Analog Electronic Circuits
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Module No 01
Lecture 39
Problem Session – Widebanding Techniques: Introduction & Use of inductors

We are going to start our discussion on Widebandingtechniques and we will devote quite a few lectures to this topic. Today we shall discuss the introduction to Widebanding techniques and how inductors can be used. Obviously if you want to use inductors, it cannot be an integrated circuit. It has to be a discrete circuit or an IC chip with an inductor added from outside okay. But before we take up this, thereare a couple of circuits that are left in tuned amplifiers which I want to draw with you.

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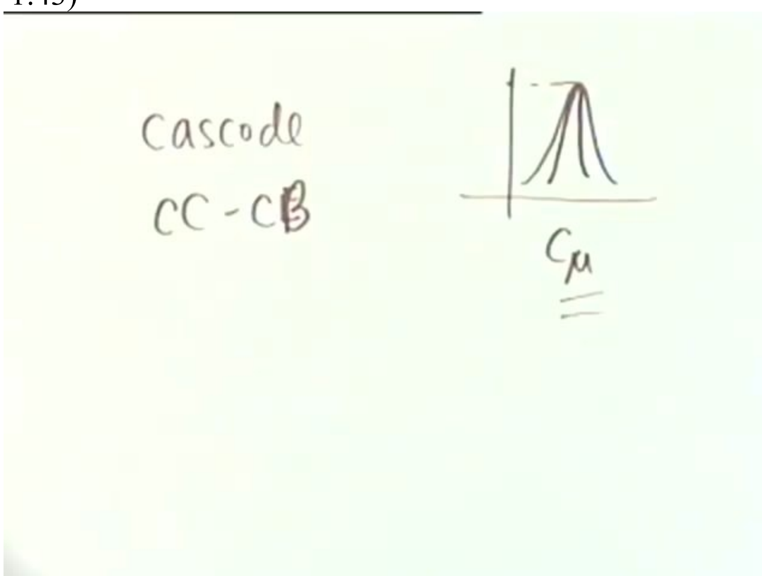

Well, I said that if you want to sharpen the single tuned amplifiers response, then you cascade a number of them. If you cascade 2 of them and keep the normalised magnitude as 1, then naturallythe response will sharpen like this and if you cascade more of them then it will become sharper and sharper and we will showor we will come to that relationship later. But we showed last time that even coupling two tuned circuits, even using two tuned circuits in a single amplifier, single transistor poses problem, problems due to C mew. This is the menace, menacing problem in the design of any high frequency circuit.

So I say, there are 2 modifications that exist in which the effect of C mew is minimised and the 1st one is a cascode and the other one is aCC-CB combination.

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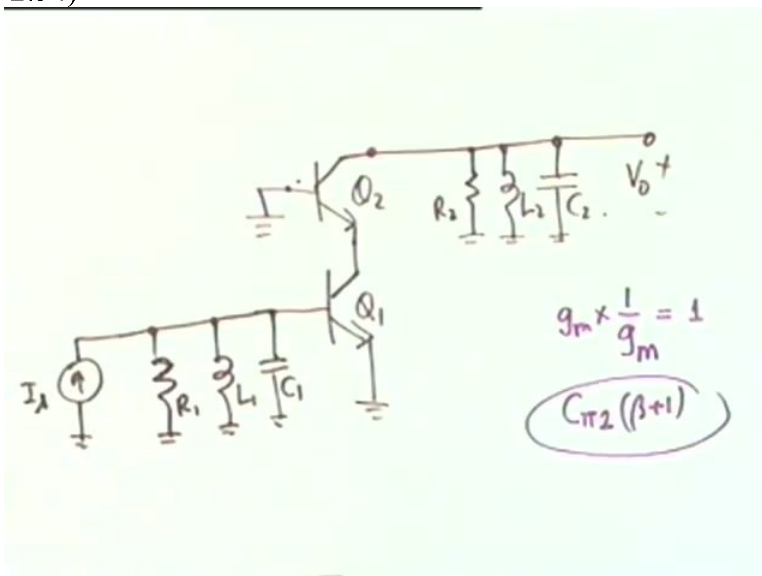

In thecascode stage, one transistor sits up on the other and the circuit is this. I am not drawing the biasing circuit, only the AC part of it. Q2 sits up on Q1. The base of this is grounded and to the collector of Q2 is connected one tuned circuit. Let us say R2, L2, C2 and here is the output voltage V0. Now you know how R2 is created. R2 may not be an externally added resistance. It may be the loss component of L2, that is L2 is in series with RS2 which is equivalently made into a parallel circuit like this.

And the other tuned circuit is in the base of Q1, that is I am only drawing the AC equivalent circuit. So you have an R1, an L1 and a C1 where R1 takes care of the internal resistance of the source, I sub S and also the losses of L1, okay? And the biasing resistors, RB1, RB2, what else? It also has to absorbR pi 1 all right? All these combined make up the resistance R1. Nowthe reason why C mew cannot affect the performance of the circuit substantially is the following. Thatthe impedance between this point and this point is R pi divided bybeta + 1 and therefore the impedance is approximately 1 or GM and when you multiply by GM GM RL, it becomes approx. it becomes equal to 1.

So 1 + GM RL becomes 2. So at the most what is reflected here is 2 C mew. Agreed? No further deterioration and C1 can then be correspondingly reduced to take care of 2 C mew.

Student: (())(5:10) biased properly then?

Professor: Yes, Q2 has to be biased properly. It has to be. That is the same collector current, the Q2 and Q1 have the same collector current okay. That is why, the GMs are equal.

Student: Sir, there is no resistance in the base.

Professor: There is no resistance in the base and therefore it is biased it is biased from thefrom the emitter side okay. Maybe there is a negative supply here. That is taken care of, okay. Now the question that may arise here is that the impedance between these 2 points is notjust the resistance. There is a C pi 2 of Q2. But what does C pi 2 come as? C pi 2 comes as the load, it comes as C pi 2 multiplied by…

Student: Beta + 1.

Professor: Beta + 1. So it comes as a large capacitance. A large capacitance, the shunting effect of R pi 2, large capacitance means low impedance and therefore theload that Q1 faces is approximately 1 by GM shunted by C pi 2 beta + 1. And usually 1 by GM is smaller than this impedance and therefore that dominates. Okay. The other thing is, what about the C mew of Q2? Well, as you see, C mew 2 is from the collector to the base and therefore it simply adds to C2 in parallel. Agreed? So C mew does not have much of an effect here and if these effects are taken into consideration, that is if we use a trimmer here, a small trimmer here okay or maybe C1 itself is variable then you can tune the 2 circuits to exactly the same frequency and you can geta sharpening of the frequency response.

