Circuits For Analog System Design

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Lecture No. # 32

Capacitive Sensor Circuit with High impedance Amplifier

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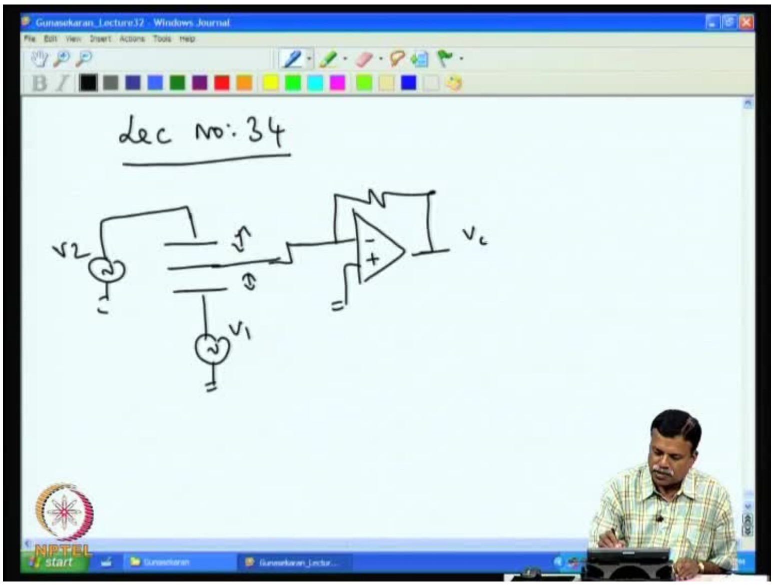

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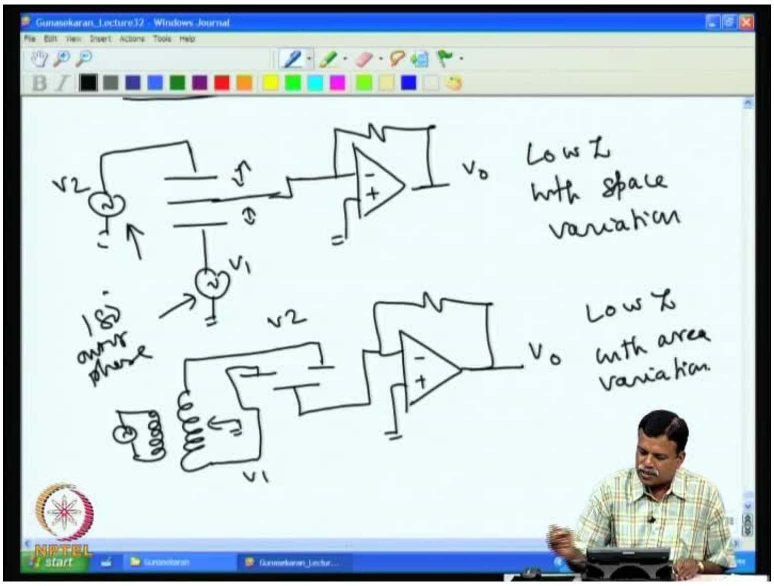

In the previous lecture, we were discussing about capacitance measurement using operational amplifier circuit. So, there we had discussed, if we use non-inverting amplifier, for example, if you have a op amp, and then if you use a non-inverting amplifier for capacitor measurement, we connect the resistance here and then we had shown that we can put three plates, then we can have a source here x, and then, another source which is V 1 V 2, and then we can connect to this. This is actually useful for space variation. Actually, if I have a space variation, then what was the output was coming, and then, we also had shown that if you use a non-inverting amplifier again, I can also use for area variation. So, I can have this. Then, instead of these two sources are 180 degree out of phase. So, the same thing can be achieved with a use of transformer. We can have a centre tapped transformer which gives me more accurate 180 degree out of phase voltage. So, I can have two plates excited by this and the center plate can be connected to this amplifier.

So, we can have, this is grounded, and then we can have other source connected to this. So, you will have a V 1 and V 2, and then you will have the output voltage. Here this is the second method, that is low Z with space variation; this is high Z, low Z, this is again low Z, low impedance, low Z, with area variation.

