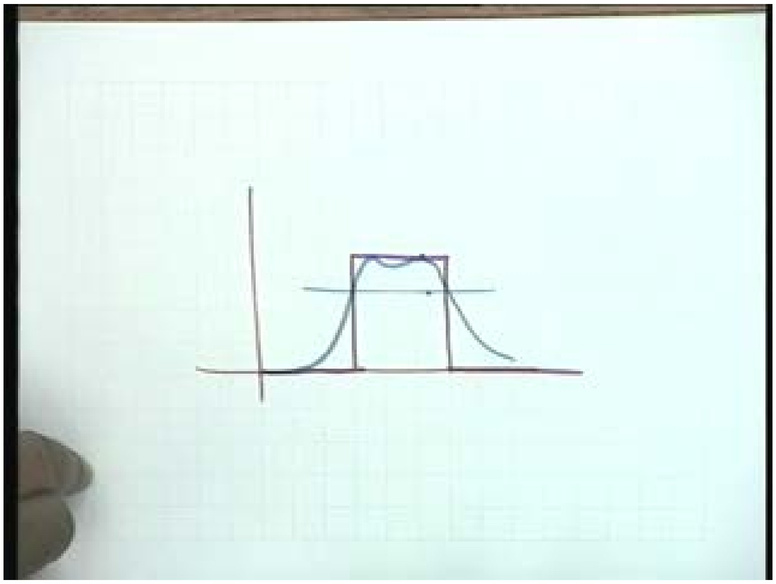
Student: Sir, with the same case, we can increase the separation two peaks?

Sir: No, not with the same coils, you will have to change the coils. Now, what I said was the case would be of maximum interest when between these two frequencies, between the two half power frequencies, omega c 1 and omega c 2, the amplitude response, the magnitude response lies within 3 db. If this dip goes below 3 db, then we lose interest and this is used for so called wide banding technique.

For example, you take the broadcast band, one of the medium width broadcasting center Delhi B, for example, Delhi B is 1000 kilohertz, let us say. Now 1000 kilohertz, one might think that a single resonance circuit having high Q at 1000 kilohertz should be good enough to pickup this station, but 1000 kilohertz is not 1000 kilohertz; it is modulated by music, speech, whatever you want to transfer and therefore, there is a certain non-zero band width.

May be 1000, the actual spectrum, if you take the Fourier transform of what you receive, the actual spectrum would be 1000 plus minus let us say fm, where fm is the maximum modulating frequency and therefore, to tune to 1000 plus minus fm, you do require not a very sharp fall to (..) against the adjacent. Let us say, (..) center or some other center. But in between, you require that this band should cover not just 1000 but 1000 plus minus fm. This is a typical use. There are many other uses where one once a band pass response like this.

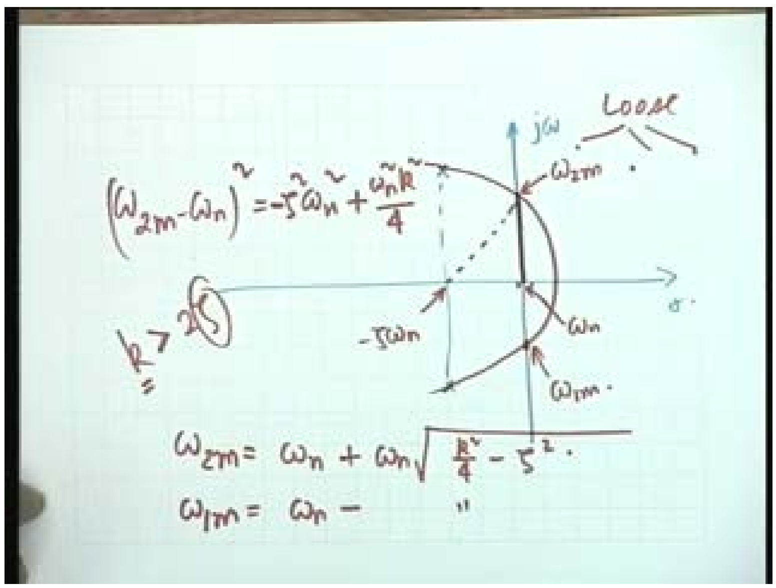
(Refer Slide Time: 39:29)



Ideally, what you require is something like this. That is, you want to pass a certain band of frequency then reject others and the double tuned circuit gives you a reasonably good approximation like this, where this level should be between 3 db, 0, 0 db and 3. So that is the use of a double tuned circuit and the IF coil in the radio receiver, it is an example of two coupled coils.