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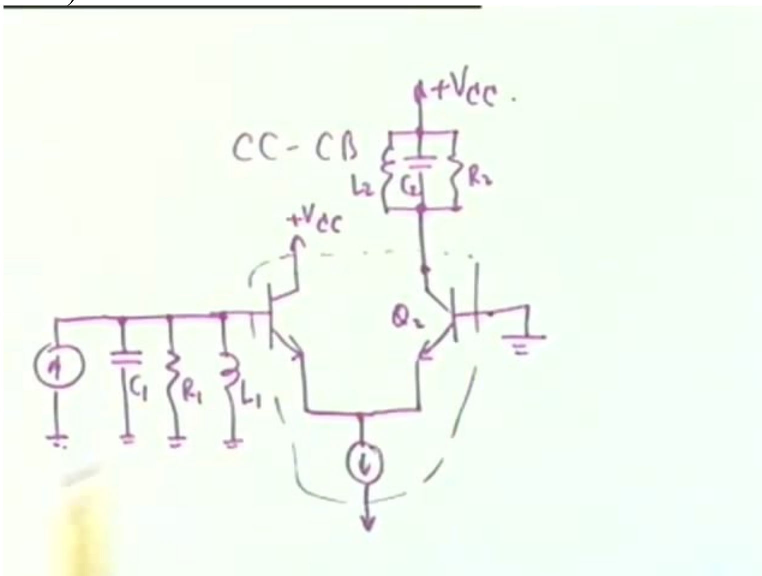

The other circuit is the CC-CB combination and this circuit is the one that is preferred in IC because its configuration is exactly that of a differential amplifier okay? The configuration is like this. This is the CC circuit and the CB is coupled to it through the emitter, that is which is exactly that of the that of the differential amplifier. And they are biased by the same kind of arrangement, namely there is a current amplifier here. There is a current source here okay. Exactly like the differential amplifier and the 2nd tuned circuit is used here.

This is L2, C2 and R2 which goes to + VCC okay. Again, the C mew ofQ2 simply shunts C2. So it can be taken care of. There is no Miller effect. The C mewof Q2 from here to ground is simply, this point is AC and therefore it simply shunts C2. And the other tuned circuit is here at the base. In other words, I am not showing theC1, R1 and L1 okay. Is this a total biasing, is any other biasing considerations needed here? Nothing is needed because this point as far as DC is concerned, is grounded. Okay.

So this is a perfectlybiased circuit. It will work. And this is available as a chip, including the current source. That is, 2 matched amplifiers, 2 matched transistors and a current source. This is available as a chip. These 2, you have to add externally okay. Nowas I said,C mew 2 only affects C2. What about C mew 1between the base and this point. The load here for the CC stage is 0. And therefore C mew reflects simply as C mew. That is all okay, which can be taken care of by C1.

So these are 2 circuits for getting a sharp response from 2 identically tuned circuits. 2 circuits identically tuned, having identical characteristics and therefore they sharpen the response. Now there is no reason why you cannot cascade more than 2 okay, more than 2.

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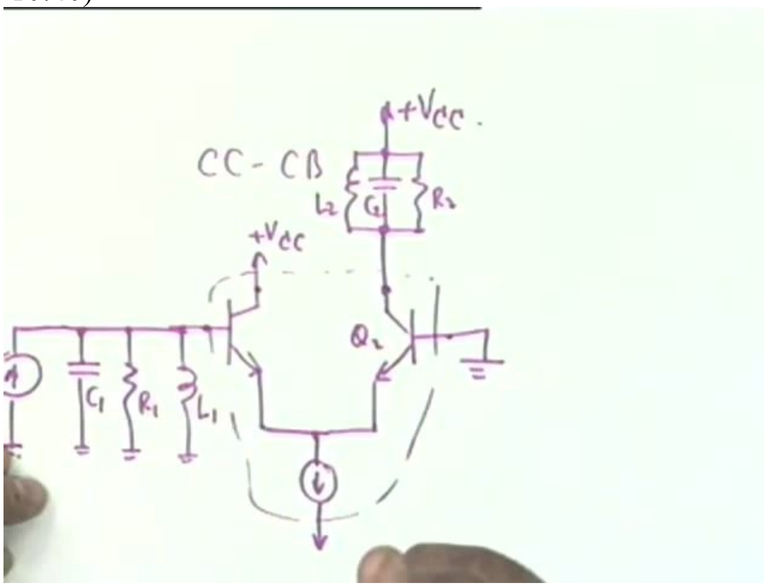

For example, a CC-CB cascade the CC-CB cascade, can you use another CC-CB in Cascade? That means, can you use 4 such tuned circuits? Obviously, this cannot be coupled directly to the next stage. Why not? Because then this tuned circuit shall be affected. So what you do is, you put an emitter follower here, again a common collector stage. One common collector stage and then another CC-CB combination okay. You can get 4 of them and 4 of them will make it much sharper.

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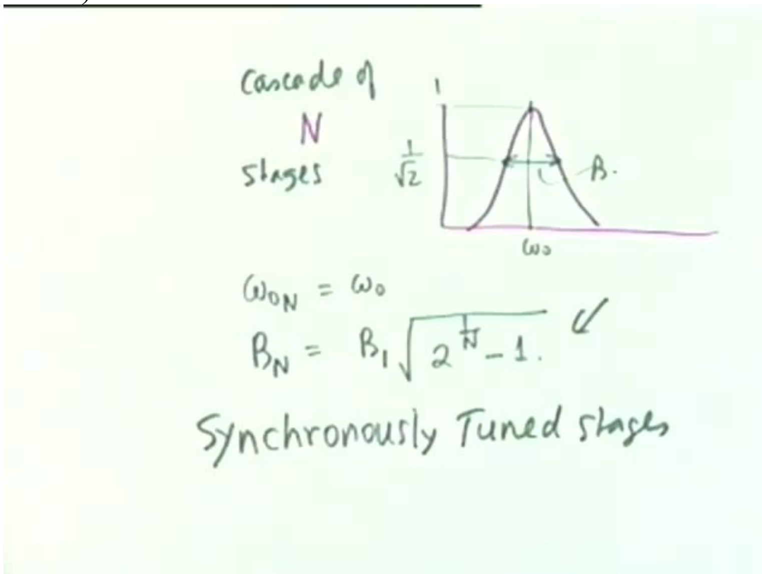

It can be shown that if N such stages are cascaded, N stages, each of which has a response like this, if N that stages are cascaded each of which has a response, omega 0 and the bandwidth is B, if this is 1, then this is 1 by root 2. If N stages are cascaded without interacting with each other, that is in a noninteractive manner. What does it mean? One tuned circuit does not affect the performance of the other tuned circuit. If they are cascaded in a noninteractive manner, then the resonance frequency Omega 0 N that is not change. Right? Because they are all tuned at the same frequency, so this is omega 0.

But the bandwidth BN changes. It shrinks and the shrinkage factor, it can be shown that it is the bandwidth of 1 stage multiplied by square root of 2 to the power 1 by N - 1. This is the rule for shrinkage. And it can be very simply derived. I will show the I will indicate the steps in the derivation a little later but let me give a name to such a cascade. A cascade of yes?

Student:(())(12:44)

Professor: No. It is decreasing. 2 to the power 1 by N. If you have N equal to 1, it is 1. You have an equal to 2, it is 0.41 square root which is 0.6, that is a shrinkage factor. Okay. How it is derived, I will come a little later. But there is a name given to this. All tuned circuits are tuned at the same frequency and this is called, such cascades are calledsynchronously tuned stages.

