Analog Electronic Circuits

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Module No 01

Lecture 34: Sinusoidal Oscillators: An Example of Positive Feedback

This is the 34th lectureon sinusoidal oscillators: an example of positive feedback, We have so far discussed only negative feedback and we should see how positive feedback can be utilised, As I mentioned, the concept of feedback started with positive feedback, One wanted to increase the gain of an amplifier but then this is people soon found out that if you increase the gain of an amplifier, thecircuit becomes unstable, It tends to oscillate and then this principle of positive feedback which gives a tendency of oscillation was utilised to generate sinusoidal waveforms and this is the subject that we are discussing today, namely oscillators,

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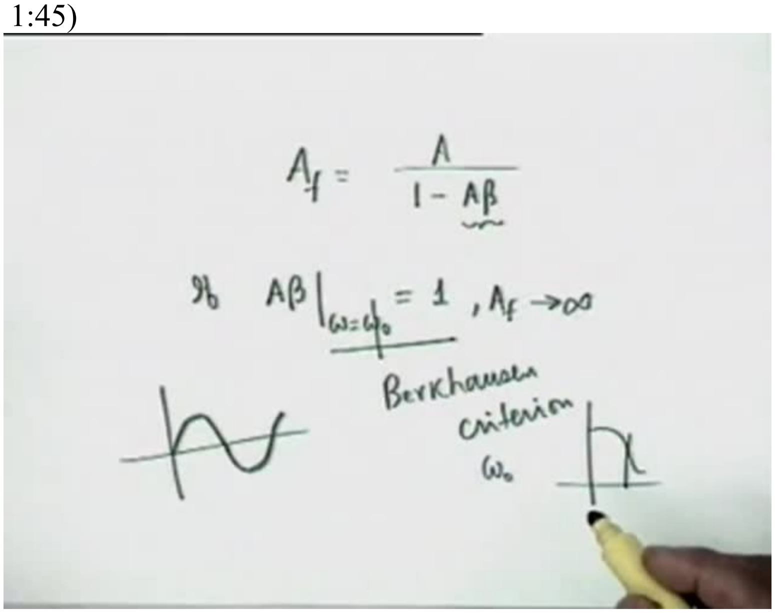

In the general feedback configuration, you saw that the feedback gain is given by AF equal to A divided by 1 - A beta, And if the feedback is negative, then this sign changes to + A beta, Now we are talking of positive feedback, So we want A beta to bepositive, AndI also mentioned that if A and beta are frequency dependent, if this quantity A beta depends on frequency, then at the frequency at some frequency omega equal to omega 0, if A beta is equal to 1, then AF tends to infinity and the amplifier shall require no input to produce an output which means that it oscillates, It oscillates at the frequency omega 0, It may so happenthat besides omega 0, there are other frequencies at which this condition is satisfied and all those frequencies shall be produced, And therefore you shall get a non-sinusoidal waveform which can be decomposed by a Fourier series into a sum of sinusoidal waveforms, Even if this condition is satisfied only at one frequency,it is logical to conclude that this would be a critical condition, It is a critical condition,

In fact what we want for starting of the oscillations is that A beta at omega equal to omega 0 should be slightly greater than unity so that the oscillations start and stabilise, How do they stabilise? Our analysis would be, so for negative feedback is based mostly on the linear equivalent circuit of the transistors and the active devices, Now as you know, the transistors are highly nonlinear devices, It is only for incremental operation that we can consider it to be a linear device, Now because of the nonlinearity, once the oscillations starts, there is nothing to stop the oscillation if the device was purely linear,

And therefore oscillation amplitude should continue to increase, It requires no input and therefore output is fed back to the input, amplitude will increase, Then again amplitude and it goes on, Ultimately, the power supply and the nonlinearity of the device restricts the oscillation amplitude, So it is non linearity which restricts the amplitude of oscillations and this nonlinearity is very difficult to analyse because it involves nonlinear differential equations with amplitude stabilising nonlinearity which cannot be modelled exactly and therefore, we cannot find out the amplitude from a linear analysis,

The other question is, who starts the oscillation? I mean, how does the device know that it has to oscillate? The gain becomes infinity, Now what happens at the input? Noise, Noise usually is white, that is it is a wideband noise, So from amongst these noise components, that particular frequency is selected at which A beta omega equal to omega 0 is equal to 1 which as you know we said this is a Barkhausencriterion, That is A beta I equal to 1 is theBarkhausen criterion for oscillation at the frequency omega 0,

Now this nonlinearity which stabilises the amplitude has another effect, A nonlinearity produces distortion of the sine wave, Any sine wave which is not pure sine but a distorted sine, maybe slightly clipped off at the top of slightly clipped off at the bottom, as you know, Fourier series says that this can be decomposed into a fundamental component and its harmonics, So any oscillation that you generate in the laboratory through such circuits will have harmonics in them and there are ways of reducing the harmonics which we shall go into a little later,

But obviously, common sense says that if you want oscillation at omega 0, you cannot generate subharmonics, that is you cannot generate omega 0 by 2, Its harmonics will be Fourier series says omega 0, 2 omega 0, 3 omega 0 and so on, And therefore commonsense says, if you have a low pass filter which passes omega 0 and cuts off others, obviously you can get a purer waveform, This is a very simple means, Okay? But let us look at the circuit 1st,then we shall look at this phenomenon,

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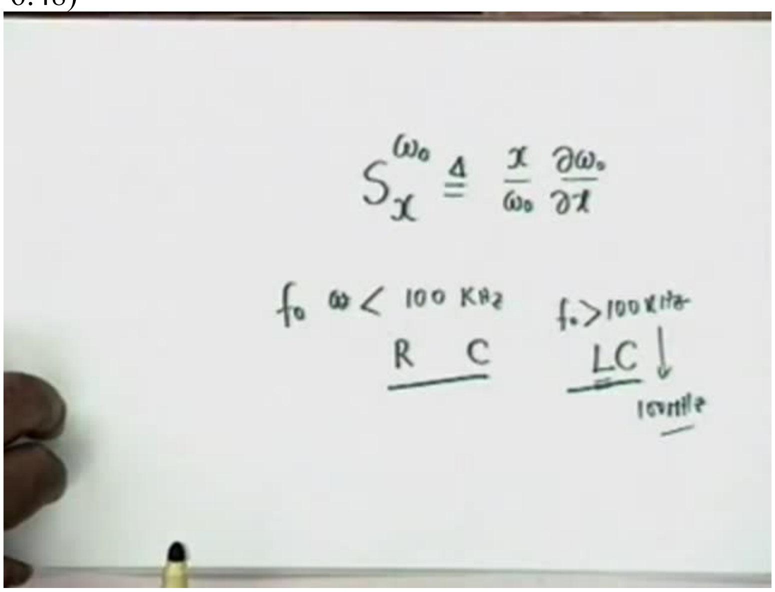

Now if you generate oscillations at omega 0 ok and suppose the temperature of the room changes, you know transistor parameters are heavily dependent on temperature and other environmental conditions and therefore omega 0 may change, Omega 0 is usually determined by a passive circuit, resistance, capacitance and inductance and all the 3 parameters, all these 3 passive circuit elements also change with environmental conditions, They change with ageing and therefore omega 0 may also change,

There can be drift in omega 0 as time proceeds, If you keep the circuit on for a very long time, the transistor heat dissipation may be enough to generate, to change the circuit elements, And therefore, a measure of frequency stability is used with the usual sensitivity parameter, Sensitivity of omega 0 with respect to X, I have already defined this, this will be equal to X by omega 0 partial of omega 0 with respect to X, Partial because X may be a multiplicity of parameter, It could be resistor, capacitor, inductor, temperature, humidity and many other conditions,

