Analog Electronic Circuits
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Module No 01
Lecture 38: Tuned (or Narrowband) Amplifiers

The 2 topics on our menu for the next discussions is narrowband amplifiers and then we will follow it up by wideband amplifiers. What we have discussed so far is the usual bandwidth that can be obtained with RC coupled or other types of amplifiers. We shall consider the 2 extreme cases, very narrowband and then very wideband amplifiers. Today, we discuss narrowband amplifiers. So tuned amplifiers.

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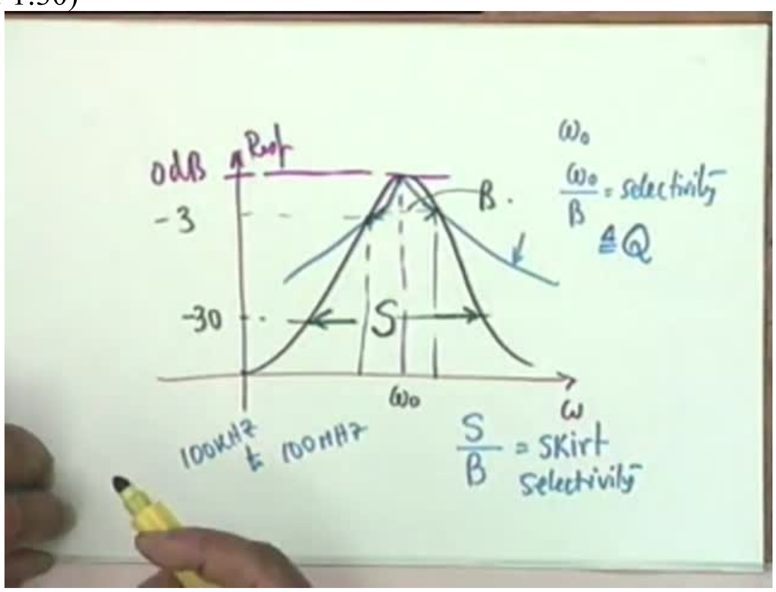

A tuned amplifier basically is required to obtained a bandpass characteristic with a narrowband, that is the characteristic that we desire to obtainis of this type where we characterise this characteristic by means ofseveral parameters. And one of them is the this is the response vs frequency, this is the characteristic that you want from a tuned amplifier or a narrowband amplifier and to be specific, let us say the maximum is put at 0 dB. You can always normalise this. You can always normalise the gain so that the maximum is at 0 dB.

The response is characterised by the resonance frequency omega 0. The 3 dB bandwidth if this is - 3, a 3dB bandwidth which is usually denoted by B, capital B and in addition, there is a

3[rd]parameter that is used in practical circuits which is the - 30 dB that is when the characteristic falls down by 30 decibels from the maximum. This is denoted by a capital S okay. These are the 3 parameters that are used. Now suppose I have 2 characteristics. One is this black line and the other is the blue line.

Look at this. (())(3:34) another characteristic like this. Obviously, the blue line is poorer narrowband amplifier. Although the bandwidth, 3 dB bandwidth is the same, the blueline represents a poor quality narrowband characteristic than the black line and that is why, this bandwidth is important, the 30 dB bandwidth and usually one defines a parameter, one defines the following parameter. One is omega 0, the other is omega 0 divided by B. This is called theselectivity of the response. Alsosometimes called the Q of the circuit.

As you know Q is defined for a coil, for a condenser, for an element but Q is also defined for a circuit by the ratio of the omega 0 to bandwidth. And the ratio of S to B is called the skirt selectivity. It is the measure of the slope of fall at the 3 dB points. It is a measure of slope of fall, obviously this slope. Have I made a mistake? Okay, S by B. Do you want S by B to be high or low?

Student: Low.

Professor: Low. So it should really, it is a misnomer. It should really be called skirt rejectivity. Is not it right? But anyway this is the definition, S by B. S by B for the black characteristic is lower thanS by B for the blue one but the black one is preferable. So for skirt selectivity, you require a low value for omega 0 by B. This selectivity, you require a high value. There is a slight contradiction here. But anywayfor a few hundred kilohertz to a few hundred megahertz such a characteristic is obtained by a tuned circuit, an RLC tuned circuit and a very simple tuned circuit.

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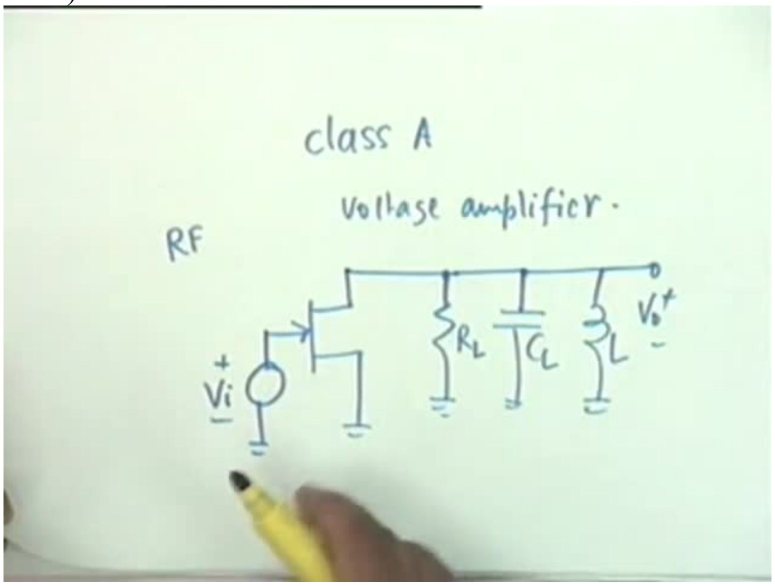

We shall consider tuned amplifiers of the following class, class A only. We will not consider any other. Class A and voltage amplifier. These are the usual demands in practice. One of the examples of a single a tuned amplifier is in the in the IF stage or the RF stage of a radio receiver or a TV receiver. You know the intermediate frequency stage, you require a tuned amplifiers like this or in the RF stageof a radio receiver. And the simple circuit is a simple way that you can achieve such a characteristics to bring variety into experience,lets use a FET amplifier. What you want is, I am omitting thebias circuit.