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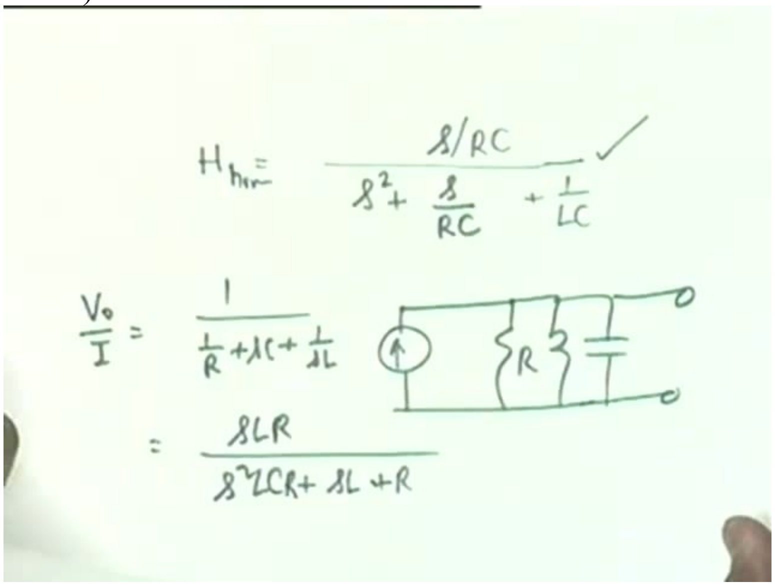

The derivation of this is extremely simple. If you remember that for one tuned circuit, the transfer function is of the form for the simpleRLC circuit the transfer function is of the form, S divided by S squared + S by pardon me?

Student: S into R by M.

Professor: S into R by M. No, I do not want to put it in this form. I want to put it 1 by LC. So it was S by RC. Is not that right? Pardon me.

Student:(())(14:08)

Professor: This is the transfer function of a single tuned circuit, is of this form. Is not that right? S squared + yes, it was a bandpass filter which I can write as let me write the normalisednormalised value that is I want to make the maximum equal to 1 and then 1 by root 2 okay.so I will write this as S by RC. Agreed? The normalised value. What is the problem? For a simple tuned circuit, well, let us derive this. I see that you are not comfortable.

This is what it is. So I have the V0 by I would be equal to the impedance of this which is 1 byR + S C + 1 over SL. Equal to SLR divided byS squared LCR + SL + R agreed withcan put in this form. That you can easily see. Is not it right?

Student: Sir, cascading of these stages, you said that all the stages should have the same set of frequency, omega not.

Professor: Correct, that is why it is called synchronously tuned. Okay? So this is the expression. I want to simplify…

Student: Sir, we do not get this.

Professor: You do not get this?

Student: Sir, OCR.

Student: Sir numerator.

Student:(())(16:01)

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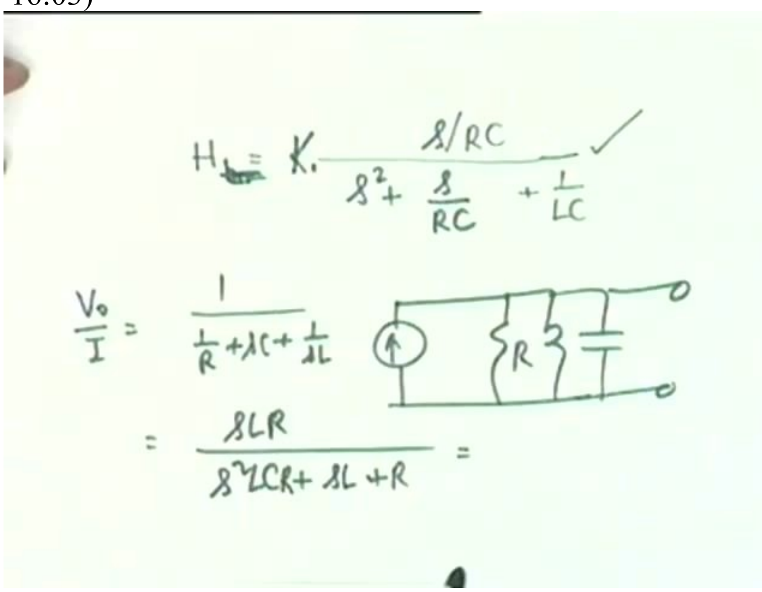

Professor: No no, I do not. In the numerator, I do not get it. What I am doing is, I want to normalise. I can write this, the denominator I can write it like this?

Student: Hmm.

Professor: Then a constant X, then a constant multiplied by S by RC. I can do that? What I want to do is to write it in normalised form so that I do not have to deal with individual tuned circuits. I can deal in general.

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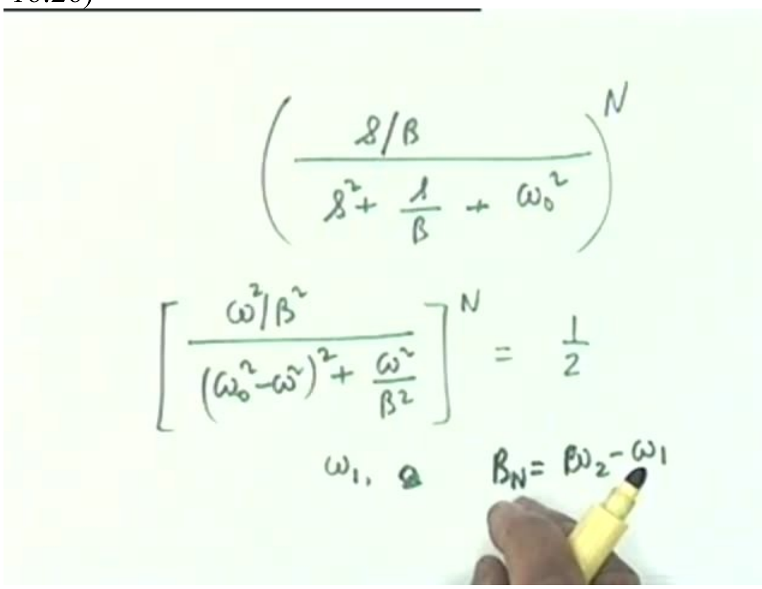

In general, my normalised response would be S by B divided by S squared + S by B + omega not squared. Okay? And what I am trying to do is to multiply is to cascade N such stages. So to the power N. Which means that to find out the bandwidth BN, I have to solve for this expression, omega squared by B squared divided by omega not squared - omega squared whole squared + omega squared by B squared okay? This is the magnitude. This is the magnitude squared of the inner expression. Agreed? Or have I done it too fast?

Student: Yes.

Professor: Putting S equal to J omega and taking the magnitude.

Student: Sir, how did we get whole to the power N term?

Professor: Because I am cascading N such stages. I am cascading N such stages so the transfer function will H1, H2, H3, H4 and so on. Okay. And this is the magnitude squared of the inner expression. If I raised it to the Power N then how do I calculate the bandwidth? This should be equal to?

Student: 1 by root 2.

Professor: No, I have already taken a square.

Student: 1 by 2.

Professor: 1 by 2. So solve for omega 1 and omega 2 from this equation and find out BN as equal to omega 2 - omega 1. You will see that it simplifies to the expression that I have written. That is BN equal to B1 square root of 2 to the power 1 by N - 1. I leave that algebra to you okay. Now there is nothing sacred about synchronous tuning.