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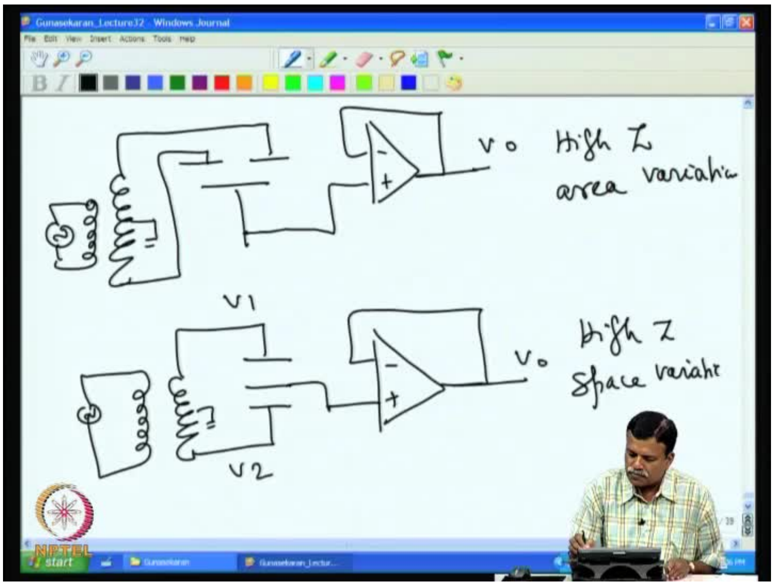

Then there is a, similarly, there are two other methods that is we can show same technique that I can use it in the high impedance amplifier stage. So, I can use a high impedance amplifier. Then we can have same two techniques, that is, we can have excitation voltage here, and then the two voltages, for example, if it is an area variation, then we can connect the similar stuff here and then connect to this amplifier, this amplifier, then you will get the output voltage. Same thing can be done with, again I will this is we call high Z, high Z, space variation.

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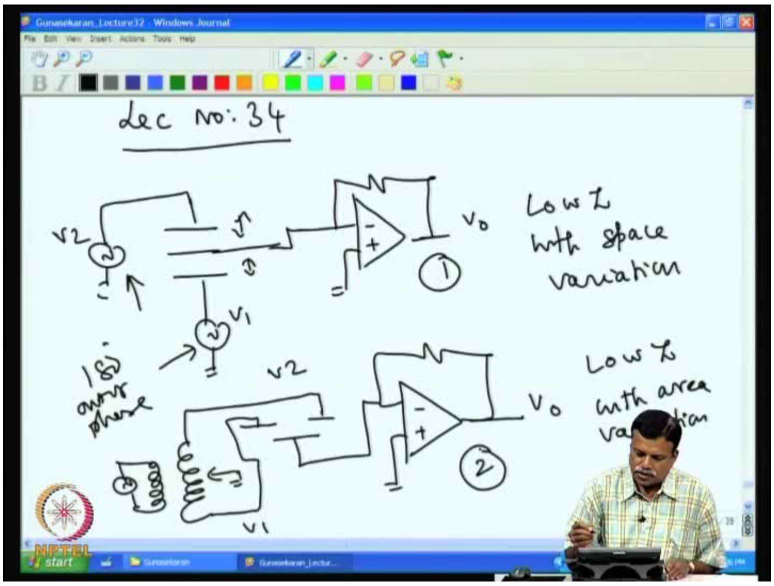