So this is a measure of frequency stability, Any filter can be characterised by this frequency stability criteria, Let us look at some specific circuits and then we shall go into consideration of this, Now if the oscillations are to be generated at low frequencies,up to about 100 kilohertz I must say F0, it is convenient to use resistors and capacitors as the frequency determining elements because inductor at low frequencies, not only we require very large values but inductors are difficult to make without losses,

You make an inductor, it always has a resistance associated with it, There are losses, In addition, inductors may have edi losses if you use a core okay and there are magnetic nonlinearity, You know the hysteresis curve and therefore inductors are not very favoured elements at low frequencies, And low frequency for RC oscillator, it goes right up to 100 kilohertz, On the other hand, if the frequency is beyond 100 kilohertz, then we usually use an LC oscillator because inductors are easy to make,

You can makeyou wind a couple of turns on a pencil and take the pencil off, that becomes an inductor, okay? These are the simple air core inductors at high frequencies,So and I must tell you that there is a limitation on inductors, It can go up to about 100 megahertz, Beyond 100 megahertz of course, the problem of it is difficult to make an inductor beyond 100 megahertz, which shall have sufficiently high Q okay? Because the inductor is small, the resistance is also small,and the losses take over,

Number 2, beyond let us say 1000 megahertz, 1 kilo megahertz okay,the conventional circuit, the concept of lump circuits, that loses its meaning, So we have to go to some other devices, We shall consider for this particular class, RC and LC oscillators only, You must also realise that in integrated circuits, we have no other alternative but to use RC oscillators because we cannot make an inductance in that small space, So even for high frequencies, we shall have to use RC oscillators or LC oscillators where L is simulated by RC elements and active devices.

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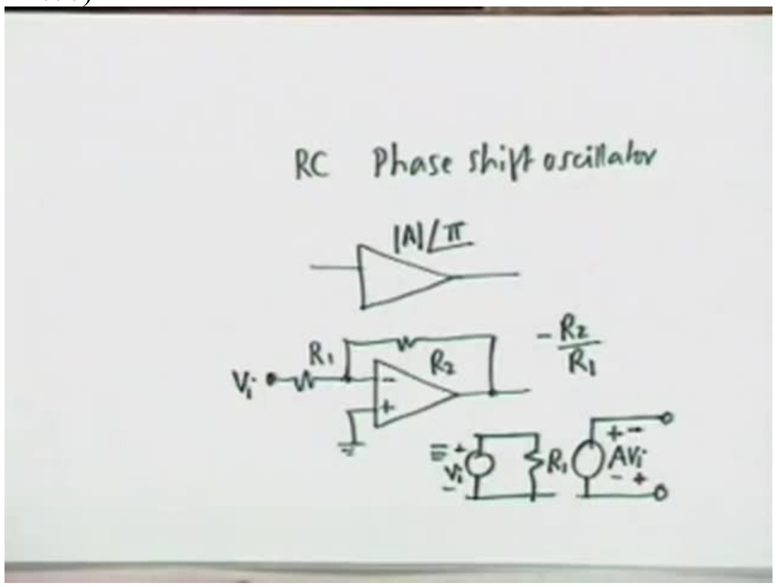

One of the popular RC oscillators is the so-called phase shift oscillator and the basic device that it uses is a positive feedback device in which you have an amplifier, you have a basic amplifier which is magnitude A angle 180, that is a phase inverting amplifier, Purely that is single BJT, an emitter amplifier is a phase inverting amplifier or a common source amplifier, FETis there or you can also use an op amp for example, You canalso use an op amp in which the input resistance is let us say R1 and this resistance is R2,

Then, the gain as you know because of the op amp, if the op amp is assumed to be nearly ideal, then the gain is - R2 divided by R1 and the input impedance is R1, So this can be modelled asif this voltage is VI, then you have VI, the input impedance is R1 and then AVI which is let me take this polarity, The output impedance is approximately 0 okay, Output impedance is approximately 0 andif the amplifier is ideal, and A is negative okay, A is negative or we could say AVI with this with the polarity reversed,

If I use negative here and positive here, then I use A as positive, Okay? I could also use a common, common source amplifier for example,

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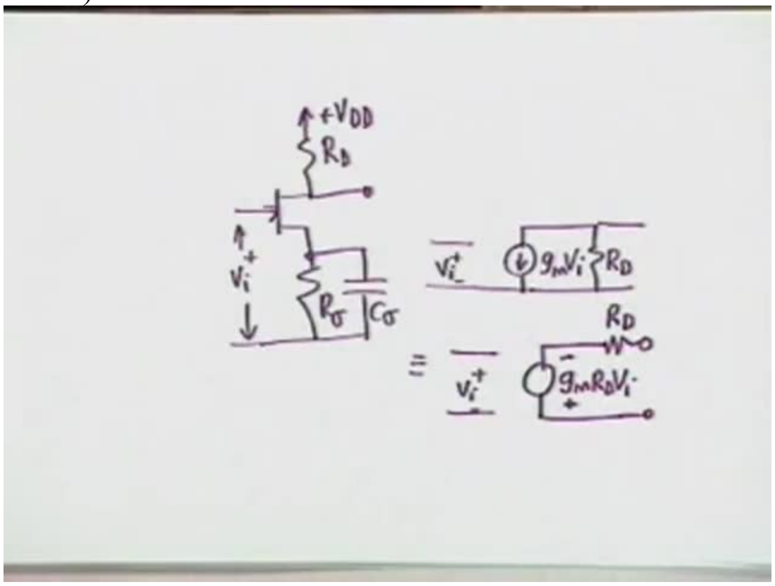

Let us use a JFET, R sub D,+ VDD and then R Sigma shunted by C Sigma, Depending on the type of the active device that you are using,the analysis shall be slightly different, You see, if we use this as thebasic amplifier, V sub I, then you know that the equivalent circuit is V sub I, the input impedance is 0 and then you have GM V sub I because this is shorted, GM VI, and in parallel with RD in parallel with the load resistance RD whose equivalent circuit is the following, VI if you convert this into a Thevenin equivalent, then you get GM RD VI with this polarity,-+,

So there is a phase shift of 180 degrees but here, you have an a output resistance R sub D, Okay? So the basic device can have an output resistance, can have an input resistance as you saw in the case of an op amp, the inverting op amp, inverting configuration, if it is a BJT amplifier, basic BJT amplifier, the output is taken here, It is a BJT, then both input resistance shall be there, input resistance and output resistance, Output resistance would be R sub C and input resistance should be approximately R pi, Beta + 1 RE will come if this is if the emitter is not shorted,

Butifthe emitter is not shorted, you know you get a reduction in gain because of negative feedback all right? So it is your choice,If you can do with RE unbypassed, go ahead, If you cannot, then you bypass this, okay,