The IF stage of the ordinary receiver, either in TV or in radio is an example of a double tuned circuit. Double tuned circuit is an extremely interesting circuit to experiment with and fun in the laboratory. Even if it is not set as one of the experiments in the lab, you can ask the lab technician and I am sure the teacher will be very pleased if you say I want to set up this and observe, please. Now let us look at the values of the two maxima.

(Refer Slide Time: 40:25)



If there are two peaks, the values are like this. You have the poles and the peaking circle is something like this. This is zeta minus zeta omega n and this is omega 2 m, j omega 2 m. I am not writing j and this is omega 1 m. We are interested in finding, this is omega n, we are interested in finding the value of omega 2 m. Obviously, it can be found out from this right angled triangle. You can write omega 2 m minus omega n whole squared, that is this squared equal to zeta squared omega n squared zeta squared omega n square this distance squared.

Student: Minus of this plus

Sir: Minus of this plus, what is this? This is the radius, omega n K by 2 so omega n squared K square divided by 4. By simplifying this, you can find out omega 2 m as equal to omega n minus or plus.

Student: (..)

Sir: Commonsense, it is above omega n, it must be plus. Plus omega n square root of K square by 4 minus zeta square and obviously omega 1 m, this maximum shall be symmetrically located with respect to omega n. So it should be omega n minus the same quantity. These are the expressions for the two peaks. One must not lose sight, however of the assumptions where, that the damping was very small and the coupling was loose but at the same time, double peaking occurs for over coupled case, over coupled under loose coupling.

Loose coupling has three stages: under couple, critically couple and over couple. Now over couple, over coupling may be increased to an extent that all these assumptions go down the drain. Then all, none of these expressions will be correct, is that clear? If you bring them too close to each other, then there will be sharp peaking but in between the dip will come so low that the circuit would be useless and therefore, these are to be decided from experimental considerations, that is, by trial and error by bringing them close together and so on.

There is no clear analytical expression between airspace between the two coils and the coefficient of coupling. You can derive it but it is not useful. Yes, there was a question.

Student: Sir, loose coupling depends only on the value of k. So while

Sir: k depends on

Student: Ys sir, k depends on loose coupling. So but, over coupling can be increased by decreasing sign.

Sir: Over coupling can be increased by?

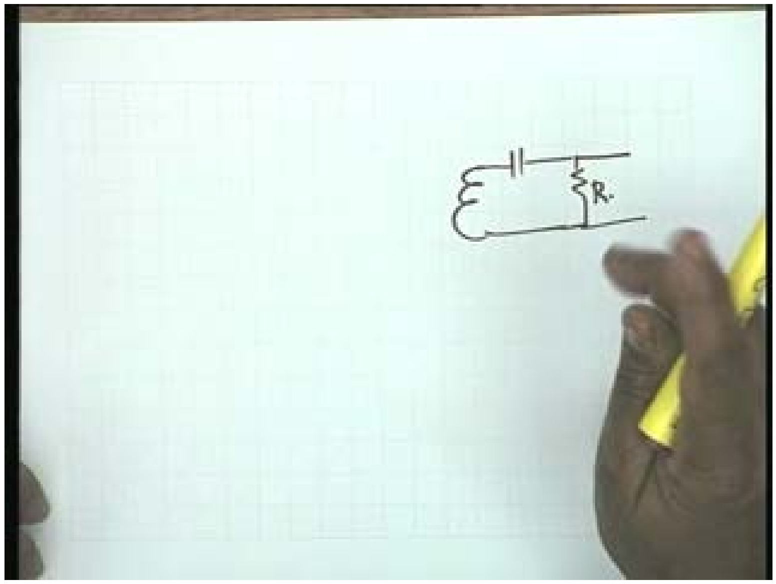
Student: Decreasing the damping coefficient