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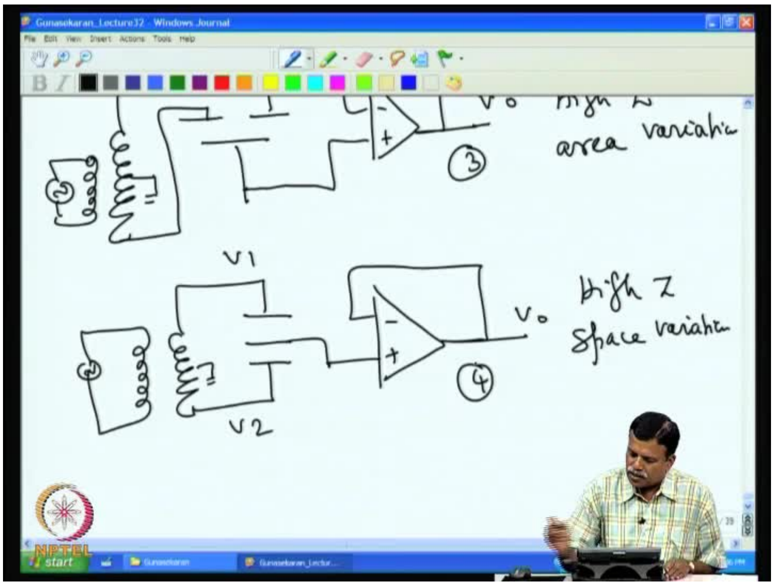

Same thing I can do similar stuff. You can have the same transformer, then we can have a space variation here, and this is connected here then to V 1 V 2 are connected here V 1 and V 2, then you get a output. This we call high Z high impedance; the high means, sorry, this is high Z area variation, high Z area variation. This is high Z space variation. So, we will number them actually, because, now we want to see in a consolidated manner what are these amplifiers, what are disadvantage and advantage, and which one this. We call number 1, and this we call number 2, and then, we call this number 3, circuit number 3, and then, we call this is circuit number 4 (Refer Slide Time: 04:33)

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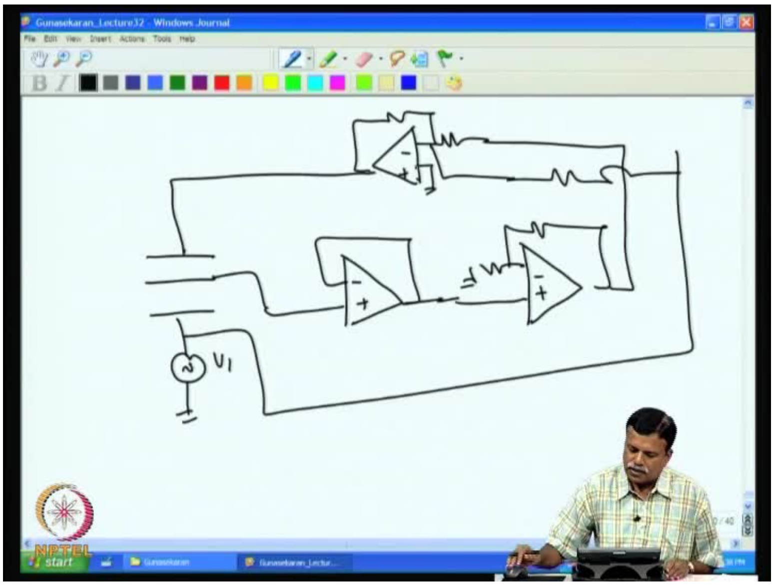

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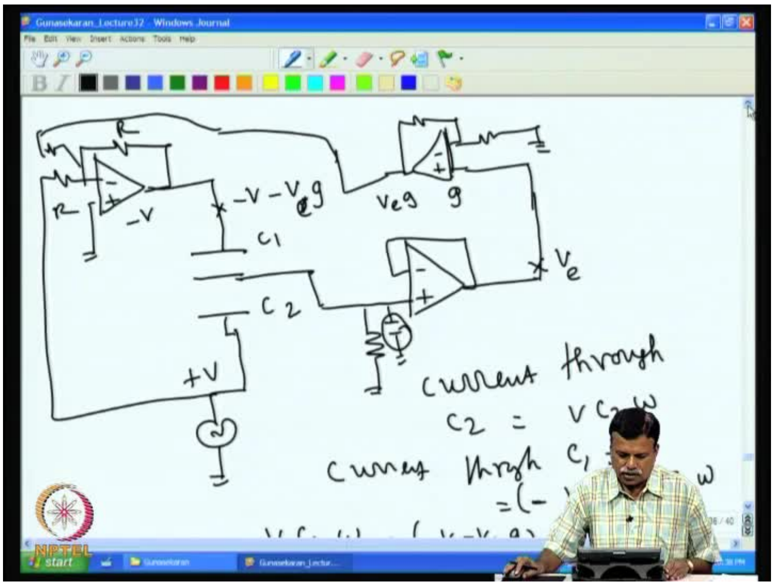