What you want is, you have aVI and the load of the drain should consist of a parallel RLC circuit. Let us call this L, CL and in addition, you have to use an inductance L. If I omitthe biasing circuits well, this is the circuit for a single tuned amplifier. Single tuned because it uses only one tuned circuit okay?

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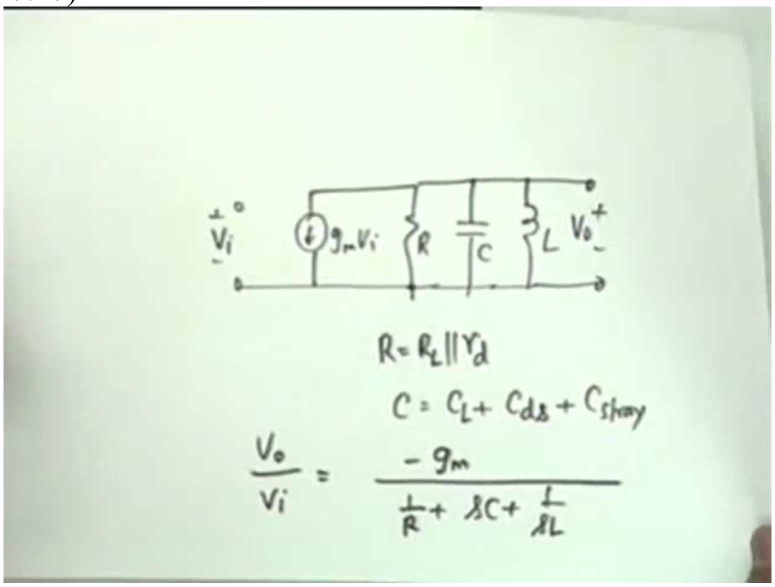

Now the equivalent circuit of this would be VI +-, then GMVI. I will use this as R, I will use this as C and I will use an L here. Can you tell me why these are different? Why R is not RL? This R combines RL with small r subscript small d, the dynamic resistance of the FET quite so. What is C? C combines CL +Cds between the drain and source and any stray capacitance that might crop up in the circuit. So this is the total circuit. And you know that the gain of this stage is very easy to see.V0 byVI would be equal to - GM times the impedance of the circuit which is 1 by the Admittance of the circuit. 1 by R + SC + 1 over SL.

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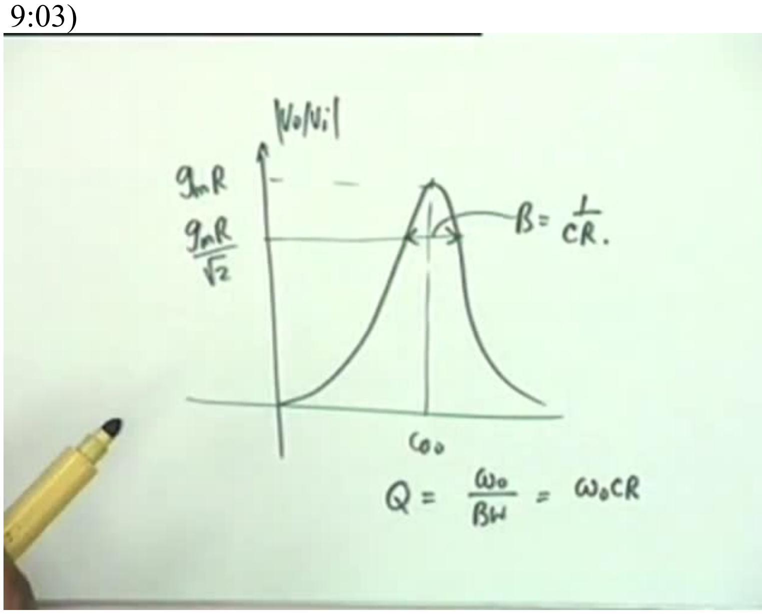

I can write this gain, V0 byVI as equal to - GM divided by C. If I take C common, then I get 1 by if I take C common then 1 by CR + S + 1 over SLC okay?

Student: Excuse me Sir.

Professor: Yes?

Student: Can you please show the previous slide?

Professor: Previous slide, yes.

Student: Thank you.

Professor: You have got a question. Oh, you wanted to write it down okay. Now you can recognise that this is a simple 2^{nd} order circuit. It has, does it have a pole?

Student: Yes sir.

Professor: How many?

Student: 2.

Professor: And does it have a zero?

Student: Yes sir.

Student: Yes sir.

Student: One.

Professor: At the origin, 10 at the origin. So the pole zero diagram is this. Are these poles complex or real?

Student: Complex.

Professor: They could be, they could be real also but a real pole does not serve much of a purpose. You require them to be complex. Not only complex, you require them to be close to the J omega axis okay, close to the J omega axis. The real part of this pole should be as small as possible. Who determines the real part? The resistance R. The resistance R determines the real part. Now you want R to be high or low in this case?

Student: Low.

Student: Low.

Student: High.

Professor: Wrong. You require this R to be as high as possible. If this was infinity, then the pole should have been exactly on the J omega axis. Okay. Now V0 byVI when you put this equal to J omega, it is - GM by C 1 over 1 over CR + J omega - 1 by omega LC which makes it clear that the maximumvalue maximum magnitude is reached at the frequency omega 0 equal to 1 by square root LC, that is when this is equal and this is 0. And the maximum value is GMR and the bandwidth B can you guess what the bandwidth is?