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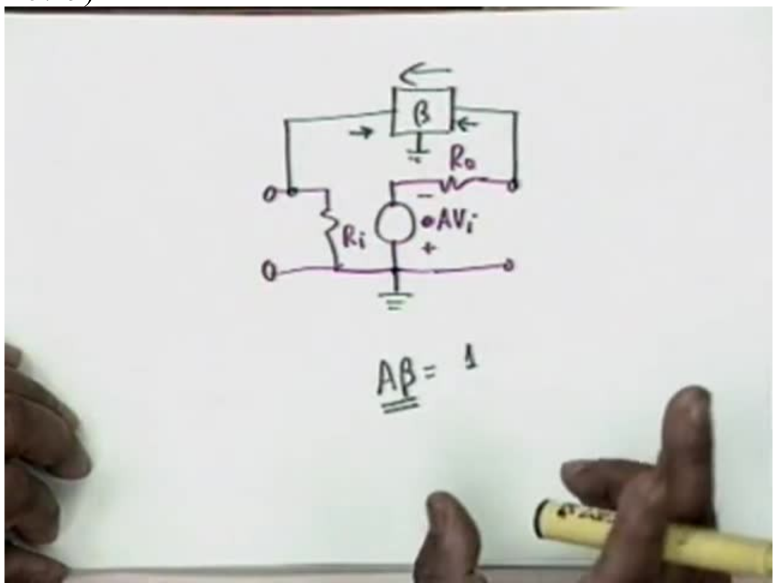

So theamplifier, the basic amplifier, the basic inverting amplifier in general shall have an input resistance RI, let us call this - A or I will simply say AVI with this polarity and a resistance R0, Okay? This is the basic, the A circuit ,The beta circuit is usually a passive circuit, Now since this is an inverting amplifier, let us connect this, since this is an inverting amplifier, we want to connect between this point and this point, a network, a beta network for positive feedback, Now if it is to be a positive feedback, obviously the beta network,well let us say this is grounded, this is grounded okay?

I have connected a beta network, Output is being fed back, We shall assume in the analysis that R0 is approximately 0, We shall assume that the basic network basic amplifier is an ideal one, that is RI tends to infinity and R0 tends to 0 orthat the input impedance of the beta network is much larger compared to R0 and that the output impedance of the beta network is much smaller compared to RI and therefore in an actual circuit, in an actual transistor circuit, you shall have to take care of these imperfections okay?

And the frequency of oscillation that we shall derive shall not be valid,This will be modified, frequency of oscillation and the condition for oscillation, they have to be modified in accordance with the imperfections of the basic amplifier okay? Now in the RC phase shift oscillator, the beta network is one which produces which has to produce a 180 degree phase shift because we want

A beta to be equal to 1, The angle of A beta should be equal to 0 or 360 or multiples of 2 pi okay, So the beta network must produce a phase shift of 180 degrees,

Now since the beta network is passive, it shall also introduce an attenuation, That is, the gain of the beta network in this direction shall be less than 1 which is the purposewhich is being compensated by the basic amplifier, That is, the product of A beta should be equal to 1, So if beta is let us say 1 by 29, then A has to be 29 to be able to generate oscillations,

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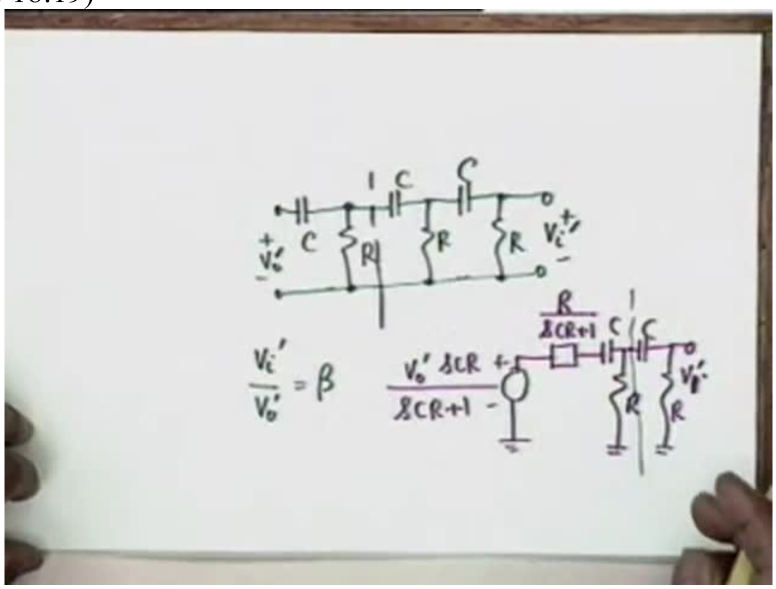

And the phase shift network that is usually used is the following, I am starting from the output end of the amplifier, So this will be my V0 okay, Then CR, CR and CR, a 3 section phase shift network, Question, Why are 3 sections needed? I want to produce 180, A single section RC network can produce at the most 90, 2 infections can produce at the most 180 but that happens at very high frequencies okay or very low frequency, that is at DC or 180, this is the limit, And therefore, to produce a phase shift of 180 degree in between 0 and infinite frequency, we require 3 sections,

We cannot do with less than 3 sections, And this is the simplest network that is used, Since I am connecting this to the input, the input of the amplifier, the output of this CR network should be VI, Agreed? This this is the condition for oscillations okay? Or if you so desire, let us decouple them, Let us call them V0 prime by VI prime, So we have to find out for this passive network, the transfer function VI prime by V0 prime, This will be my beta and I have to find out the condition under which beta has a phase shift of 180 degrees,

The analysis of this network can be done by various ways butif you have beenfaithful to (()) (19:58) and his 204, you should now know that there are simple techniques of analysis, You do not have to write loop equations and node equations, Youcan take Thevenin's theorem, For example,if I apply Thevenin's theorem here, then I get V0 prime SCR divided by SCR + 1, D is missing, This is the voltage source and then we have an impedance which is yes, R divided by SCR + 1,

You should know this, R and C in parallel produces this and that comes in series with C, one R then another C and another R, This is V0 prime, I am sorry VI prime okay? Then the next step what you will do is apply Thevenin's theorem here, there is no chance of making a mistakeunless you are very keen on making a mistake, On the other hand, the loop analysis, node analysis, you missorientation or you miss a term, then youget into problems,

Also you have to invert matrices, It would be a 3 by 3 matrix inversion, Nothing is needed here, You cando it almost by inspection, If you continue this up to this endI will skip this analysis,

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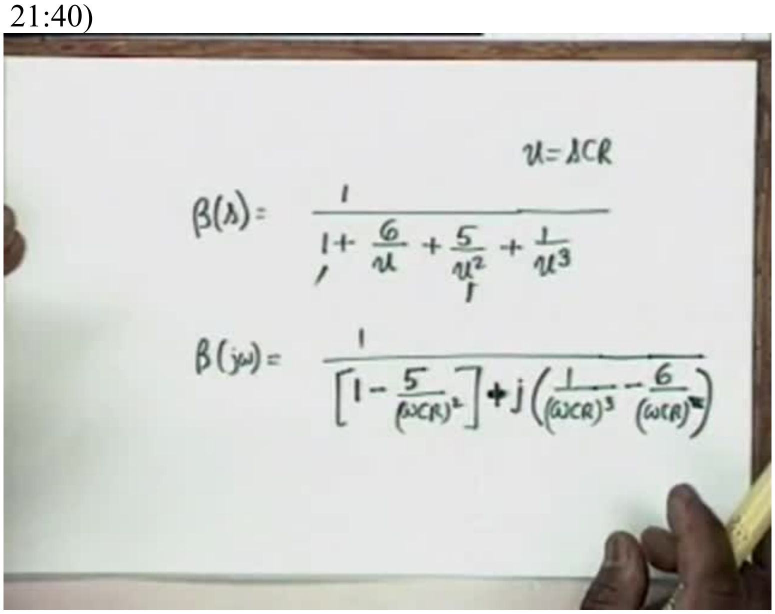

You get the transfer function beta of S, let us do in terms of the Laplace transform variable, The result becomes 1 divided by 1 +, you can verify this 6 divided by U, well I do not want to write

SCR again and again, U I have used for SCR okay? + 5 by U square + 1 over U cubed,This is the result that you get, I have put it in a particular form for convenience of analysis, What is the, does this check? Is this result correct oris there an obvious defect in this result? See at DC, what is the transmission at DC for this network? 0,

So if U equal to 0, you see that denominator goes to infinity and thereforea DC response is satisfied, At U equal to infinity, the denominator is simply 1, So the transfer function is 1, At U equal to infinity, all the Cs act as short, so transfer function is 1, You must do this checkingI mean automatically and spontaneously, It does not require any effort, Okay, Now since I am interested in generating pure sinusoidal oscillations, I should look at beta of J omega and you see that this is 1 - 5 by omega CR square,

I have taken this term and this term, I put U equal to J omega SCR, then +…

Student: J

Professor: Yes?