Sir: Okay, since, here is the following. You see, since it is a relative value of k and 2 zeta. Now I want k greater than 2 zeta. I can do this either by increasing k or by decreasing k. You are quite right. Now however, a practical engineer will not try to do that because he does not want any zeta. He just does not want zeta greater than 0. This is inevitable. You cannot make an inductor without a resistance because the wire that you are using to wind the inductor has a certain resistance. You do not use an extra resistance unless you want to shape the curve. Suppose, we have got such fine, such beautiful wires; incidentally, the finer the wire?

Student: Higher the resistance.

Sir: Higher the resistance. So being lower will be the value of Q. So you have got thick wires and we have wound them up. Now you find that the resonance is so sharp that it is not useful. If it is very sharp, then the dip will come low. So you, intentionally, then use less little bit of resistance in the circuit. Resistance in the circuit, usually, is not added unless your load is resistive.

(Refer Slide Time: 45:48)



It might appear, it might so happen that the secondary has to transfer power to, let us say, the input of an amplified stage. The input of an amplified stage, the impedance is basically resistive. So this resistance is inevitable. This resistance is inevitable, then you will have to change your coil and capacitor to be able to adjust to the particular band of frequencies and the sharpness of resonance that you really desire. Now as I had said, yes.

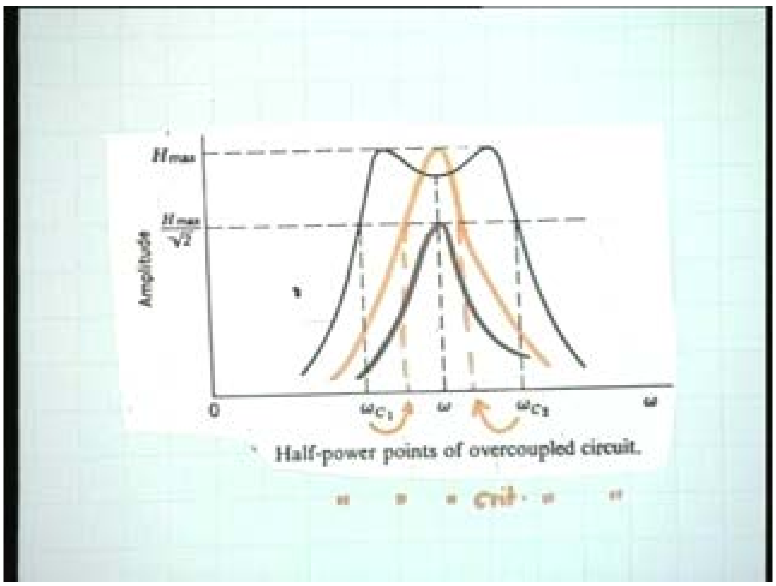
Student: When does the user have a control over k

Sir: We have a control over K, we can bring them closer together or separate out. These are determined by these companies manufacturing IF coils by trial and error and once they do this, now of course there are computer added procedures, once they do this they keep it fixed and the manufacturing is also done with computer aids. So the precise control is needed.

They cannot afford to manufacture a radio set. It means the IF coil is defective. Instead of 465, if the frequency is 490, then the whole set has to be thrown out and you remember that nowadays everything is manufactured by integrated circuit processing. They are not discrete components. IF coil, usually is a discrete component, but it can also be made for very high frequencies by IC inductors, that is, by depositing conducting layers in a spiral manner so that it behaves like an inductor and then there is no way you can correct it.

You cannot simply take out the IF coil and throw it, You cannot replace it and this replacement is going to be very costly because if a company has to make profit, they have to make 20000 in a day and they cannot go on sampling each of them to find out which one is correct. They cannot take a take a risk. Yes, any other question? Look at this now.