Student: R by L.

Professor: 1 by RC. It is this, this factor which is the bandwidth, 1 by CR. You must have done this in your circuit theory class but if you have not done it, take the climate, find out the values at which the magnitude is 1 by root 2 and then find that this is the story. That is, what we have achieved is something like this. Omega 0, this magnitude,V0 byVI magnitude is GMR and if this is GMR divided by root 2 then this B, this is B is equal to 1 by CR and therefore, the Q of the circuit, the selectivity which is omega 0 divided by bandwidth is equal to omega 0 CR. It is proportional to R. The higher R is, the higher is the value of Q okay. I will not do the algebra because you must have done it in the circuit theory class. Now the problem, where is the problem?

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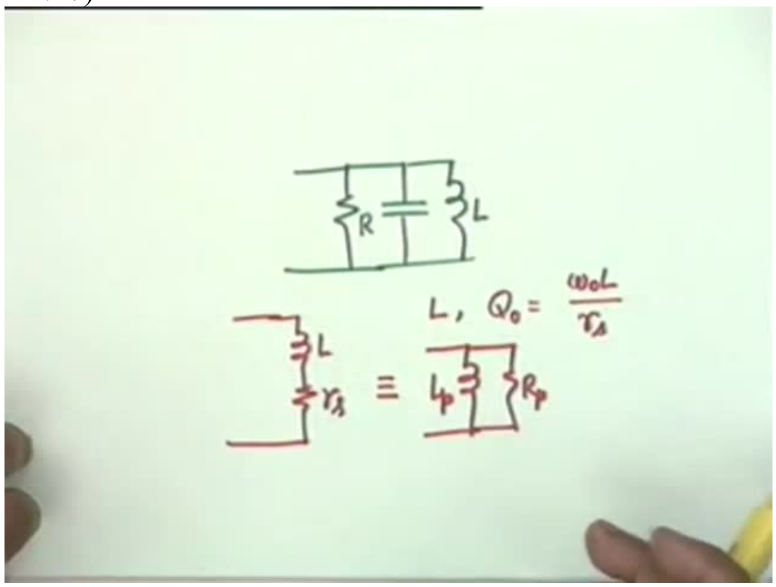

The problem is that my circuit, I drew the circuit as R, C and L. So long as I can realise such a tuned circuit, it is wonderful but unfortunately, I cannot do that. What I realise is whenever there is an inductance, there is a resistance. So this inductance is not a pure inductance. It comes in series with a resistance, let us call it rs which causes the resonance frequency to change, the maximum gain to change and everything else. Also analysis. In the analysis, you seeyou have to put J omega L + RS instead of RS.

And however, such inductances are always described or characterised by the inductance and its Q parameter. We call it Q0 at the frequency at which you want to use it. Now what is Q0? Omega 0L divided by.

Student: R.

Professor:rs, the series resistance. This describes the coil. The coil has an inductance and a value of Q. Q is this. Now it would have been wonderful if this series combination could be replaced by a parallel pure inductance LP and a pure resistance RP. Obviously in general at an arbitrary frequency, you cannot do thatokay. But at a particular frequency, at the resonance frequency, this is possible to be done. Why should we do this?

Because then it is (())(14:32) analysis. Iwill have the same circuit again if I can reduce it to this form.

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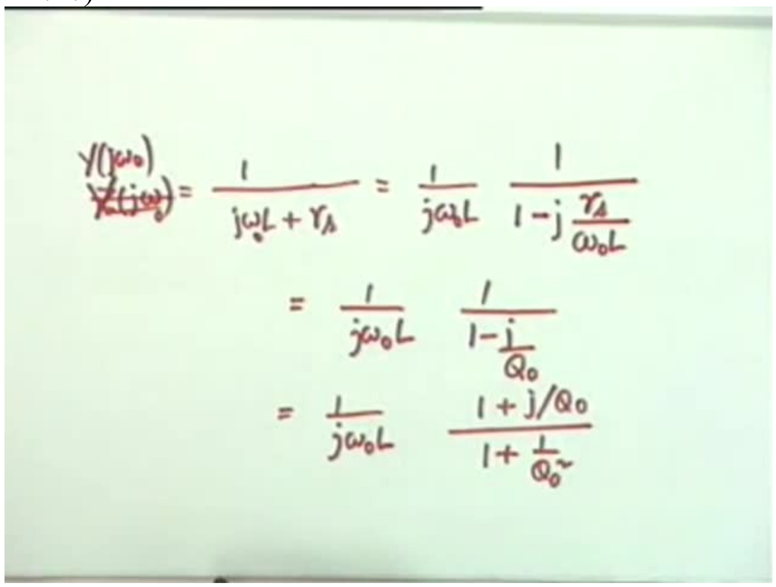

And reduction to this form is not a verydifficult problem. The impedance of the inductor at the frequency omega 0, at the resonant frequency is J omega L + J omega not L +rs okay, which I can write as 1 over J omega not L. Then 1 -rs.

Student: Sir, this is admittance.

Student: Admittance it should be.

Student: This is admittance.

Professor: This is the admittance, I beg your pardon. This is the admittance, Y of J omega. If I takeJ omega not L out, then I get 1 - J rs divided by J omega not L. Agreed? Which is equal to look at this derivation. 1 by 1 - J by Q not. Agreed? I can write this as 1 by J omega not L1 + 1 over Q not square 1 + J by Q not. All right?