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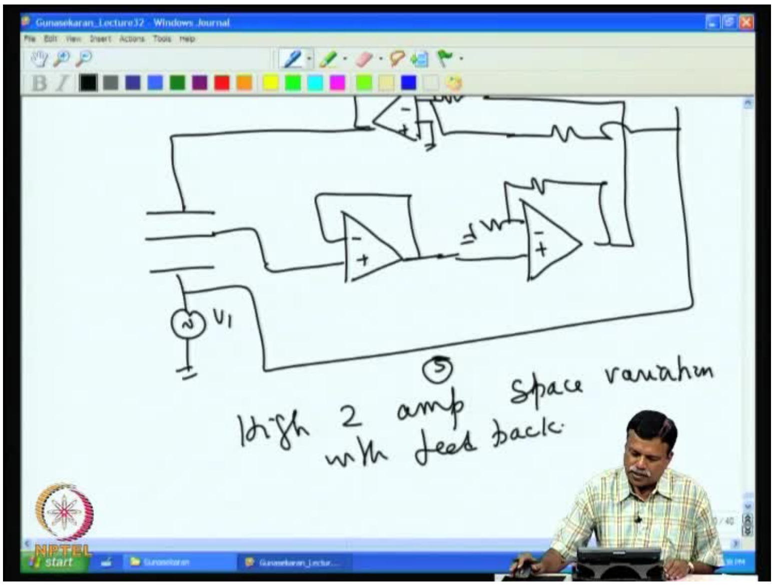

Then, we also can have two more variants possible in this, that is, we can have high Z amplifier, high Z amplifier. Then, in high Z amplifier, you want to make the output V 0. So, what can be done is, for example, if it is space variation, I can have the excitation voltage given here, and then this is given to high input impedance terminal and then this can be amplified, this can be amplified, and then this can be summed with, error, output can be summed with the feedback. This can be done. We had seen this earlier actually; this earlier, last class we had seen, that is the same circuit as that off with feedback, you know, the high impedance amplifier with a feedback. The same circuit which we are now we are calling as circuit number 5; we will call this as circuit number 5. This is actually high Z amplifier, high Z amplifier, high Z amplifier with space variation with feedback.

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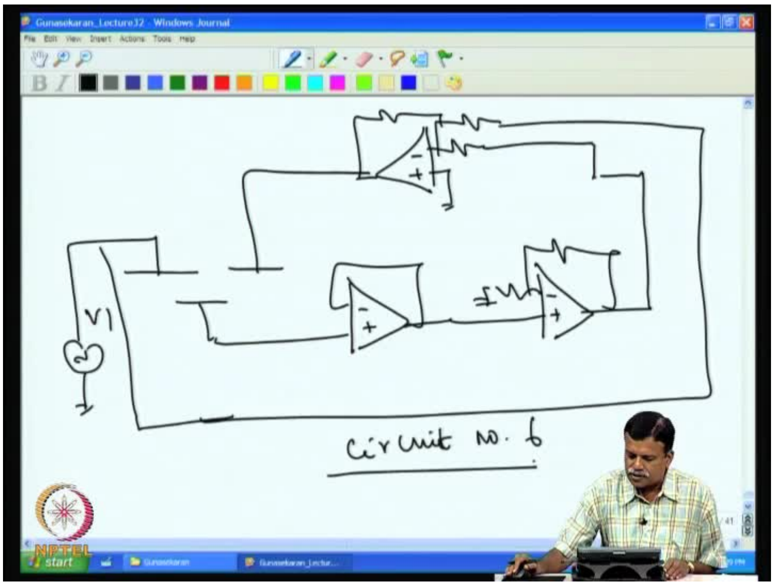