Student: J,

Student: J,

Professor: J 1 by omega CR whole cubed,+ J or - J?

Student:- J,

Professor:- J okay,This will be -,

Student:+,

Student:+,

Student: 1 by J,

Student:+,

Professor: okay,

Student: Sir -,

Professor:-,

Student: 1 upon omega, 6 upon omega CR,

Professor: 6 upon omega CR whole square,

Student: Why square?

Student: No square, Sir,

Professor: pardon me?

Student: no square,

Professor: No square, okay, Let us not make a mistake, Now if you look at this expression, obviously if the phase is 180 degrees, then the imaginary term should be 0, Phase is 180 degrees means that beta will be a real quantity and a negative quantity, That is all,

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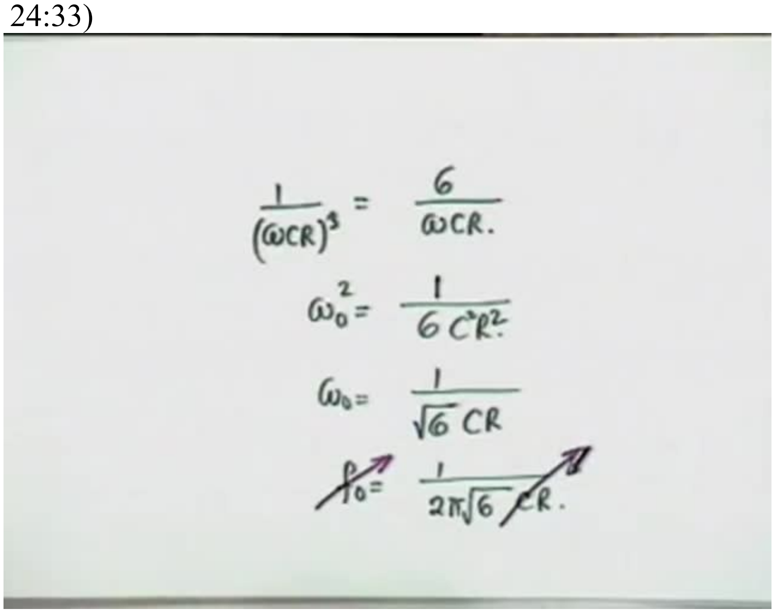

And therefore for 180 degrees phase shift, we require 1 by omega CR whole cubed should be equal to 6 divided by omega CR which means that this is satisfied at omega 0 equals to omega 0 squared is equal to…

Student: 1 by 6CR,

Professor: 1 by 6 CR which means that omega 0 would be equal to 1 over root 6 CR or F0 a frequency of oscillation would be 2 pi root 6 CR,

Student: 6,

Student: C Square R square,2^{nd} equation,

Student:C Square R square

Professor:C Squared R squared, of course, Okay, So if at all the circuit oscillates, this will be the frequency of oscillation, As you see, the frequency of oscillations are determined by C and R, The the circuit, the passive circuit elements, the beta circuit elements okay?

You also see one difficulty that if F0 is to be varied, if it is to be a variable frequency oscillator, then either all the Cs have to be varied simultaneously, Simultaneously because this depends on C and all Cs were equal, assumed to be equal, Or all Rs have to be varied simultaneously, And the usualinstrument that you get in the laboratory, RC decade oscillator, they are phase shift oscillators in which the Cs are varied simultaneously, The 3 capacitors are ganged together so that one dial variation varies all the 3 Cs,

These are usually air capacitors, large air capacitors mounted on the same shaft and if you rotate the shaft, all the 3 capacitors vary identically and simultaneously, This requires very huge mechanical precision and that is that goes into the cost of the equipment, The components themselves are not costly but this mechanical precision, Nevertheless, such oscillators are very popular and they are available the laboratory,

Student: Sir?

Professor: Yes?

Student: Sir but even if we have different Cs, very close, even then we can get oscillations,

Professor: Yes, you can but it is not according to a verypleasant, I mean, you do not know how much we varied, You vary one capacitor, you do not know what is the rule for variation, You have to analyse again, Now in a laboratory, we just want vary a dial, 1 kilohertz, 1,1, that is it, And this is the simplest way to do it,

Student: Sir, we can calculate it using (())(27:09)

Professor: Of course, then you will not buy the instrument which is so inconvenient, You have to calibrate every time and so on, Nevertheless, this is the usual thing, Of course, resistors can also be varied, 3potentiometres can be put on the same shaft and varied simultaneously but C variation is preferred is preferred becauseit requires less mechanical precision than resistor, Also resistors as you know, there is a contact problem, There is apotentiometre, in a capacitor, you have the interdigital types, It goes in or out,

On the other hand, a potentiometer, there is a contact, If you go on varying this, there is an wear and tear, Whereas in a capacitor, this wear not tear is not there, So capacitors are preferred,

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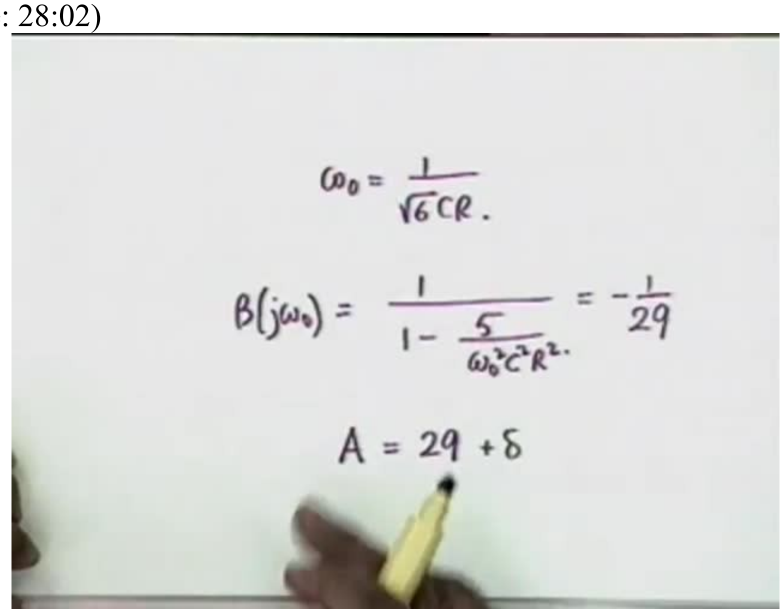