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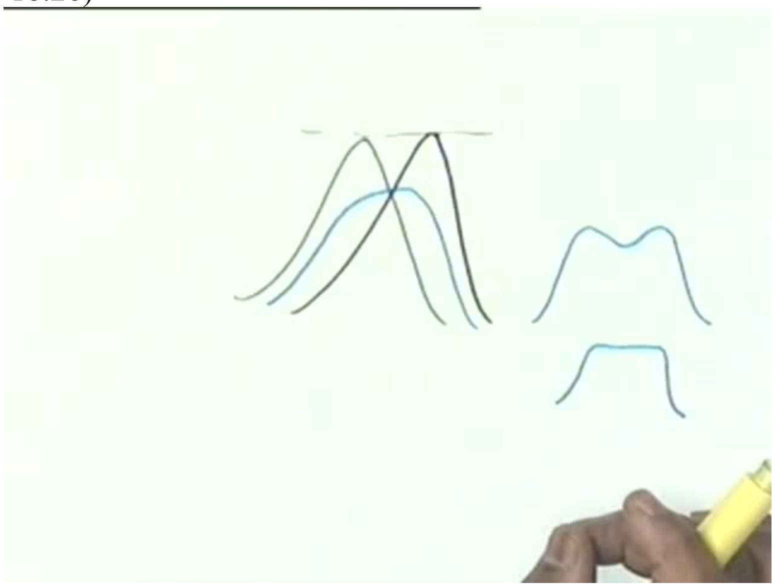

Suppose you have asynchronous tuning. That is 2 responses, one is like this and the other let us say is like this. Their maxima are the same.Their maxima are the same or maybe we normalise this to make them the same. Okay? So ifI multiply these 2, what I am going to get is something like this. Okay? Where this top can be shaped depending on the difference between the 2 resonance frequencies. For example, if they are pretty far away from each other, then perhaps what I will get is something like this. I will get 2 peaks like this and a dip in between. Okay.

I can bring them closer and get something like this. A flat top. Such a response, a flat top, such a response is preferred in circuits which have to pass a band of frequencies. Not a very small band.It is not just one single frequency omega 0 but omega 0 +- Delta omega as is required for example in an IF amplifier. In the IF amplifier yes?

Student: Sir, what is that central blueline which you have drawn?

Professor: Oh, this is the curve, this is the result of these 2.

Student: Why should it be lesser?

Professor: Oh, I have not normally. If I normalise this, then it will come up to 1. Okay? It will come up to this if I normalise this, okay. Otherwise, it can go higher or lower. But let us let us normalise, all right. So this composite response can be either double peak or also be like this, single peak ifthey are brought very close to each other. For example, if they are coincided, then you knowit will be a single peak. If they are slightly separated, then I will get the skirt selectivity I will get better but the top may become flat.

Such a response is preferred in the intermediate frequency stage of let us say an amplitude modulator receiver. A receiver which has to receive amplitude modulated transmission. You know that the bandwidth is the carrier frequency +- the modulation frequency. So you require a band of frequencies to be transmitted and such a response is always preferred. It usually what is done in IF amplifier is it is the 2 tuned circuits are coupled magnetically. That isanother possibility. For such responses, you can have let me draw this.

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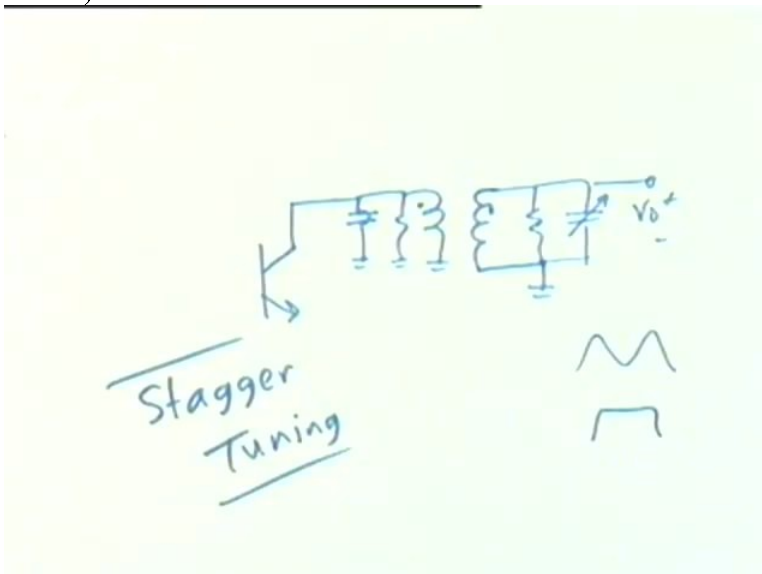

You can have a single transistorwhich has a tuned circuit and another tuned circuit which is coupled magnetically okay. And you take the output here. Thisis the way of stagger tuning all right. Since the 2 frequencies are not required very typical, you can tune one of the capacitors so that the desired response is obtained, so that the tuning is staggered, that is the resonant frequency of this circuit is not the same as that of this circuit. Butthe coupling is through magnetic coupling okay. As you bring the 2 tuned circuits closer together, as you tighten the coupling, the double peaks appear.

There is a critical value of coupling, critical value at which it would be maximally flat like this. And this is called the stagger tuning. Okay. Both increase the skirt selectivity, that is they sharpen the response. One, the synchronous tuning is used when you have a very narrow band whereas stagger tuning is used when you have a larger band to (())(22:50). We shall perhaps take some examples in the problem session. We now go over to widebanding techniques.As I said the sequence was 1st we did with oscillators, then we went to narrowband amplifiers, now we are going to widebanding amplifiers. Okay.

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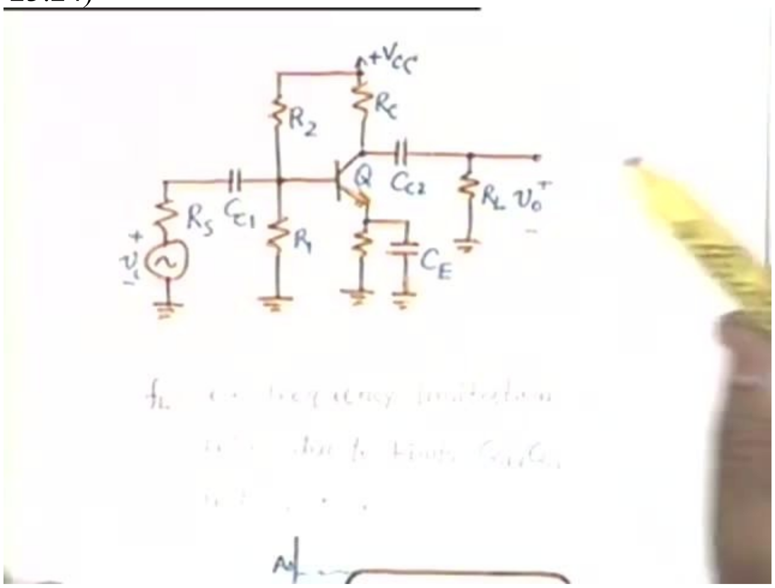