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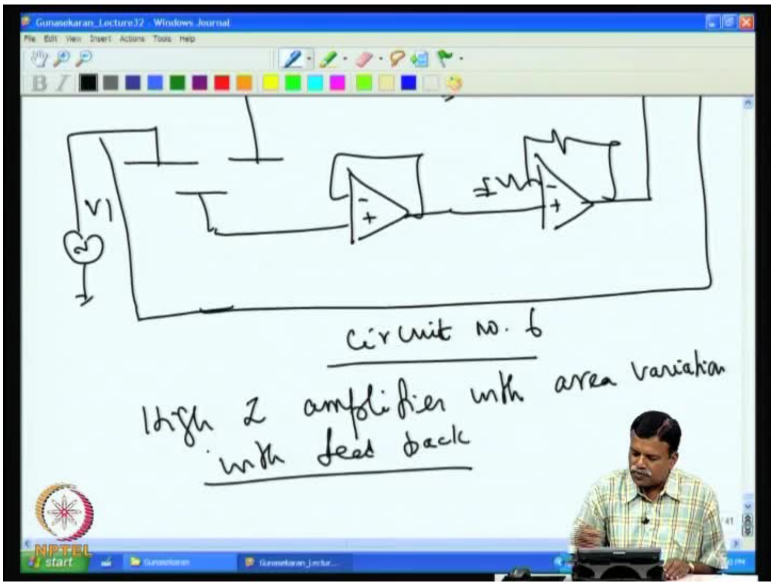

Same thing possible in another variant is the 6th circuit, wherein, we will have high Z amplifier with feedback, will have high Z amplifier with feedback with area variation. We can have two plates and connected to this one, and one can be excited with a source of V 1; the other one can be a from feedback. So, we can have this, amplify the signal, then we can have the summing amplifier connected here. This can be connected to an input and this actually connected to this. (Refer Slide Time: 07:35) So, this we call circuit number 6, circuit number 6; this is high Z amplifier, high Z amplifier with area variation with feedback. (Refer Slide Time: 07:40) So, we have six different possible circuits for this capacitance measurement. So, we have to see each one of it where to use and then which is better for a given application.

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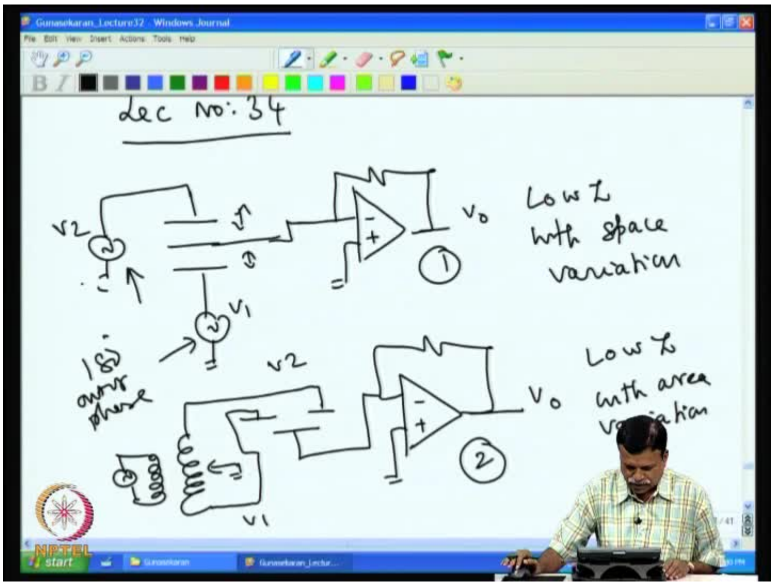