However, if omega 0 is equal to 1 by root 6 CR, then you go back to the transfer function, The imaginary term is 0, so you get 1 - 5 divided by omega 0 square C Square R square, And as you can see, omega 0 square C Square R square is 1 by 6 and therefore this becomes - 1 over 29, And that is what gives rise to the fact that the gain required for the basic amplifier A has to be 29 and then as I said,to start the oscillation, 29 does not suffice, You have to make it slightly greater than 29 to start the oscillation, Otherwise, it would be off and on, off and on,It may oscillate, it may not oscillate because it is sitting on the borderline okay? You have to make it slightly greater at the cost of a slight distortion in the generated waveform because A equal to 29 is theBarkhausen criterion, A equal to 29 satisfies the Barkhausen criterion exactly, That means if A equal to 29, you will generate omega 0, If A equal to 29 + delta, you might also generate harmonics because of the nonlinearity that comes into effect but this nonlinearity, these harmonics can be taken care of other ways,

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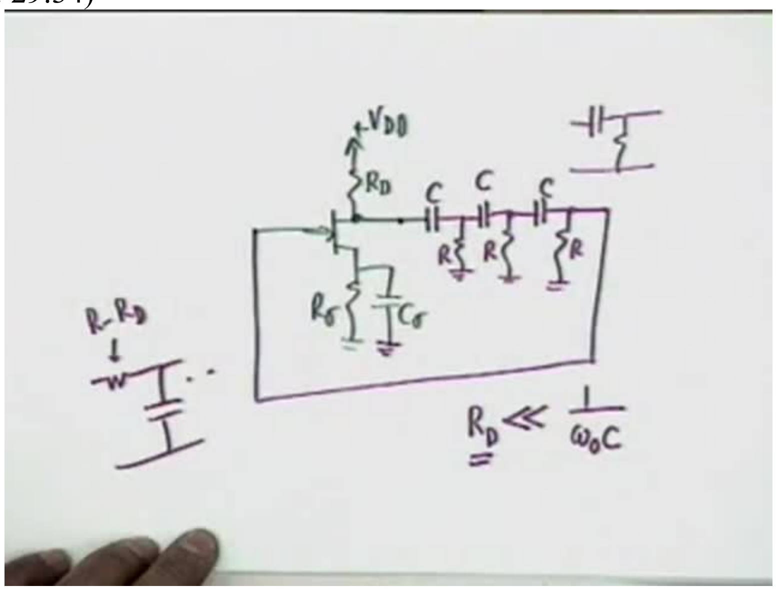

So if I drawn anoscillator circuit, if I now draw an oscillator circuit, let us say using an FET, we have R sub D, R Sigma and C Sigma, this is + VDD, this is the basic circuit, Then we draw, we bring in the feedback circuit, CR, CR, no further coupling capacitor is needed because this capacitor itself serves the job, CR and then another CR and this now has to be taken to the input, This is the circuit of an FETRC phase shift oscillator, 180 degrees phase shift could also be produced if the Cs and Rs are interchanged, If capital R, one would, this would be a leading phase shift or lagging phase shift?

Student: Lagging,

Professor: No, From here to here, would it be a leading or lagging phase shift?

Student: Sir, leading,

Professor: Leading,

Student: Sir how?

Professor: Oh, think a simple CR, The phase shift is at leading or lagging?

Student: Leading,

Professor: Leading, The output leads the input but 180 degrees is 180 degrees, Whether it is leading or lagging, it comes back to the same negative axis okay, So I could even take a simple RC,Rs and Cs could be interchanged, But you see the problem, If I interchange, I will require an extra blocking capacitor, extra coupling capacitor, That is correct, So this is preferred, But then, there is a problem with this one also, Life is always a mixture of pain and pleasure okay? Thecost that you theprice that you pay is that the output impedance of theFET is RD and therefore at frequency omega 0, RD must be much less compared to 1 by omega 0C,

C comes in series with RD, If you recall the equivalent circuit, equivalent circuit is GM RD VI, that is the with negative polarity in series with an RD and therefore RD, unless it is ensured that RD is much less than 1 by omega 0 C, the frequency of oscillation shall be affected, The gain of the circuit shall also be affected, This transfer function, beautiful transfer function that we got in terms of U shall no longer be valid, RD shall show its (())(32:21) and you can make an analysis, On the other hand, if I use a resistance here, if I use RC, then this resistance can absorb RD,

That means, the 1st resistance, the 1st resistance, instead of using R, I will use R - RD,Do you understand this? Using that coupling capacitor, this is the price that you pay but RD can be absorbed in R, Is the point clear?

Student: No sir,

Professor: No? Okay,

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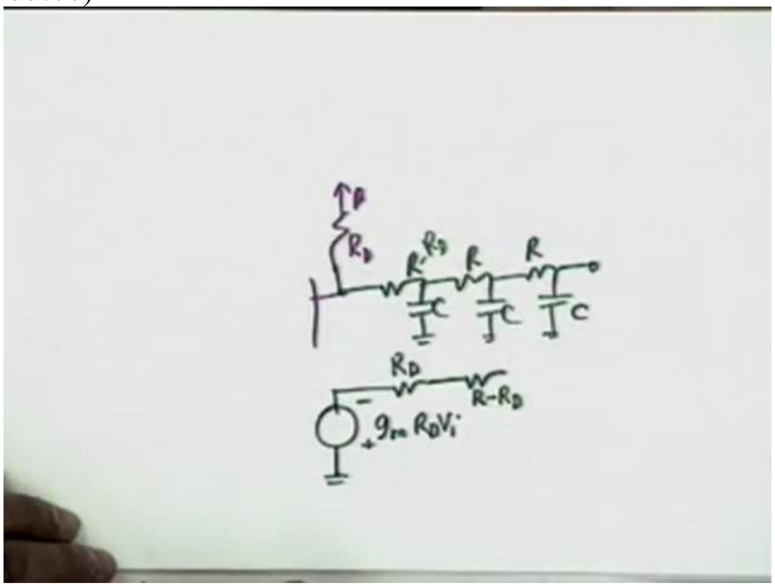

SupposeI have an oscillator like this, RD, I will not draw the rest of the circuit,And then, I have RC, RC, RC okay? Suppose I produce 180 degrees phase shift with this, then obviously, the equivalent circuit would be -+ GM RD VI, whatever that is, in series with RD and then I have R, okay? I want this to be R, So instead of R, I shall use R - RD,Then the formula shall remain valid, All the 3 Rs shall be identical, all the 3 Cs shall be identical,

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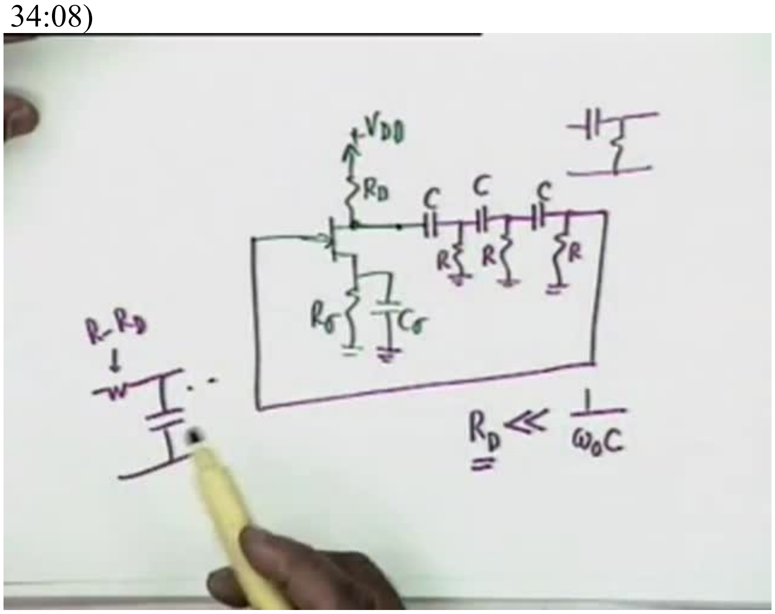

Now obviouslyif it is an FET common source amplifier, then this R is not disturbed, This R is not disturbed, It is not shunted by anything, Agreed?