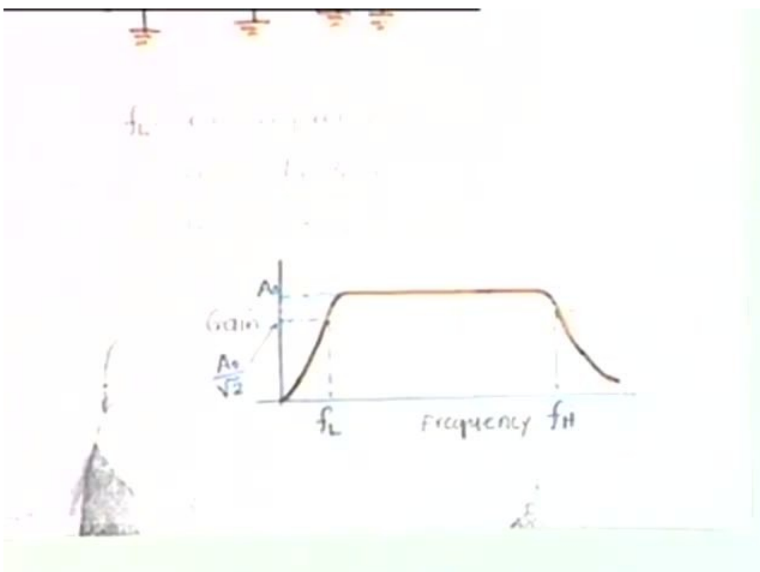

If you recall the RC coupled amplifier, can you see the circuit on the screen? Can you see the circuit on the screen? I have redrawn the RC coupled amplifier. If you recall the RC couple amplifier, we require 3 capacitances, CC 1, CC 2 and CE 2.what are these?

Student: Coupling capacitors.

Professor: Coupling capacitors or blocking capacitors. They are also called blocking. And this is a bypass. All right. The effect of this is that the low-frequency response, can you see this on the screen? The low-frequency response, the DC response is 0 and thenit rises to a certain value. It remains almost flat over a certain band of frequencies and then falls down again. The high-frequency fall is due to the internal capacitances of the transistors. Okay? That is C pi, C mew and C not. Or CDG, then C?

Student: CGS.

Professor: CGS and CDS, okay, the 3 capacitances ofan FET. Now as far as FL is concerned, the low-frequency 3 dB point, as you know, these are determined by all these 3 capacitances together all right? But the usual designthat we do is 2 of them we make very high okay and one of them is used to control the FL. As far as integrated circuits are concerned, as you know we cannot use a capacitor. That is barred. We cannot use a capacitor. We cannot make it. That is tedious, such a large capacitor.

So what we do is, we make coupling direct. Is not that right? We make direct coupling. No capacitor and therefore as far as IC amplifiers are concerned, they all start from DC. That is the frequency response is that of a low pass filter. Is that correct? This is a bandpass. Now one can argue, why cannot we do, why cannot we use the same techniques that we use for ICs in discreet circuit design? Why cannot we use the same techniques? What is the problem? Can anyone point out? I have already discussed this.

Student: Sir what was the question?

Professor: The question is, in integrated circuit, we do not have to bother about FL because we do not use a capacitor. So our response starts from DC. Why is it that in discreet circuit design, we do use 3 capacitors? Why cannot we use the same techniques as we use for integrated circuits in discreet circuit design. Why not?

Student: Size of the circuit…

Professor: Size of the circuit

Student: (())(26:09)

Professor: No, size of the circuit can be bigger because (())(26:13) capacitances are costly. Why do why cannot we break free of these capacitors?

Student: Sir, we require bigger resistances (())(26:21).

Professor: We require bigger resistances.

Student: Sir, R1, R2 and…

Professor: All these can be avoided. You see the basic problem.

Student: Sir, we have a DC part in the output which we want to block. If we want a pure AC output.

Professor: Oh, that problem is there in ICs also. We get rid of that by level shifting. We get rid of that by class B operation. Okay. That is also there. The basic problem is, if you recall how integrated circuits were biased, what was the biasing (())(26:54)?

Student: Current mirrir.

Professor: And what does current mirror need for its success? It needs.

Student: Identical…

Professor: Identical transistors. They are made on the same chip by the same processing steps and therefore the transistors become identical so that the VBE is identical, I sub C is also identical. Now that is very difficult to achieve in a discrete circuit. Hardly ever, you get 2 transistors which are identical. Hardly ever. Even if you couple them so that VBEs are identical, the collector currents are not identical. Besides spread of other values, hardly ever you can make 2 transistors, 2 discreet transistors identical andtherefore IC techniques cannot be used.

Student: Sir but in case of a (())(27:45) we do not need the transistors to have the same kind of properties.

Professor: Of course, we do. IX, the saturation currents have to be same. They have to be identical. There is no other way. Okay. So it is a fact of life that in discreet circuit design, you have to use these 3 capacitors and if you want to make it wideband, that is if you want to reduce FL and this is where a stereo amplifier, a quality stereo amplifier costs. If it has to go right up to fraction of a Hertz, it costs a huge lot of money because the capacitors that are used, that have to be high valued and they have to be very high-quality capacitors and that is where you pay the money if you want low-frequency response.

Well, if you do not want, then hell with it, no problem. Okay. So in discreet circuit design, there is nothing that we can do about the low-frequency problem. You have to use high-quality, high valued capacitors. You have to pay money. In this in integrated circuits that is not a problem. So in integrated circuits, the problem is that of FH. How can you extend FH? That is the widebanding technique. And we shall discuss several techniques to make a wideband amplifier.

Student: Sir what is a high-quality capacitor?

Professor: High-quality capacitor is a capacitor which has very little leakage. Okay? Leakage, that is the parallel conductance. Almost all capacitors, if you put aacross a multimeter, electrolytic capacitor for example, it will not show infinity. It will show a current because there is a leakage okay. Now so widebanding basically means widebanding basically means extending FH to higher frequencies. And this can be done by various techniques. We shall discuss a selected few of them.

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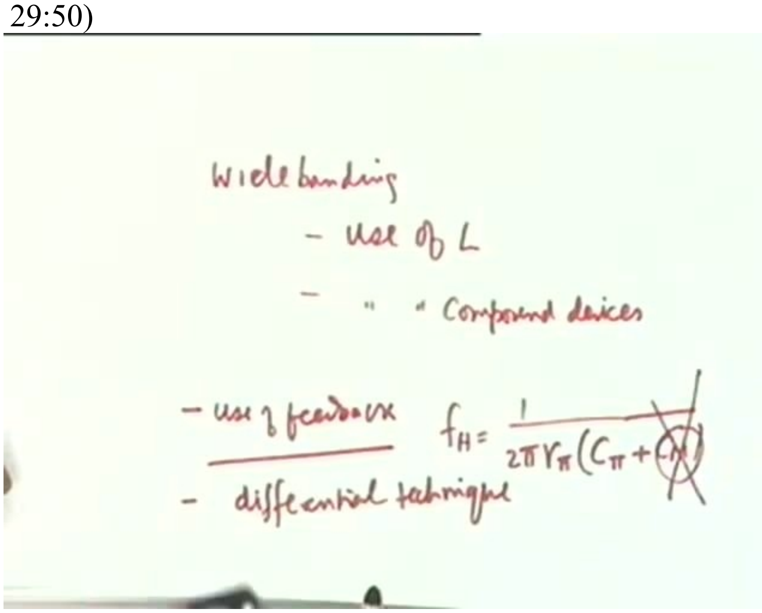

One is widebanding techniques one is use of inductors. Obviously you cannot use it for ICs.You can do it only fordiscrete circuits. If it is to be IC, then you have use the inductor externally okay.Use of inductance and then use of compound devices. An example, 2 examples of which we have already seen, the Cascode, there is 2 transistors and the cascade of CC-CB. Such compounds devices because they kill Miller effect. You see, Miller effect is the main problem inFH. How is FH determined? FH is 1 over 2 pi for a single transistor amplifier R pi multiplied by yes?