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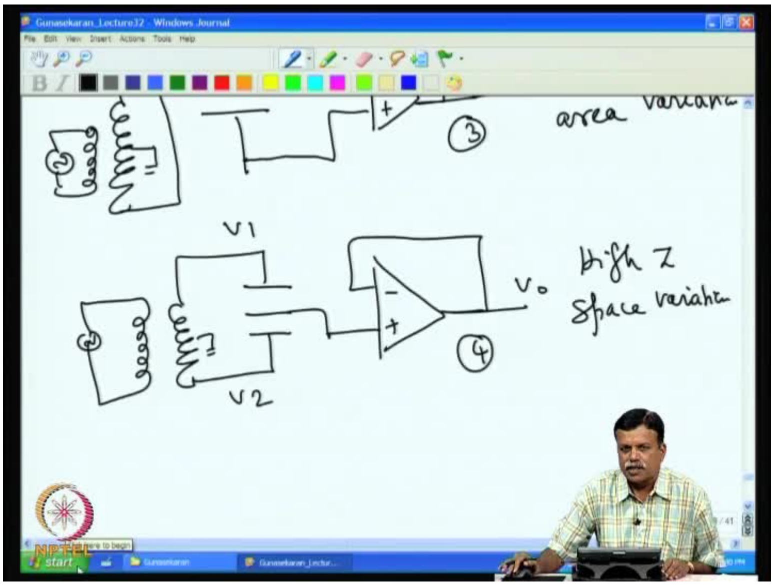

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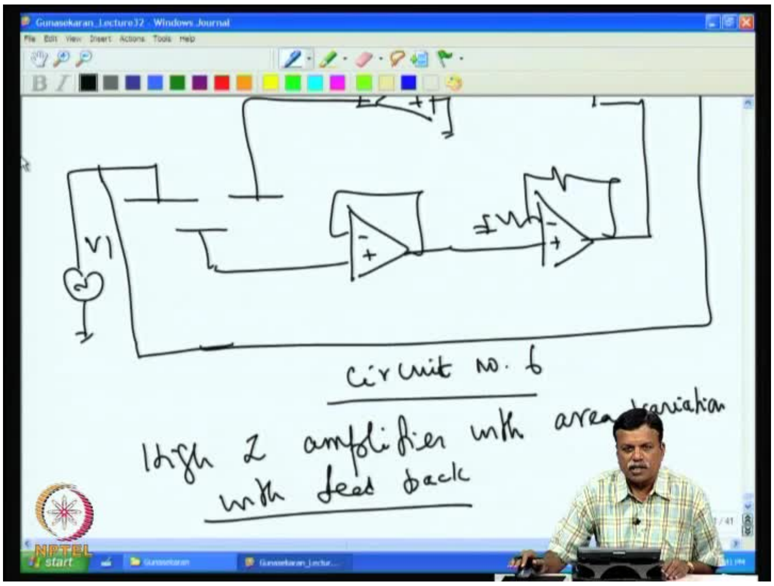

So, we have picked up basically two different applications - one is area variation, another one is a space variation, and then, we had taken two different amplifiers - one is non-inverting amplifier, other one is inverting amplifier. So, non-inverting amplifier gives you high impedance input; so, we call high Z amplifier, and the inverting amplifier gives you low impedance; so, we call it is a low impedance, low Z amplifier, and then, in, for in the case of high impedance amplifier, we can also have a feedback and then one can make the output to 0. So, same thing also possible with low Z amplifier which will make another two more circuits, that is the 8 variants, really possible actually.

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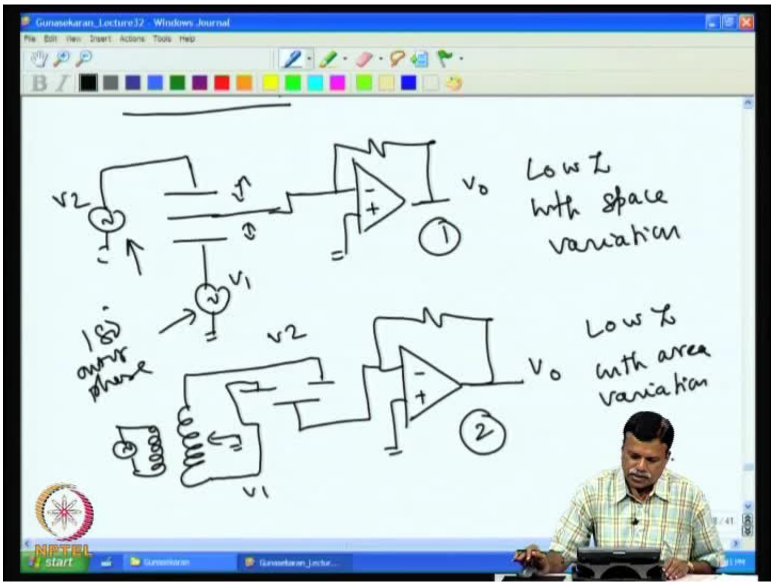