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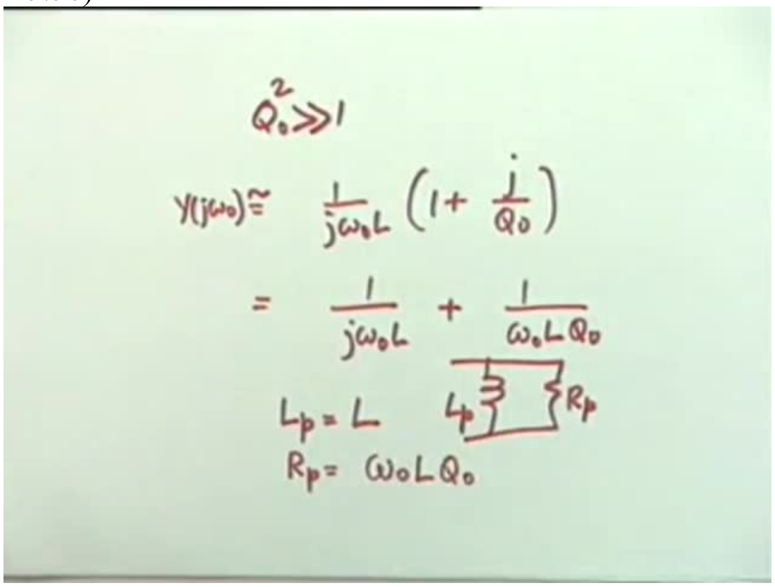

Andif Q not is much greater than 1 Q not square much greater than 1, so even for Q not equal to 3, this should be true. Q not square is approximately 10. IfQ not square is much greater than 1, then the admittance Y of J omega not is equal to 1 over J omega not L 1 + J by Q not which is equal to approximately 1 by J omega not L + how much is left here? Omega not L Q not. And therefore LP, this is equivalent to a inductance LP and a resistance RP where LP is equal to L, the original inductance and RP is equal to omega 0 L Q not.

You can see now that Q not is RP by omega not L. It is proportional to the resistance because we have expressed it in the form of a parallel combination.

Student: Excuse me Sir?

Professor: Yes.

Student: Sir, if we want R as large as possible, then why did we use an external resistance R at all?

Professor: Just a minute. We have to go back to the original circuit.

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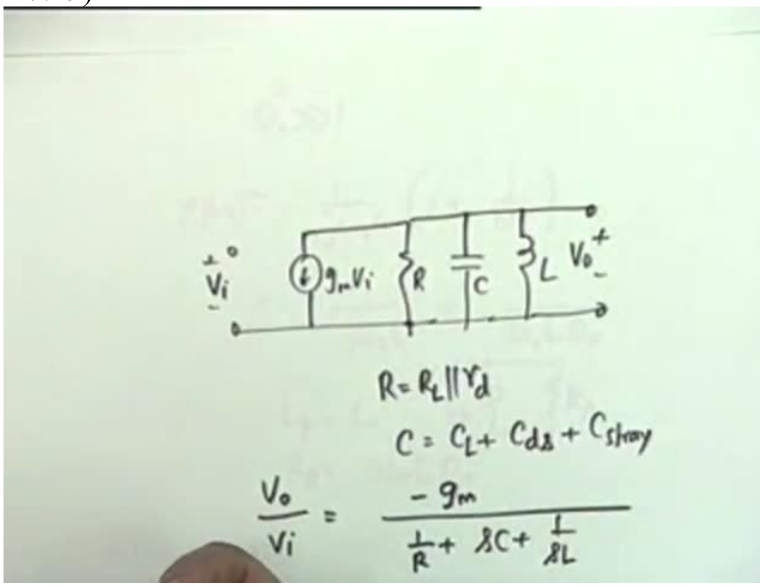

What was your question? If I made R as large as possible, why do I insert this resistance? Okay. Any answer? What is this resistance? This is the capital R sub capital D. You require a resistance to bias the FET and it is that resistance in parallel with the dynamic resistance. The resistance is inevitable. It shall be there. It can be large but it shall be there okay.

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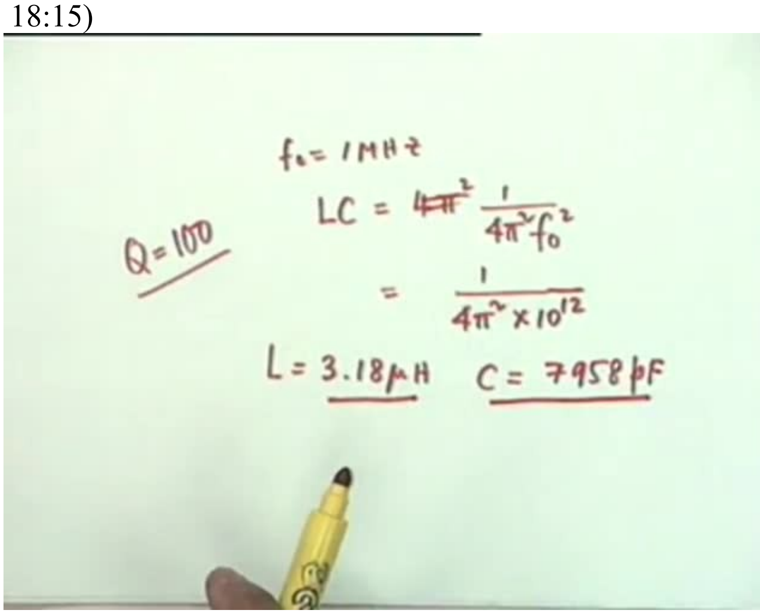

Now it turns out that in practiceif the frequency, even for moderate frequencies, let us say if the frequency is 1 megahertz , then the inductance and capacitance should satisfy the relation, LC equal to 4 pi squared, no, LC equal to 1 by 4 pi squared f not squared. Agreed? Right? So in this case it is 1 by 4 pi squared 10 to the 12, the product of L and C. A choice, one choice, one typical choice is let us say L equal to 3.18 micron Henry and C is equal to 7958 picofarad.