Student:CT (())(30:48)

Professor: CT that is the total which is C pi + CM. It is this CM which creates the problem. It is a large capacitor which can swung C pi because CMis gain multiplied by C mew and therefore if we can get rid of CM, obviously the high-frequency N shall be extended. And two such compound devices, we have already seen, the Cascode and the CC-CB combination. We shall seewe shall look at them in greater details at a later point of time. We shall we will analyse them and see how they extend. Then the 3rd technique is use of feedback.

This we have already explained that negative feedback increases FH and decreases FL and therefore negative feedback can be used for widebanding but the price that you pay is a reduction in gain okay. We will see how negative feedback can be used locally, that is for a single transistor. What techniques you know of single transistor negative feedback.

Student:Unbypassed.

Professor:Unbypassed emitter.Anything else? You know another technique.

Student: Sir,self biasing.

Professor: Not self biasing.

Student: Base and collector are joined…

Professor: Base and collector are joined through a resistance and their meter resistance is 0. Emitter is connected to ground okay. So you can use either locale or you can use overall. For example, you make a 3 stage amplifier and then make an overall feedback. It could be series-series, series-shunt, one of the 4 configurations. So these of feedback is one.

Then we will show that the differential amplifier technique that is so popular in integrated circuits. Op amp and every other circuit uses a differential amplifier. This differential technique can also be used for widebanding. So differential technique. And another technique which has come only recently. Differential technique, we will show this circuit later, make a detailed analysis. But another technique which has come only recently and is gaining greater and greater importance is signal processing based on not voltage but current.

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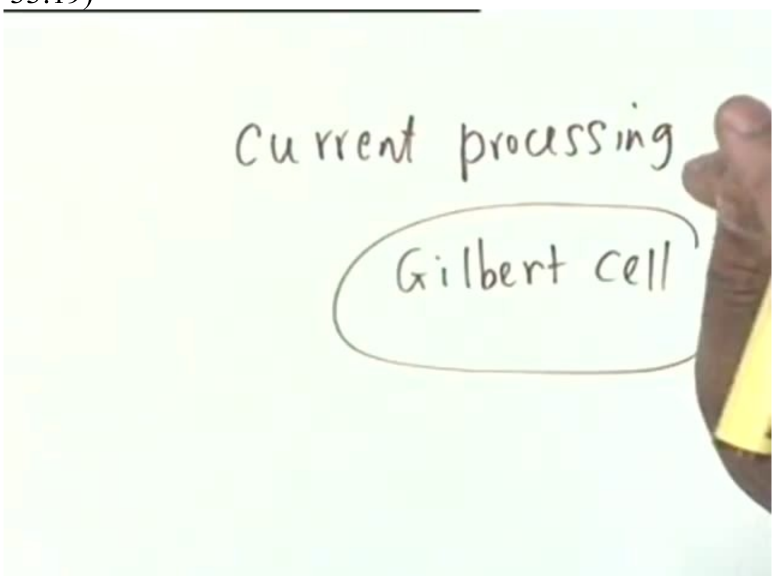

So current processing and we will see that in current processing rather than voltage, you see in current processing, if you havea resistance in series with a capacitance and you pass a current through this, you force a current, that current is not going to depend on the capacitance. Do you see the basic idea? If you take the voltage across the resistance, then it will obviously depend on the capacitance. But if you force a current, then the capacitance effect, capacitance loses its teeth and therefore current processing can obviate some of the disadvantages of voltage processing voltage signal and we will see at least one example of this.

The so-called Gilbert cell. This is an IC chip that is available for widebanding technique,widebanding amplifier. Now let us 1st look at the use of inductance.

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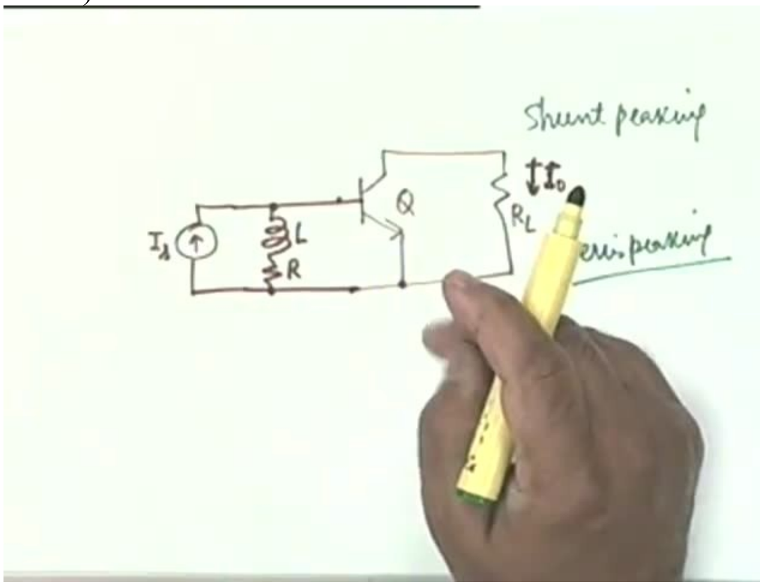

And a very simple circuit that can be used this purpose and I will not show anybiasing in this discussion. One of the very simple circuits which has been popular in the early stages of transistor circuit design and is based on a similarity with valve circuit designis that you use a transistor in which the base in the base you connect an inductor. An inductor cannot be made without a resistance and therefore L, R and let us say the impedance let us say the it is a current source drived okay. Now one should be able to understand immediately how this causes widebanding. No, why did we connect this in shunt, L, R?

This should show not only current source, even if you have a voltage source,your of course this is an effective correct? And therefore we have connected but why did we connect in shunt? What is the impedance, effective impedance between these 2 points,R pi and CT? Is not it right? R pi and CT. And if we connect an inductance obviously what we are trying to do is to make a kind of a parallel resonant circuit. All right? That is we are trying to annul the effect of Miller capacitance by using an inductance in parallel.

So some of the reactance of the capacitance is being cancelled. Now, we are not resonating however. Why not?

Student: Because (())(36:19)

Professor: Because we want a wideband amplifier. We do not want a peaking. We want as flat as possible up to as higher frequency as possible. So we are using an inductance to reduce some of the effect of C2, the reflected capacitance.

Student: Sir but if you use an LC circuit, you are inevitably going to havepeaking.