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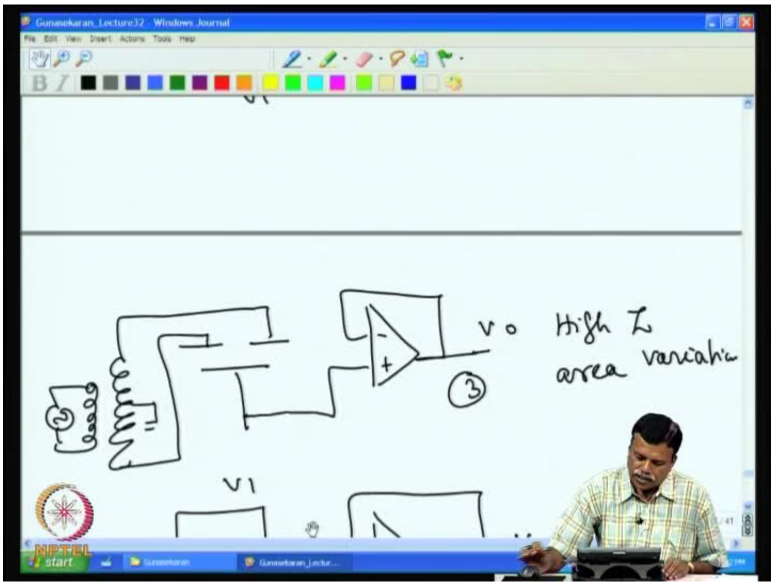

Now, we will see about the other two circuits operates, that is, low Z amplifier with feedback, what is the effect that it comes, because it may not be required, in a, in the real application, because if you take the low Z amplifier that is our circuit number 1, circuit number 1, if you take this is actually we are calling low impedance because we are giving it to the non-inverting input. So, this is at a ground potential, because this is, since this is at ground potential, this also ground potential. We call this a low Z amplifier, and in the case of circuit 3 and the other 3, 4, 5, 6, you are given the input to the non-inverting amplifier, so, this offers high impedance. So, this we call it is a high impedance amplifier.

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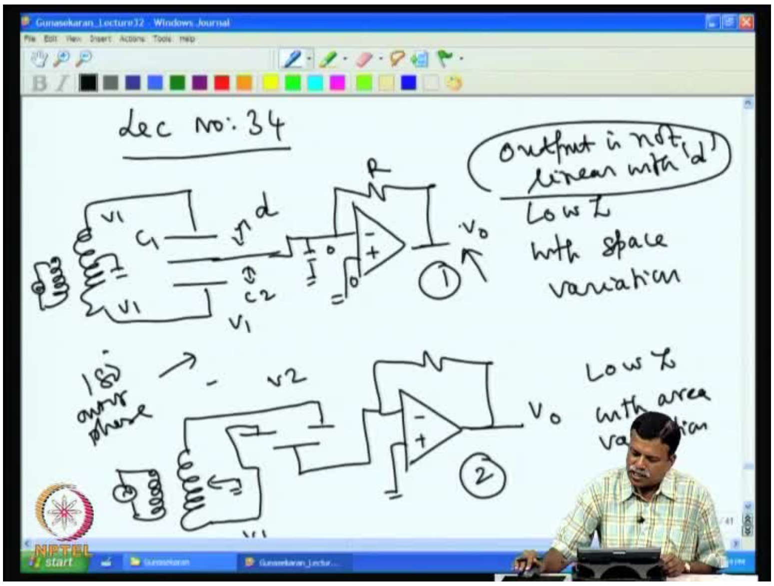

Now, if you take the low Z with space variation, we had shown in the previous class that low Z with a space variation, we will have a output voltage, that, what is coming here this resistance R. So, the current actually is delivered by this and the current delivered by this. If these two are from V 1 V 2 are from the same transformer, then they are identical voltages, but they are 180 degree out of phase can be there.