Now this is usually a very small value of inductor very small value of inductor. If you want a Q of let us say 100, getting a Q of 100 with the small inductance like thisis a difficult problem. Also, this capacitance is a large capacitance. If I can reduce it further, it would be to our advantage. The smaller the capacitor, the smaller is the size and the better is its loss characteristics. Agreed? The higher the capacitor , the bigger is the loss. That is why, electrolytic capacitors cannot be used in such circuits at all because they have a very low resistance in parallel okay.

So what one does is, if the values that you require are not manageable, then you use a transformer. And the transformer is usually an auto transformer, not the 2 coils separated by distance. It is usually the same coil which is tapped.

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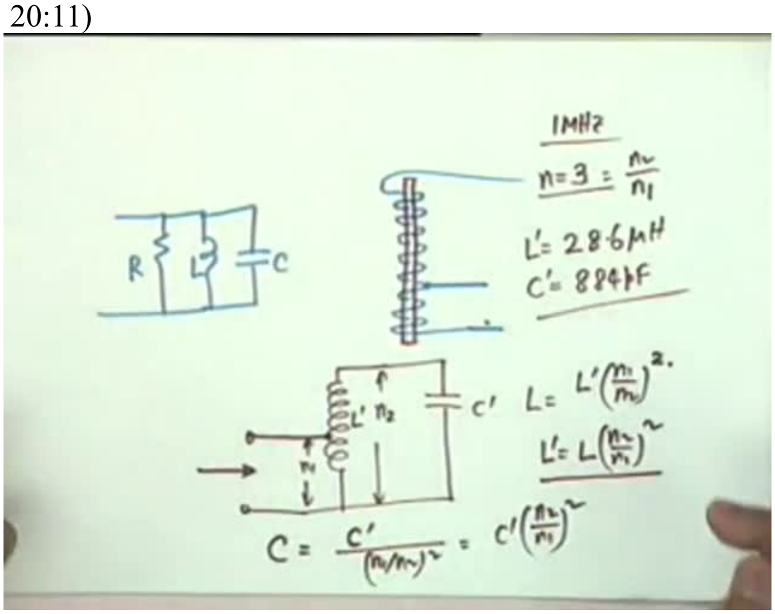

And at radio frequencies, this can be very easily made by taking a ferrite core and winding a coil around it. Suppose and then and then taking a tap, let us say from here to here. What you make is a large inductance okay at the same Q and then you transform this to a smaller inductance across this. Agreed? The Q is preserved. Not only that. If you make this transformation, then you can use a smaller capacitor across this to transform this into, I beg your pardon. Yes, to transform this into a larger capacitor okay. Let us see what these relationships are. Suppose I want to make a tuned circuit like this. R, L, and C.

I want to make a circuit like this where L is very small and C is very large. I want to use a convenient auto transformer or a tapped coil to make this circuit. I want to use a smaller capacitor and I want to use a larger inductance. This is very common in RF circuits. What one does is the following. One takes an inductance and suppose we terminate in a capacitance. C prime and L prime. Suppose the number of turns in this is N2 and then I take a tap. Suppose the number of turns is N1. Then at these terminals, theinductance that you will see would be L equal to L prime. Yes. Multiplied byN1 by N2 squared. Is that clear?

The impedance reflected here, the inductive impedance would be J omega L prime multiplied by the turns ratio whole squared. Therefore the inductance is multiplied by this. Is that clear? Okay. So L prime that you make is LN2 by N1 whole squared which is obviously larger than what you require. Similarly, the capacitance that you see here would be C would be equal to C prime divided byN1 by N2 whole square which is equal to C primeN2 by N1 whole square. Therefore the actual capacitance that you use is less than the capacitance that is required. Okay? Is that clear?

For example, if, considering the previous example, 1 megahertz is your tuned frequency, resonance frequency and suppose you use a turns ratio of 3 that is which is equal toN2 divided by N1, then one can very easily see that you can do with an inductance instead of 3.18 micro Henry, you can do with an inductance which is 9 times larger that is 28.6 Micro Henry and a capacitance C prime which is 9 times smaller. So you can do with it 884 puff. Can you tell me any other reason why this auto transformer facility would be useful? Any other reason? Suppose the capacitance, you see while inductance you can find tune by putting an extra turn or half a turn or a quarter turn.

Capacitor, there is nothing that you can do. It is only standard values which are available. Onlywhat you can do is you take a standard value, then use a variable capacitor which is called…

Student:Varactor.

Student:Varactor.

Professor: Oh no.

Student: Variable capacitor.

Student: Sir, ganged capacitor.

Professor: Variable capacitor.Varactor is a…

Student: Diode.

Student: Diode.

Professor: Diode okay. Variable capacitor is called a trimmer. The wires use a trimmer.

Student: It has any mechanical control?

Professor: You have a mechanical control. You seewhat it is is a small parallel plate capacitor. Okay? Small a button,an another button, put a dielectric in between. A metal button and a metal button, put a dielectric in between okay.

Student: Area is variable.

Professor: Area is variable. Okay. So there is a screw at the top which you can drive and vary the capacitor but it is messy. One would be perfectly comfortable. If it is a fixed frequency, 1 megahertz, I do not want all this mess. I want a fixed capacitance and therefore an auto transformer there helps. You can slightly change the tap to make this a standard value which is available in the laboratory okay. For example, 792 puff if I remember, that is a standard value okay. Some standard value that is available the lab. So an auto transformer is used. An auto transformer is also used if you require couple a tuned amplifier to a next stage.