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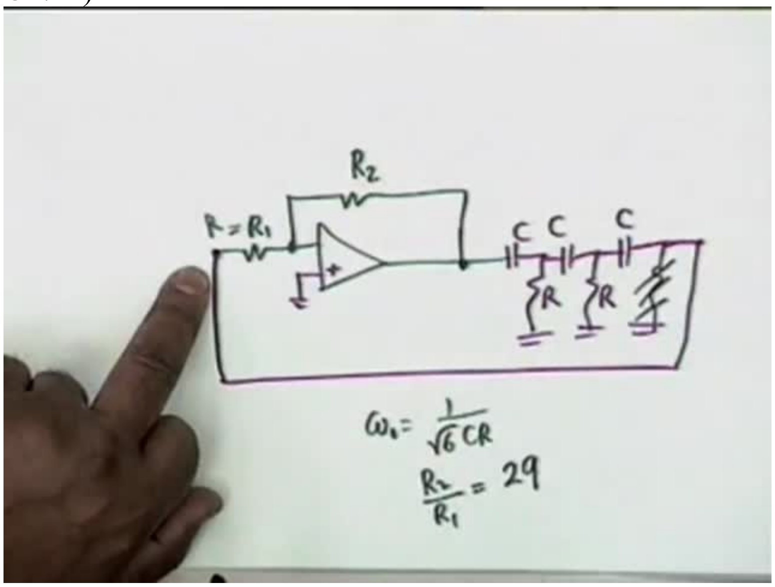

On the other hand, if you had used an op amp, an inverting op amp, R, did I use R2 or R1?

Student: R2,

Professor: R2 and R1, okay, Then you see a CR network for example here okay? Let let us use a CR network,This is grounded, CR, CR and CR, Okay? This I am going to connect here, The input resistance, this is my VI, the input point, Input resistance of op amp is R1 and therefore R1 shall come in parallel with R, Is not that right? Again, the frequency of oscillation and the condition for oscillation will change because one of the resistors has become different, Okay? Can you suggest a remedy? Instead of this, I simply do not use this and I use R1 equal to R,

Do not I get the same result? Because this point is virtual ground, I get the same result, So in anop amp, is easy to take care and the frequency of oscillations shall still be given by 1 by root 6 CR and R2 by R1 will now be required to be 29, 1 by 29,- 1 by 29 or + 1 by 29? No, it has to be exactly equal to 29, Thegain of the stage has to be - 1 by 29, So R2 by R1 must be 29, Is the point clear?

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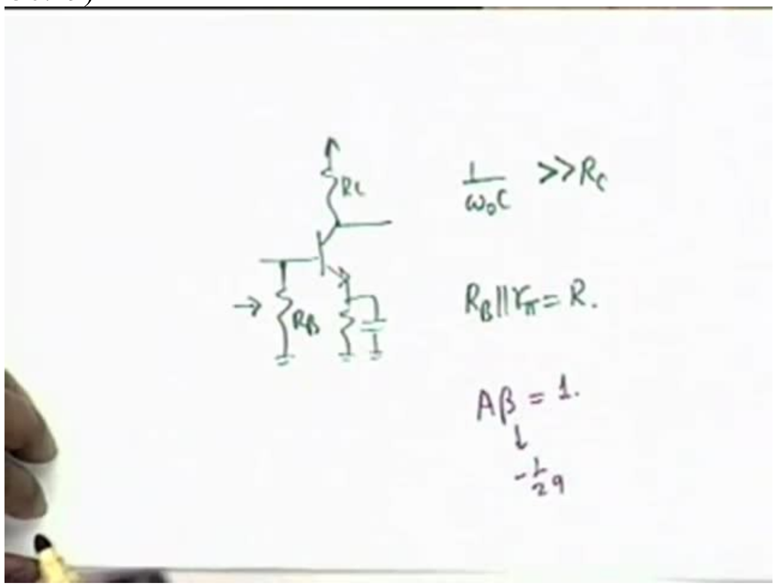

On the other hand, if Ihave a bjt, I have a problem, Okay? I have the biasing resistor, equivalent biasing resistor, R sub D, And from here, I connect the RC or CR circuit, Then you see, RC affects the frequency of oscillation and the input impedance which is the parallel combination of RB and R pi, also affects the frequency of oscillation, You might say that I will make RB parallel R pi equal to my R, I can do that, Then the frequency of oscillation would still be given by that simple formula provided 1 by omega 0C you have made…

Student: Much greater than…

Professor: Much greater than R sub C, Otherwise, R sub C will show in the formula, Okay? It would be instructed not to make any of these adjustments and find out how the frequency of oscillation and the gain requirement changes okay?

Student: (())(37:28)

Professor: Yes?

Student: Sir, when I have found out beta to be - 1 by 29 and I want A beta to be 1…

Professor: Right, soA has to be - 29,

Student:- 29,

Professor: Yes, butwe assume A beta equal to 1, Beta is - 1 by 29, Yes, A has to be - 29, A is - R2 by R1 and R2 by R1 has to be 29,

Student: Sir, can you show the previous sheet?

Professor: Sure,

Student:(())(37:58) R before the differential amplifier,

Professor: Right,

Student: How is it like, how is (())(38:02) internal resistance?

Professor: Oh, we assume the op amp to be ideal,

Student: RICM is 0,

Professor: Yes, RICM is 0, RICM is infinity, Not 0, then it will be shorted, But this point is virtual ground and what we wanted is an R going to ground and therefore this is a very simple and neat way of designing an RC phase shift oscillator, Op amp is the best choice,

Student: Sir?

Professor: Yes?

Student: Sir, in previous example, you had put RD in series with R Sir,

Professor: Because it does come in series,

Student: Sir, does not it come in parallel?

Professor: No, I have converted this to a voltage source,

Student: Okay,

Professor: My gain is now - GM RD okay? Now let me also mention that 29 is not a very sacred figure, 29 is not a very sacred figure,

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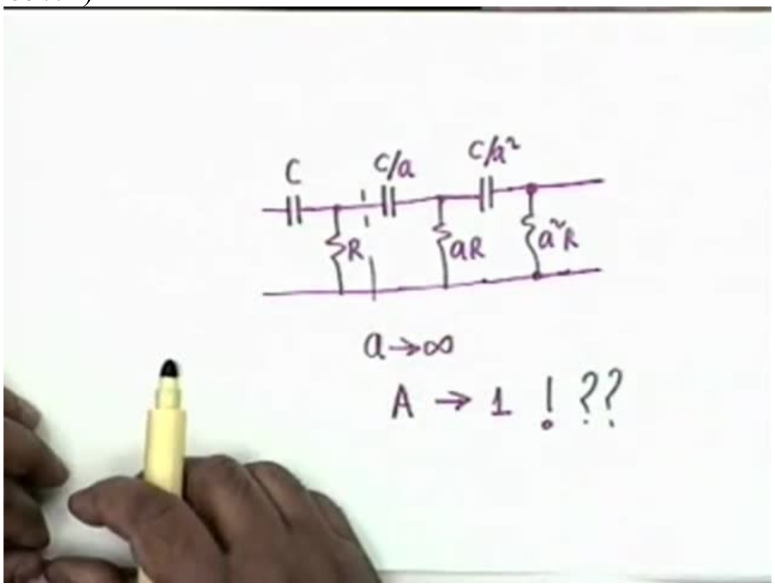