Professor: No, not necessarily. We willuse an appropriate value of L and R so that there is no peaking. We will take care. In fact we will attempt to make it maximally flat. That is, we will attempt to make it maximally flat like this. What should occur, we take care less design,it may be something like this that there is a peaking and then it comes down. We do not want this. We want as flat as possible okay. We willsee this. Number 2. Why a parallel LR? Why not a series LR?

We couldalso cancel some of the reactance by taking a series LR circuit okay by making a series kind of a resonance. Well, as we shall see through an example later that series resonance is less effective than parallel resonance. Usually series resonance is less effective than parallel. Well it is not resonance. Let us say, what should I call this? Let us call this as shunt peaking. That is, a coil is connected in shunt. It is called peaking, although we will not allow peaking. We will suppress the peaking. Well, if I use an LR in series, this is called a series peaking. Both circuits are used, that is an inductance, a coil is may be used in series or maybe used in shunt. Next point. Can I replace this inductance by a parallel inductance and a parallel resistance?

Student: Yes.

Professor: Sorry, no. Why not?

Student: (())(38:26)

Professor: Because that equivalent is valid only at theresonant frequency, at a single frequency. Here we are concerned with wideband. So that complicates analysis. This R has to remain as R. We cannot replace it by a parallel resonance. Parallel LP-RP combination. May I repeat the reason? The reason is that our operation shall be over a wide band of frequencies. It is not a single frequency operation as in a tuned circuit as in a tuned amplifier or a small band of frequencies around thetunedfrequencies. So we cannot replace this by a parallel circuit. And all we have to do now is to draw the equivalent circuit.

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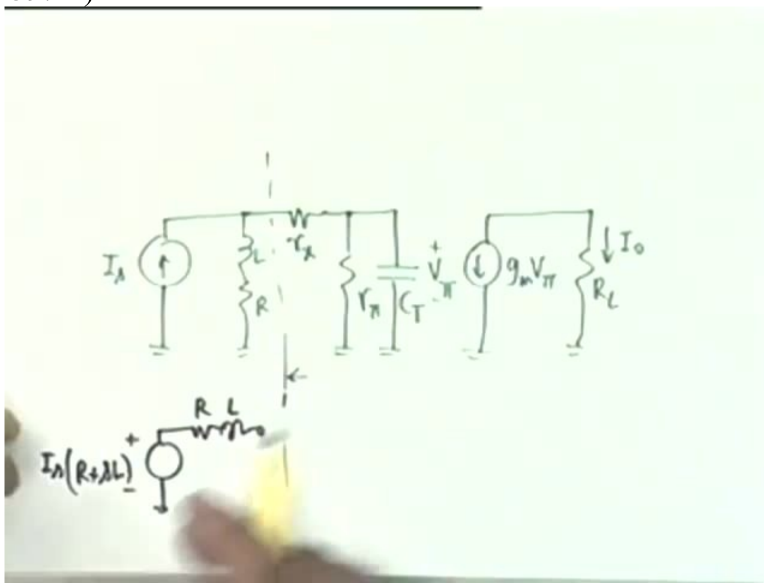

And the equivalent circuit is this. If you draw it carefully, you have an LR, then let us not ignore RX anymore because we are going to very high frequencies and at very high frequencies, the capacitor reactances may be comparable to RX. Wherever inconvenient however, let me warn you, we shall throw out RX, wherever inconvenient. It is possible to take care of it here, so we are saying fine, we will respect you, we will respect your position. And then you have the R pi and the capacitor CT.

We use the Miller effect to simplify the circuit. This voltage is V pi. Then we have GM Vpi, current source in series with RL and this is the output current I0. We wish to find out I0 by IS okay. We wish to to find out the transfer function, I0 by IS. In order to do that, we apply Thevenin's theorem to the left of this black line okay. And we get the voltage source as IS times R + SL all right and in series with R and L all right? Once we do that, then V pi can be obtained by inspection and the current I0 is equal to - GMV pi. Is the point clear? Okay.

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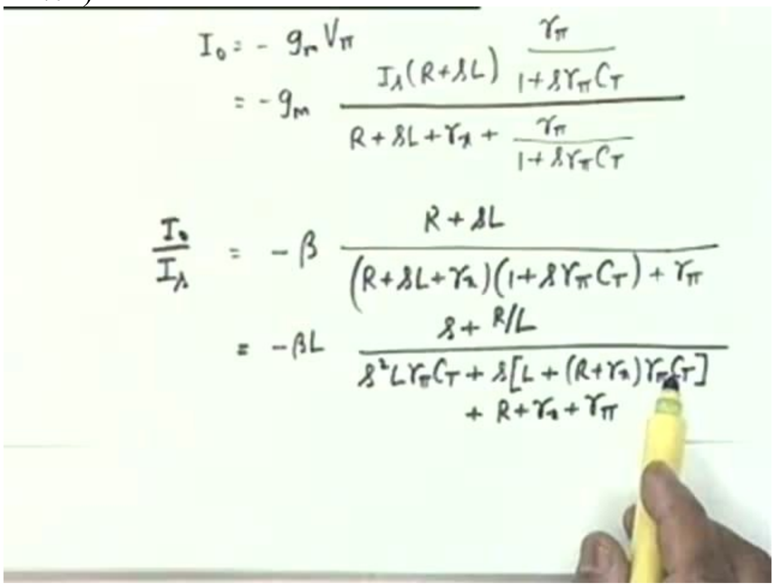

So if I do that, you see that I0 is equal to - GM V pi which is equal to - GM IS R + SL is the voltage source multiplied by the impedance R pi divided 1 + SR pi CT divided by the sum of the 3, that is R + SL + RX + R pi divided by 1 + S R pi CT. Have I written down correctly? I found out the current 1st, then multiplied by the impedance, that is right. So this as you can see, GM and R pi combine to make - beta okay.-beta and then I want to find out the transfer function I0 by IS.

So if I multiply by 1 + S R pi CT, then I get in the numerator, R + SL divided by in the denominator I get R + SL + RX 1 + SR pi CT + R pi. Is that okay? I have forgotten something?

Student: No.

Professor: No. Okay I can write this as, I will now write try to write it in a normalised fashion. I can write this as - beta L okay, I am taking L common S + R by L and in the denominator, let uscollect terms. S squared LR pi CT + S L + SL than R + RX multiplied by R pi CT okay, the coefficients of S + R + RX + R pi. Okay, I could have left the algebra but I am doing the algebra for a specific reason. Later on, I will not do this. I will simply say, it can be put in this form.

But what I want to do is, I want to put it as a polynomial in S in the numerator with the leading power 1 and a polynomial in S in the denominator with leading power,leading coefficient equal to unity.