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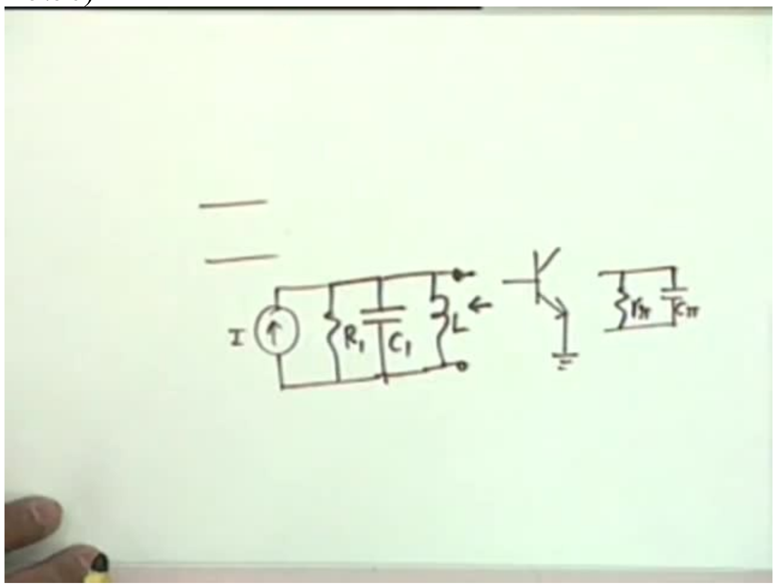

Let us say you have a tuned amplifier whose equivalent circuit is let us say like this. Some current, then a resistance R1 and a resistance C1 and an inductance L. Suppose you want to couple this to the next stage which is a common emitter amplifier. Okay, common emitter amplifier. Obviously, what this will see? If you connect it directly, then what this will se is a parallel combination ofR pi and C pi. Perhaps there would be a CM also all right? Now what is this R pi going to do? It is going to reduce the parallel resistance.

Whateffect does that have on the characteristic? The bandwidth?

Student: Broadens.

Professor: Broadens, the bandwidth increases. It is a parallel resistance and therefore it changes the characteristic of this tuned circuit. What you would like is a transformer from here to here such that the loading effect on the tuned circuit is as little as possible.

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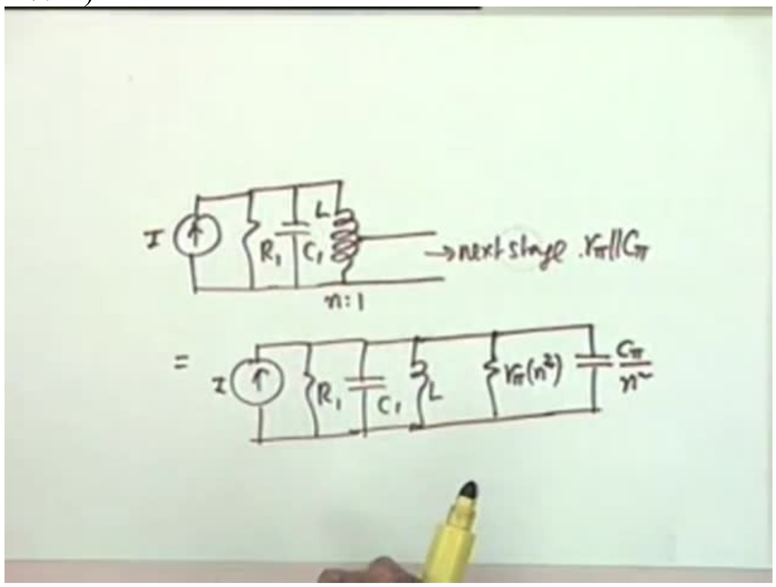

So what you do is, instead of coupling directly you couple like this. There is a problem. Okay, you couple like this. You use an I, R1, C1, then this inductance, you make it into a tapped coil. That is then couple the totalinductance but take a tap here and then couple to the next stage. The equivalent circuit, supposethe turns ratio is N is to 1 then the equivalent circuit next stage which is R pi let us say parallel C pi then the equivalent circuit would be I, R1 C1, L and in parallel will come what?

It will come a resistance which is R pi times N squared. Is not that right? So you reflect a higher resistance to the tuned circuit and the capacitance will be, what about the capacitance? It will be C pi divided by N squared. Therefore a smaller capacitance. In other words, the detuning of the circuit would be minimised. You can choose your N. If N is 3.3, then it is 10 times less. If C pi is 10 puff, it wouldreflect only 1 puff here. So the effect on C1 would be minimal, the effect on detuning would be minimal. So an auto transformer is also used in that connection . Any question? Okay.

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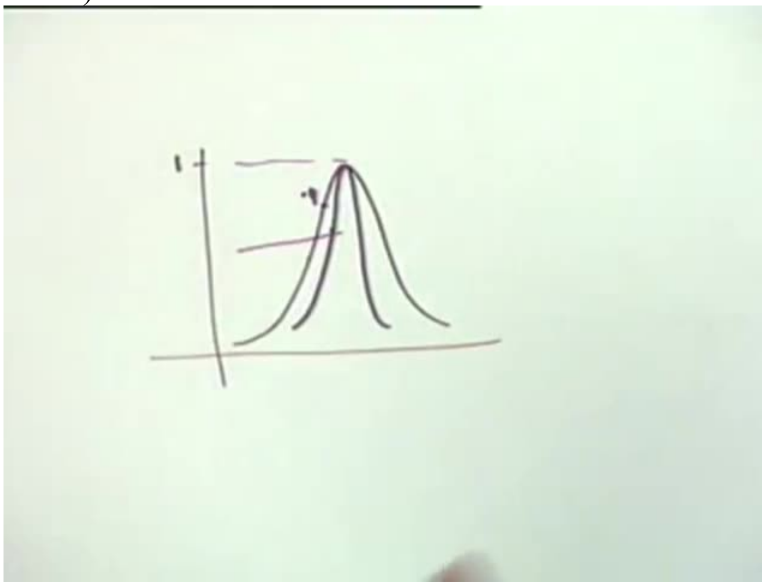

Now suppose you have made a tuned amplifier whose selectivity or the skirt selectivity is not of the proper value. You want to sharpen it. Youhave a characteristic like this. You want to sharpen it. Let us normalise the maximum to 1. How can you sharpen it? How can you make it into, how can you convert this into a circuit like this? If you cascade 2 such stages if you cascade, if youconnect two such stages in Cascade, then the resonance frequency remains the same.