(Refer Slide Time: 47:51)



I have shown two cases. One is critically coupled, the orange curve is critically coupled and the black one is the over coupled case and in both cases, one can find out the half power points omega c 1 and c 2. For this, one by geometry construction, whatever this one, where it is critically coupled will be geometry construction work.

Student: Yes

Sir: It will still work. What about the under coupled case? Let us draw that outside. What about the under coupled case?

Student: You might not have the half power point.

Sir: So then you will have the half power point. You want it or not, you like it or not, it is going to happen. You see, this is the maximum and then you will have, is it possible?

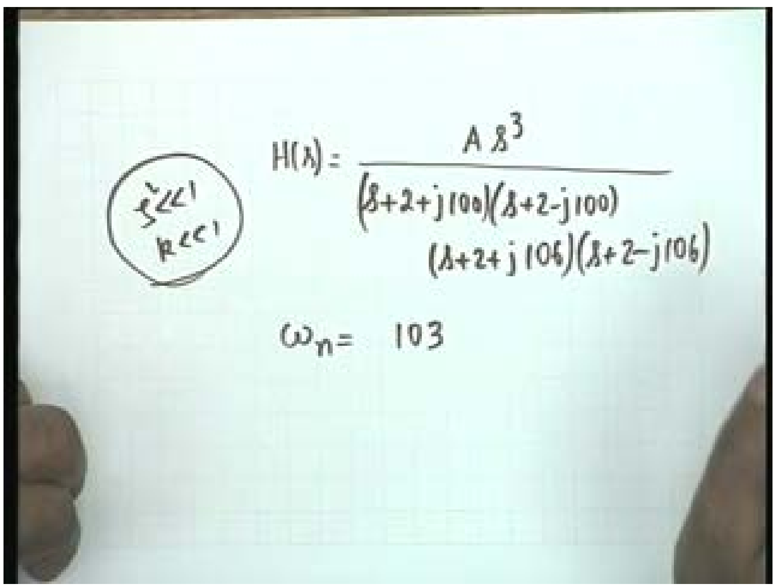
Student: Yes sir.

Sir: I leave that answer to you.

Student: It is possible.

Sir: I want you to find out the procedure to do that. We conclude this class with an example, is a very illustrative example.

(Refer Slide Time: 49:02)

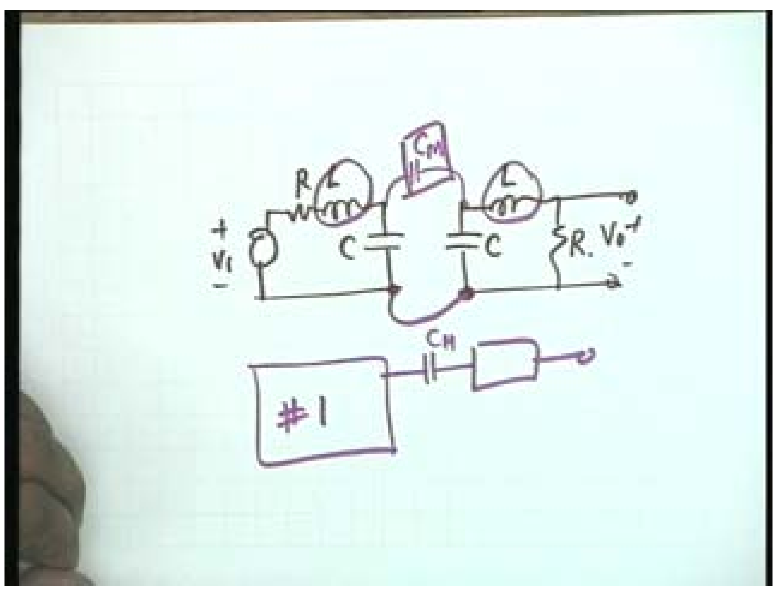


We have a transfer function of this form s plus 2 plus j 100, s plus 2 minus j 100, s plus 2 plus j 106, s plus 2 minus j 106. This is the transfer function and one should immediately recognize that it is a transfer function of a double tuned circuit. Double tuned circuit in the manner that we have taken. There is a output across the resistance in the secondary and the two complex conjugate, the two pairs of complex conjugate poles is minus 2 plus minus j 100 and minus 2 plus minus j 106 and therefore, zeta squared much less than 1 k, much less than 1 are automatically satisfied because of the symmetry that the poles obey. Can you tell me what is omega n in this case?