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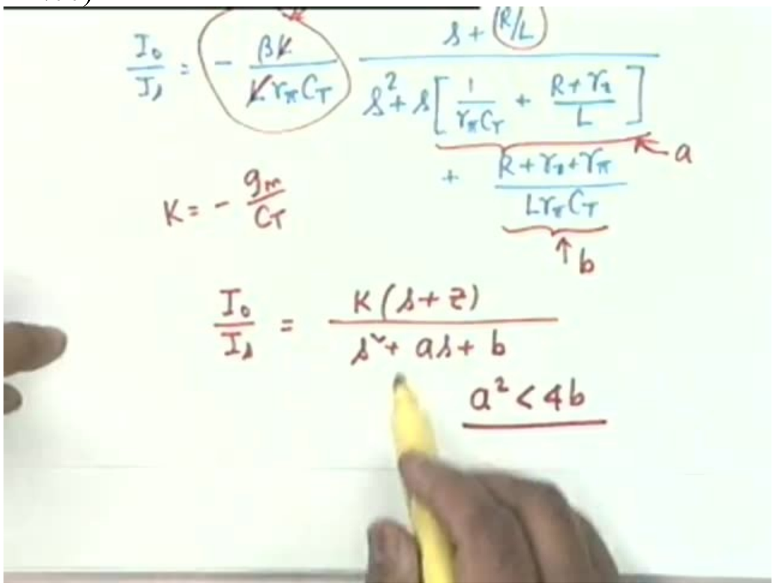

So what I get is I0 by IS equal to - beta L. I should take L R pi CT. Then I get S + R by L divided by S squared + S. Now what shall I get? 1 by R pi CT. I am dividing by LR pi CT + R + RX divided by L and R + RX + R pi divided by what? R pi CT all right? We shall call this as Z which means that the transfer function has a 0 at S equal to - Z. We shall call this as the coefficient A and we shall call this as the coefficient B and we shall call this assome value K. It is a negative value. L and L cancel. K is - beta divided by R pi CT. Essentially, you see K is - GM by CT. Agreed? K is - G, do you know what is GM by CT? We had given a name to this.

Student: Omega 1.

Professor: Omega T. That is correct, it is a gain bandwidth product, GM by CT. Okay. Now therefore what I get is I0 by IS equal to K S + Z divided by S square + AS + B. Okay? Usually, the inductance is such that A squared is less than 4B. What does that mean? It means that the poles are complex. The poles are complex. Can the zero the complex? No. This small Z is a real quantity and therefore S equal to - Z. That is where the 0 is. The poles are complex.

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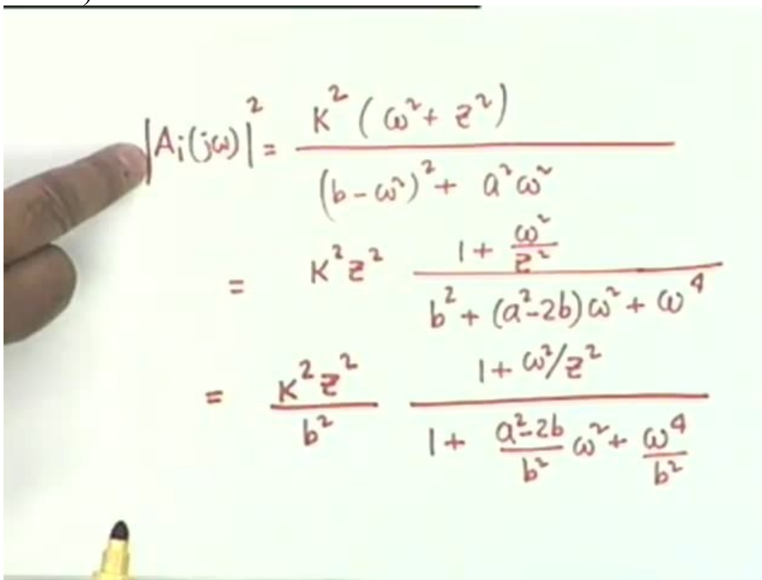

And if you write the transfer function, let us call the transfer function as AI J omega magnitude squared, I do such things by inspection, that is put S equal to J omega mentally and find out the magnitude squared. Obviously, I shall have K squaredomega squared + Z squared. All right. Okay, divided by B - omega squared whole squared +A squared omega squared. If I made a mistake, please point out. It is a magnitude squared. This I can write as K squared Z squared 1 + Omega squared by Z squared.

And the denominator I can write B squared + A squared - twice B omega squared agreed + omega to the 4. I am doing this very slowly because I am notgoing to do this again. Divided by B squared, I take B squared out. So that what I am doing now is to write the magnitude squared function as a ratio of polynomials in omega squared with the lowest power term, that is the constant term equal to?

Student: 1.

Professor: Unity. So I am writing this as 1 + omega squared by Z squared divided by 1 +A squared - 2B by B squared omega squared + omega to the 4th.

Student: Divided by B squared.

Professor: Divided by B squared. Obviously, the response of this transfer function will depend on the relative values of A and B. Right? AndA and B can be so selected that the response has a peaking, has a peak or it does not have a peak? We do not want a peek because our purpose is to wide band the amplifier. So we must avoid this. How can we avoid this?

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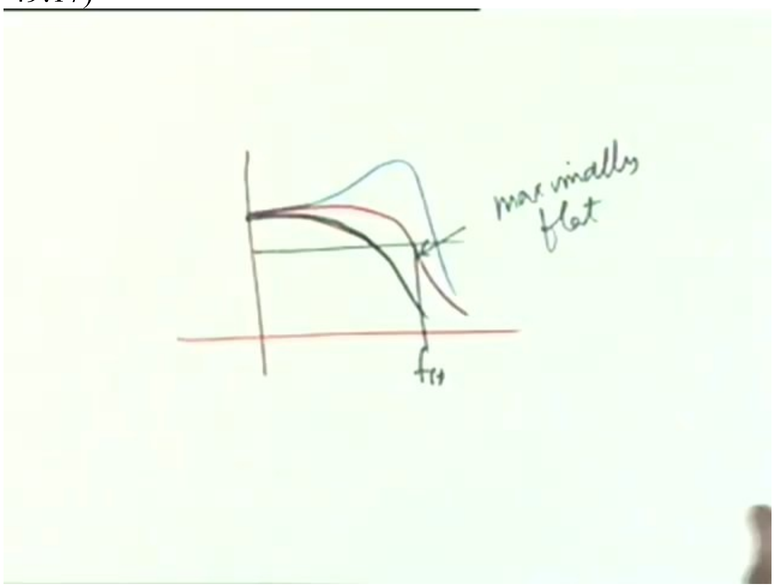

We must choose Aand B in such a manner, their relative values in such a manner that not only no peaking occurs but we want a response like this. With peaking, you can have a response like this. Without peaking, you can have a response like this. Okay. Now obviously what I should prefer is this response because this goes down. Itdoes not extend the high-frequency range. I can extend right up to some frequency FH like this. I can also extend beyond FH provided I allow for peaking. I do not want that. Okay.

So the red coloured response, I want it to be as flat as possible and the term for this is maximally flat. What is the criteria for flatness of a curve? Y equal to FX. What is the criterion for flatness? DY DX should be equal to?

Student: 0.

Professor: 0.It is either a maximum or a minimum. Now if Ican make DY DX equal to 0 and D2Y DX2 also equal to 0, obviously Ihave a second-order of flatness. Now it, I shall show next time that for the red curve for this particular situation, this is the best that we can do. We cannot get more than 2 flatnesses and this flatness I shall get I shall assume at omega equal to 0 okay. So I want flat here 1st order and also 2nd order and that with the red curve which will be called maximally flat or in short MFM, maximally flat magnitude. And this is what we shall explore tomorrow.