It becomes that this characteristic will be the square of the other characteristic which means that wherever there was 0.9 would now become 0.81 and therefore the selectivity increases. All right?

Student:(())(30:29).

Professor: Could I?

Student: Increase R1?

Professor: There are limitations. R cannot be increased beyond let us say small r subscript small d. There are limitations. With that, you do not satisfy the prescribed characteristics. So therefore you cascade 2 such stages. Or you could also do this that use 2 tuned circuits tuned at the same frequency, one at the input of the amplifier and the other at the output of the amplifier. You can do that? Let us see what this circuit looks like. Is the point clear? You may not use two amplifiers,you may use the same active device got a tuned circuit at the end, our tuned circuit at the output. Let us see what this circuit looks like and what is its problem.

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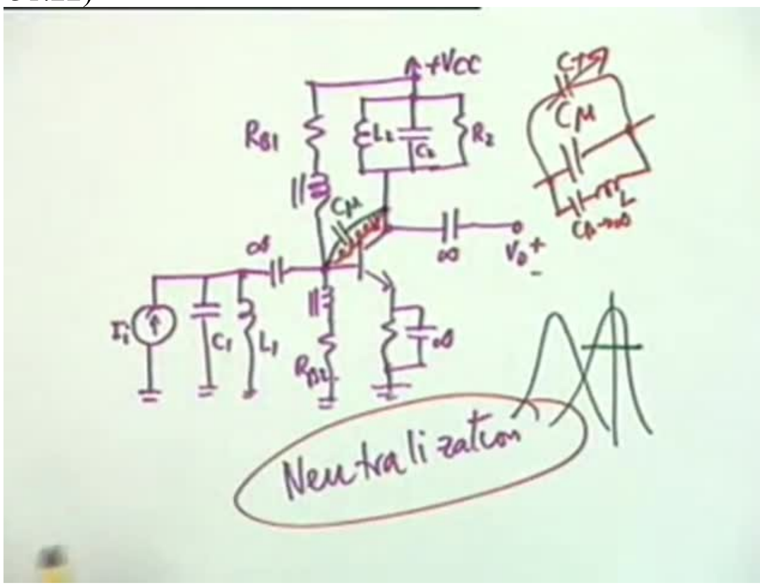

I am going to draw now a typical RF amplifier circuit and then I shall discuss what the problems are. This is infinitely large. You want to use a tuned circuit as the load. So you have L2, C2, and the losses R2 + VCC. This R2 is may not be externally added. It might be simply the losses of L2. You know that L2 will be a series combination of L2 and RS2 which can be converted into L2 parallel R2 and then this is your output, some coupling capacitor which is infinitely large, V0. At the input, let us look at it as a current amplifier, that is the GMVI perhaps of the previous stage.

At the input, we use a parallel circuit, C1, L1. I do not use a resistance but resistance will inevitably comefrom this circuit. So a coupling capacitor which is infinitely large, then I have the biasing arrangement, some resistance RB1. And if you want it to be AC open, then use an RF choke here, use an RF choke here also. So that RB1 parallel R2 does not load L1 and then you have RB2 to ground. The problem in such cases in such amplifiers is this inevitable small capacitor which causes havoc, C mew.

R pi, C pican be taken care of.R pi will contribute to the damping of this tuned circuit. C pi can be combined with C1 but what about C mew? One may argue that C mew can be reflected as a miller capacitance at the input. How would you reflect? Because this load is no longer a purely resistive load and therefore what will be reflected is not a pure resistance but it would be resistance and reactance all right? And therefore, this will totally detune the input tuned circuit. Agreed?

Worse still, you seeif you have this characteristic the output characteristic like this and another characteristic let us say like this, if they do not, if the 2 resonant frequencies do not agree, then you are actually widening the bandwidth. Is not that right? And therefore C mew plays havoc.

Student: Sir?

Professor: Yes.

Student: Sir, at resonant frequency the tuned circuit will have a…

Professor: Hmm. At the resonance frequency, now it is not an oscillator circuit. We have to accept a band of frequencies and therefore you can no longer consider this as a pure resistance. Okay you have to consider around this frequency where L2, C2 both come into effect. I was expecting this question. Well, in an oscillator circuit, a single frequency oscillator, we could do that, we could take the resonance value but not in a narrow band, not in a tuned amplifier where there is a band of frequencies in water, so the reactances have also to be considered.

Worse problem is that you see that this is nothing different from a Hartley oscillator. Is not that right? A Hartley oscillator has a capacitance and two inductances. At a frequency when this behaves as an inductance and this behaves as an inductance, it might oscillate and this is usually what happens. Whenever you want to make a tuned amplifier, it usually oscillates. Itis a fact of nature and therefore the joke is, if you want to make an amplifier, make an oscillator. It will not oscillate, it will amplify.

If you want to make an make an amplifier, I am sorry if you want to make an oscillator, make an amplifier. Okay, this is just a joke but this is a real problem. And there is a lot of effort which is RF design is much more difficult than audio design or low-frequency design okay? So what one does is, one tries to cancel the effect of C mew and this process is what is known as neutralization, is a standard practice in RF amplifiers. You have to do something, you have to do, you have to make some efforts to neutralise the effect of C mew okay.

Andthe neutralisation, can you suggest a very simple method of neutralising this?

Student: Shorting.

Professor: Short it. Then the collector will be shorted to base. Noamplification. Yes? Very simple minded procedure.

Student: Add a negative…

Professor: Add a negative capacitance. Where do I get that? The storekeeper will call you crazy if you ask for a negative capacitance.