Student: 103

Sir: 103. It is the arithmetic mean between 100 and 106. Now let us find out, I am tempted to continue this example in tomorrow's class. I want to utilize the 3 minutes that are left to tell you something more interesting in this context. If you get such a transfer function, is it necessarily that of a double tuned circuit? The answer is no and I want to tell you why. A double tuned circuit, yes, we have shown, we have demonstrated that this is the case. Suppose, we have two tuned circuits. We will continue this example in the Friday class, that is tomorrow.

(Refer slide time: 51:12)



Suppose we have two tuned circuits like this. I have a resistance, inductance and a capacitance V i. I have another tuned circuit like this and I take the output across this and for simplicity, let us say, they are identically coupled, they are identical tuned circuits.

Now obviously, if they are like this with Ls not coupled to each other, that is, this is shielded. You know what is a shielded coil? It is surrounded by a metal which is non-magnetic. So it shields the magnetic field all inside it. It cannot couple to anything, anything outside the world.

Most of the coils that you see mounted in, let us say, radio frequency and lower frequency operator, they are all shielded. Well, otherwise, they are going to make havoc. They are going to couple with anything that is nearby and cause havoc. So they have to be shielded, they are shielded. If there is no coupling between the two, obviously, V 0 shall be identically equal to 0 but suppose, we connect a small capacitor between the two. Suppose we connect a small capacitor between the two, will there be a voltage here?

Student: Yes sir.

Sir: I am appealing to your commonsense.

Student: Sir, V i is dc or some sinusoidal?

Sir: It does not matter. It is a varying voltage. Whatever it is, it could be a saw tooth, for example.

Student: (..)

Sir: We will get a voltage V 0 here.

Student: Yes sir.

Sir: The answer is no. You see, what I have done is, I have a circuit here. This is circuit 1. Let us have some fun. Then what we have done is, we have a CM and between this point and this point, this is floating, we have some other.

So the essential condition for V 0 to appear is that this two should be connected. Not necessary to ground. What is the secret about ground? It is just a reference. We do not have to go to the temple. We can have a common point of reference anywhere we like. There is a similarity between this and what Ramakrishna taught, but we will not go into that. Now if we have a reference here, then only V 0 will be (..). If CM is 0, if there is no capacitive, this is called capacitive coupling. Instead of inductive coupling, it is a capacitive coupling.

If there is a CM, non-zero CM, then you shall observe exactly the same kind of behavior as in double tuned circuit. So two tuned circuits can be coupled by capacitance also. This is called electrostatic coupling. Is it possible to replace the capacitor by a resistance?

Student: Yes sir.

Sir: Of course, it is possible. Anything connected here, it could be resistance, inductance, capacitance, anything connected here, which is non-infinity in impedance, is that clear? A finite impedance connected here is adequate for coupling two circuits, provided they have a common reference. There must be a common reference. Well, this may be connected straight or may also be connected to another impedance; it does not matter.

A hybrid coil that you see in telephone is an example of such coupling. It could be any impedance that you like, provided the impedance is not infinity. If the impedance is infinity no current can flow and therefore. This electrostatic coupling can be dealt with exactly the same manner as inductive coupling.

The double tuned circuit is an example of coupling though electromagnetic field. The capacitive coupling is an example of coupling though electric field. If there is a resistance, then if instead of a capacitor or inductive coupling there is a resistive coupling, it is a case of dissipative coupling. That is, whatever energy is there, energy is being transferred but in the process, there would be losses in the coupling resistance. Thank you.