If you taper the circuit, the phase shift circuit like this, CR, 1st one, then to make the 2nd one a C by a and aR so that the time constants are the same but you see the loading of the 1st stage by the 2nd stage would now be less, And therefore this will make less attenuation, And if we go to the 3rd one, C by a square and a squared R, If I do this tapering, then the gain requirement can be increased and it is instructed to do this analysis and show that if a can tend to infinity, if a is very large, then the gain requirement, capital A, can you guess what the gain requirement would be? I am putting with a big question mark,You verify this,

That with increasing A , the gain requirement increases and if A tends to infinity, obviouslyA cannot be infinity because then this resistance is not there, this capacitance is not there, Is not that right? So there is no feedback, But A can be between between 1 and infinity and you can see in fact, if A is 10, capital A, the gain requirement is 1 point, it is less than 2, I am claiming this but you verify this,

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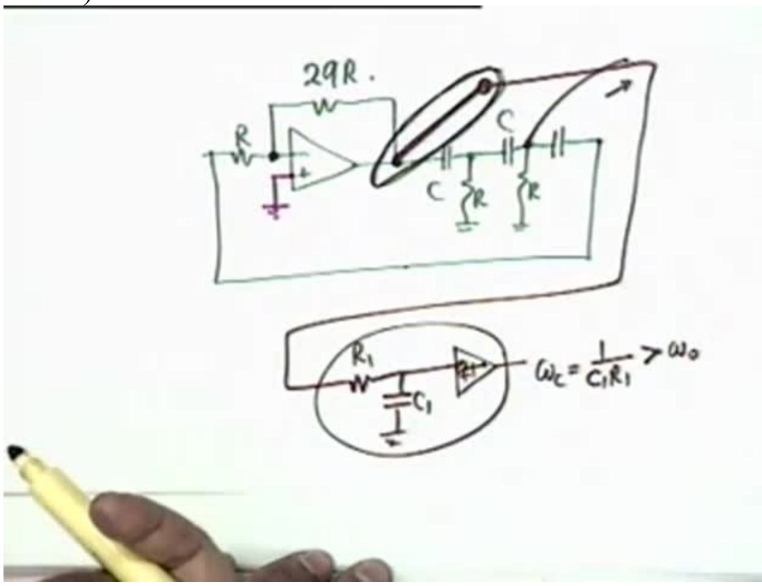

The next question is suppose I have designed an op amp based, this is R, op amp based RC phase shift oscillator, how much should this be now? How much should this be?

Student:(41:18)

Professor:Oh, this is very easy,

Student: 29,

Professor: 29 times R because you want a gain of 29,- 29 okay, Then you have CR, CR and finally to have a C only which connects it to this, Okay? Where do you take the output? Where do you take the output?

Student: At the…

Professor: At the? Say,

Student: At the end of 29 R,

Professor: This point?

Student: Yes sir.

Student: Yes sir.

Student: Sir it is across R,

Professor: It is one,One choice, the other is?

Student: Across R,

Professor: Which R? This R?

Student: Yes,

Professor: Across this?

Student: Beginning of 29 R,

Professor: Then you have no grounding, nophysical ground,

Student: End of that R,

Student: Beginning of

Professor: Here?

Student: End of that R and ground,

Professor: Here?

Student: Yes sir,

Student: Yes sir,

Student: Yes sir,

Professor: Here? Oh no, that is a Himalayan mistake, This point, potential is 0, You can take the output anywhere because throughout the except this point and except the ground because everywhere there are sinusoidal oscillations, All signals in this circuit shall be at the sinusoidal at the frequency Omega 0 but this choice is a gem of a choice, I should have used a different colour, This choice, Why?

Because anywhere else you take the output, suppose I take the output here, I am going to connect it to some device, I am going to use this oscillator and that will create a loading of this resistance, which emits the frequency of oscillation itself shall change, On the other hand, if I take the output from here, the output impedance of the op amp is approximately 0 and therefore there is no loading, You can taketo any load except when it is a short circuit, You cannot take it to a short circuit obviously because you cannot short this, Then nothing goes,

All right, so this is the point at which you should take the output, Next, even if you take the output here okay, let us bring the output here, as I said, there will always be some amount of harmonic distortion, That is there would be higher frequencies, So what you can do is, one of the simple ways of reducing distortion or reducing the harmonic content is use a low pass filter, And you could simply use a low pass filter like this, simple RC circuit such that omega C, what is the cut-off frequency of this if this is R1 and C1? Omega C is the 3 dB cut-off, 1 over ?

Student: R Sub C

Professor: R1C1, not RC, Do not confuse with this element, 1 over C1, This has to be, where should you put the cut-off frequency? Slightly greater than omega not,such that at 2 omega not, the attenuation is let us say down by at least 20 dB, that should do it, As it is, the proportion of harmonics to fundamental will be very small, You reduce it further, another 20 dB, 20 dB means attenuation by what factor? Pardon me,

Student: 10

Professor: 10, attenuation by a factor of 10, And multiplication by a factor of 0,1, So it should bring it down, This If you wantwell one of the problems is, now you are going to take your output here, right? Andany loading of this is going to change your cut-off frequency,You see the problem, So what should you do? You should use a buffer here, You should use a unity gain amplifier, If you use a unity gain amplifier here + 1 whose output impedance is 0, obviously there is no loading on this, But if you are using an amplifier you are using a buffer, a unity gain buffer, another op amp, why do not you usethis circuit?

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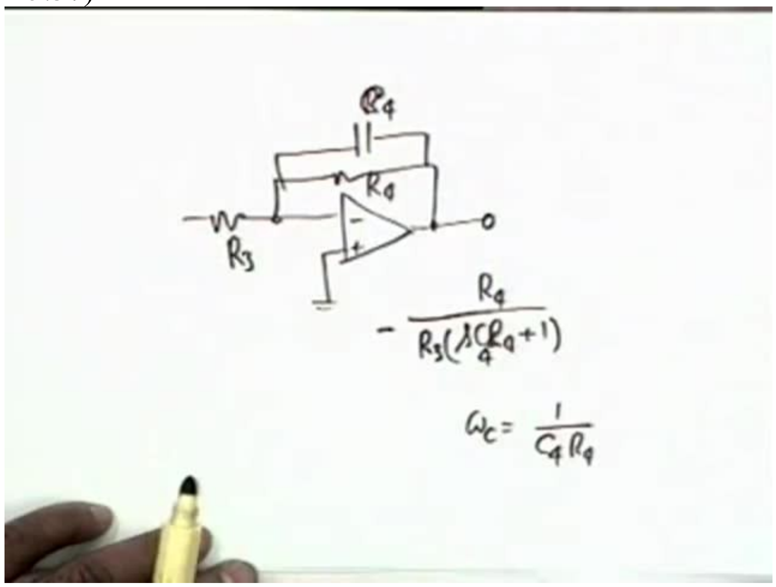

From the output of the oscillator, you use, let us say R4, I beg your pardon, C4, R4, R3, Do you know that this is a low pass filter? No? Very simple to see, R4 divided by SC R4 + 1, this is the impedance of this, divided by R3, So the gain of the circuit would be this,Obviously, this is a low pass filter with a cut-off at, what is omega C for this? 1 over C4R4, These are very simple things to do, You see, from the output of the last op amp, you apply this filter and then take your output here, This is usually incorporated inside the oscillator circuit,