Student: (())(37:00) negative capacitance as such. I think a circuit that would reflect (())(37:04).

Professor: What is that circuit?

Student: (())(37:07)

Professor: Okay. One of the simpleminded procedures is, add an inductance in parallel but you cannot add an inductance in parallel because the DC will go haywire. So complication. You have to use a blocking capacitor here. You see, C mew C mew, if you want to neutralise its effect, you have to have a CB which is very large, then an inductor, a small inductor and a 100 megahertz, a piece of wire would do. A piece of wire, straight piece of wire has an inductance. That would do. So making this inductance is not a problem.

But what is the problem is that this inductance should be such the impedance of this is approximately infinitely, not only at Omega 0 but around this. Inother words this is a very critical adjustment. Nevertheless, it is done. How it is done, is the following. Since an inductance tuning a small inductance, giving a small inductance is very difficult problem. You have to use a core and the core has to be adjustable and things like that. So what one does is, take the available nearest value of inductance,connect it.

Then obviously C mew, well, we cannot adjust it, C mew is internal. But we can always either we can always increase its value by using a trimmer, CT and adjusting a trimmer. A trimmer adjustment is much easier than adjustment of an inductance. Okay? So this is a simple minded procedure but people soon discovered that it has its own limitations. With age, things change,transistor parameters change and the circuit which worked wonderfully, on 23rd of March, on the 1st of April, it starts oscillating. Okay.

So this neutralisationhas very limited applications. What one does is, one uses circuit in which neutralisation is not required. Can you mention a circuit in which C mew can play no havoc? Miller effect is absent. Can you mention a simple transistor circuit? Hmm?

Student:(())(39:37)

Professor: FET. FET has C, G,D which plays havoc again. It plays the role of C mew.

Student: Sir, we change the biasing to common emitter.

Professor: No no.

Student: Common base.

Professor: Pardon me?

Student: Common base.

Professor: Common base, that is the answer.

Student:Sir, that is what I said.

Professor: That is what you said. Okay, then you are correct.

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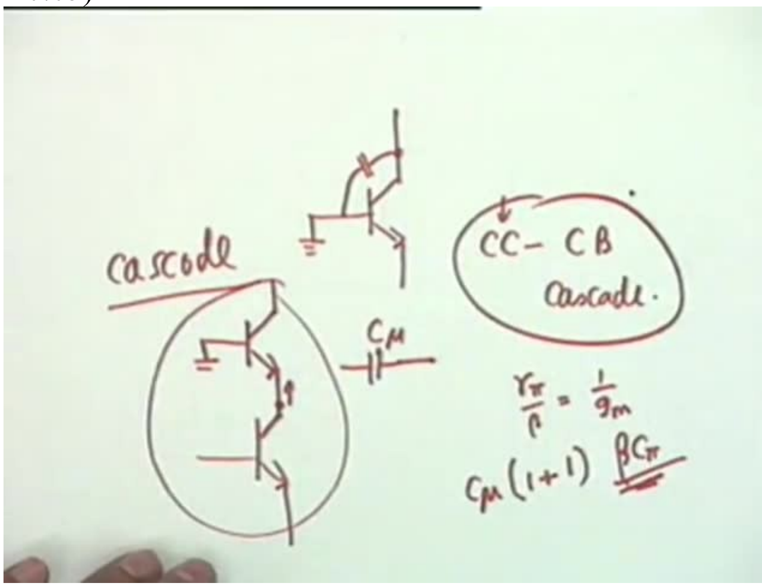

Acommon base circuit let me look at this, if the base is common which means the base is of ground, then C mew, it simply connects from collector to ground okay? And itit simply comes in parallel with the load. The load has a capacitance anyway. So it cannot affect. Is that clear? So what one does is, two possible circuits. One is a CC-CB cascade. Okay? Two 2 transistors are used as common collector stage is cascaded to a common base. Now in a common base, C mew comes in parallel with the load, so there is no Miller effect. Why a CC? Whatis the Miller effect in a CC? Okay. C mew. What is the load in a common collector?

Student: Zero.

Professor: Zero. And therefore 1 + GM RL is 1. And therefore C mew reflects as only C mew. All right? So a common collector common base cascade is a very popular method for increasing the selectivity of a tuned amplifier. The other thing, the other one is a cascode stage. A cascode stage is one. Have we discussed this earlier?

Student: No.

Professor: No. A cascode stages one in which one transistor sits up on another. Okay, thisis acascode stage. One transistor sits upon another. What happens to C mew of this? What is the effective load? What is the effective load that this transistor sees?

Student:R pi.

Professor: It is notR pi.

Student: Sir R not.

Student: R not.

Professor: No. Effective load. This transistor, the collector sees what load.?

Student: Rpi.

Professor: It is not R pi. R pi divided by?

Student: Beta

Professor: Beta because it is the emitter current. So R pi divided by beta which is equal to 1 by?

Student: GM.

Professor: GM okay. And therefore C mew reflects as 1 + GM RL which is?

Student: 1.

Professor: 1. So C mew reflects as twice C mew. That is all. It cannot reflect as 100 times C mew. So theeffect of C mew is contained. It is made as small as possible. What about the other one? What about this one? What is the effect of C mew? This is a common base and therefore it comes in parallel with the load.

Student: But in this case, the upper transistor also has a capacitance?

Professor: Upper transistor also has a capacitance. Which one? C Pi?

Student: C pi and C mew.

Professor: No, C pi comes as C pi times…

Student: Divided by…

Professor: Yes?

Student: (())(43:14).

Professor: Does it come that way? R pi by beta? Oh, it comes as beta C pi. It comes as a large capacitor. Right? Last capacitance has very low impedance and therefore its effect, its effect on C mew will be negligible. Okay, this is called acascode combinationand next time, we will discuss these 2 circuits qualitatively and then go into broadbanding effects.