And if you want better rejection, then use a 2nd order filter, Instead of 1st order, use a 2nd order filter, Or use a higher order one, much higher order one if you are very fussy if you are very fussy about the waveform, the distortion content of the waveform, Okay this is about the phase shift oscillator, As I said, even if you make even if you couple a low pass filter, to reduce the harmonic content, who stabilises the amplitude? How do you stabilise the amplitude? Anything changes, temperature changes for example, the amplitude will either rise or fall,

On the other handin the laboratory, if you are making let us say if you are testing a communication equipment, you want the input or testing the frequency response of an amplifier let us say, you are going to vary the frequency, You do not want the input voltage to change okay? You only want to monitor the output voltage, You might like to record it ona recorder, the frequency response, Then the input voltage should be fixed, You plot output vs frequency, Well, you can say even if the input changes, I will take the ratio fine, But then you require a calculation,You do not require it if the input voltage that is the oscillator output voltage is a constant, How do you stabilise the amplitude? There are amplitude stabilising circuitswhich use nonlinear elements like temperature-sensitive resistors, negative temperature coefficient or positive temperature coefficient or zenerXena diodes or ordinary diodes which are very temperature sensitive, The main problem instabilisation of amplitude, the main problem in stabilising the amplitude of an oscillator is temperature, heat, The very circuit generates heat, rather circuits in the neighbourhood generates heat, The temperature changes from season to season and therefore temperature stabilisation is one of theone of the crucial that has to be done with an oscillator,

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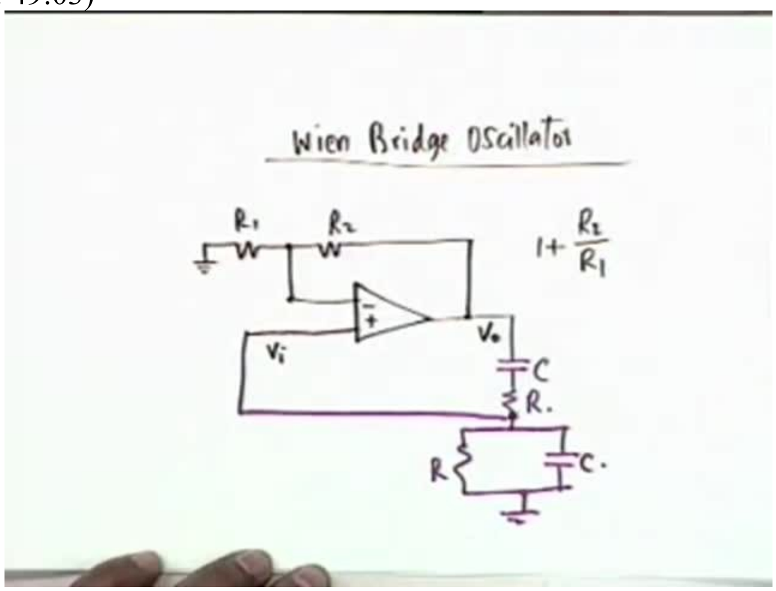

The 2nd kind of RC oscillator is called the so-called Wein-Bridge oscillator, The Wein-Bridge oscillatorthe simplest circuit using an op amp is this, I will draw the circuit and then carry on the analysis later, There is a resistance, This is alsobasically the Wein-Bridge oscillator requires again a positive gain amplifier, instead of a negative gain amplifier, If the gain of the basic amplifier is positive, wellthis is obtained by this, R2, R1 and this is grounded, And the input is applied here okay,

Obviously between this point and this point, the gain is 1 + R2 by R1 which is positive, That means, the phase shift is 0, Therefore the beta network that you want should produce a phase shift of 0 instead of 180, You can say, if we can do it 180, why should we bother about 0?

Because it uses less number of components, that is the circuit that is used is a series RC and then a shunt RC,And the output is taken from here and applied here, This is the so-called Wein-Bridge oscillator,

Why it is called a Wein-Bridge, we shall see later but you should realise that this circuit is capable of producing a 0 phase shift,A 0 phase shift obviously can also be produced by a simple potential divider, Why do not we use that?

Student: (())(51:00)

Professor: No,

Student: Frequency,

Professor: Frequency, Who will determine the frequency? A potential divider is insensitive to frequency, If the gain is 0,1, it will be 0,1 at 0, it will be 0,1 at infinite frequency also, So who will determine the oscillation frequency? That does not mean that it will not oscillate, It will oscillate, It will have get start either at + power supply or the negative supply, We do not want that, We do not want to generate sinusoidal oscillations, So the beta network has to be a frequency sensitive network, All right? How does itproduce a 0 phase shift? Let us see qualitatively. We will make the analysis later, Qualitatively, can you see what kind of a circuit is this?

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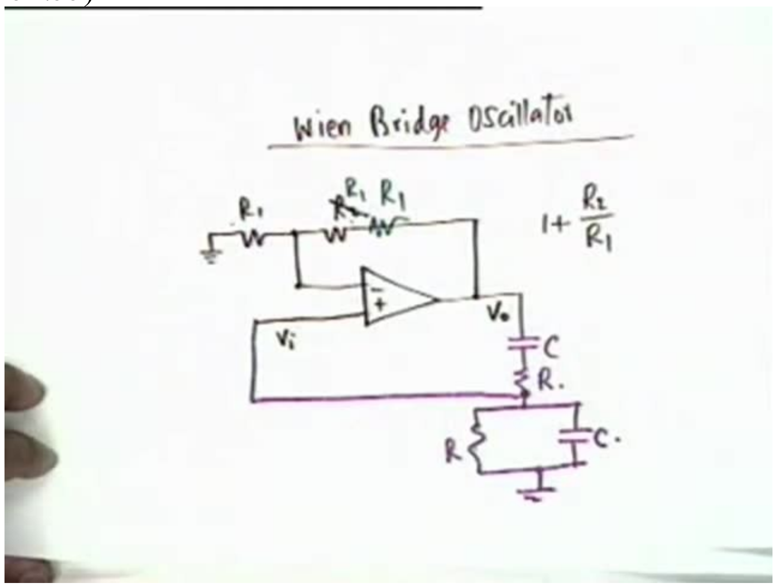

We have a CR, R and C, what kind of a circuit is this? If this is my input V1 and this is my V in and this is my output, what kind of a circuit is this? Does it favour low frequencies? Is it a low pass filter? No, At DC, obviously the toss mission is 0,Does it favour high frequencies? No, At infinite frequency, this is a short, And therefore this is a, it could also be band stop, No, it is a band pass, Somewhere in between, somewhere in between it produces a maximum like this, Start from 0, goes to 0 at infinity, Somewhere in between, it produces a maximum,

And one can show by simple analysis that this maximum occurs at the frequency 1 by CR and that at this frequency, V out by V in at Omega 0 is equal to one third, You see the advantage of this oscillator, What is the advantage? That the gain required is only 3 instead of 29,So the resistor spread, what is the spread that I want here if I want a gain of 3? Only 2, R2 by R1 has to be equal to 2, So the resistor spread is 2, There is no reason why we cannot make these resistors identical to these 2, We can do that, So the resistor spread is only 2, Not quite, Resistor spread is only 1, Tell me how, Common sense, I will make R2 as R1 in series with R1, I can use identical resistors everywhere, We will start from this next time,