Now, this we can actually modify like this, that is, I can remove this, I can remove this and connect the centre tapped transformer. So, one is energising one plate, another one is energising the other plate; so, this is the AC that it is coming here.

Now, in this case, the output that is, output voltage is actually given by, suppose we take this one C 1 and this is V 1 and this also V 1 and this is C 2. So, we had shown in the previous class that, what is the output voltage. It was shown that output is not linear with displacement d because we had shown that it d is a displacement; output is not linear, output is not linear that output voltage with d.

So, this is not a linear circuit, and then, but of course, it has advantage that there is no effect due to the stray capacitance because the stray capacitance has no effect, because this is 0 potential, this also 0 potential, so, it works very well no problem, but unfortunately output is not linear and then output voltage is not 0, and output voltage depends on frequency as well as input voltage variation. Very frequency changes then you will find that output voltage also changing, and then, if, even if the voltage changes, the output voltage also changing. So, this is not as good as ratio transformer bridge that we had discussed earlier.

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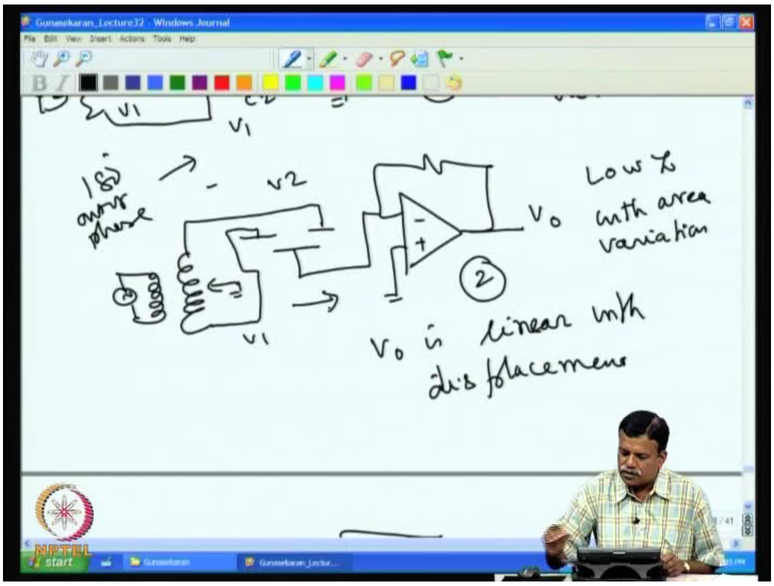

Now, the same amplifier, if I take low Z with area variation, this circuit is linear V 0 is linear with displacement, because we are moving the coil like this. I think you are not shown this equation in the last class; let me see what we have done in the previous class, whether it was derived or not.

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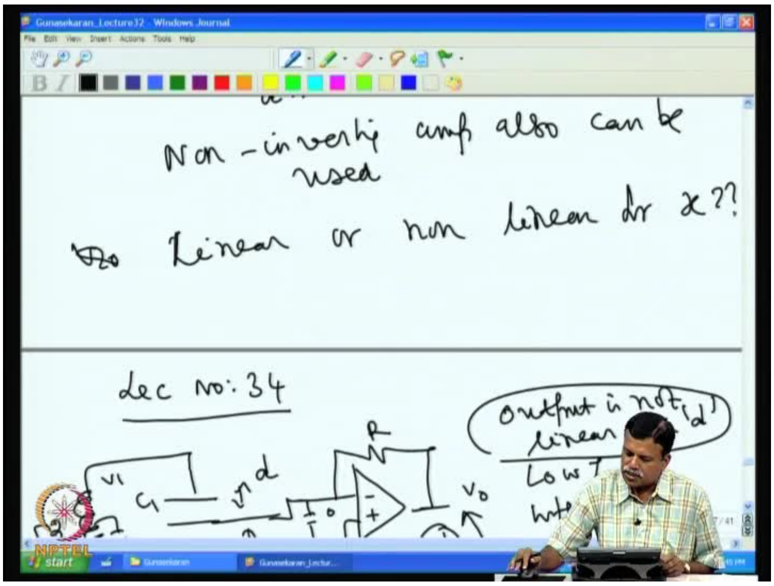

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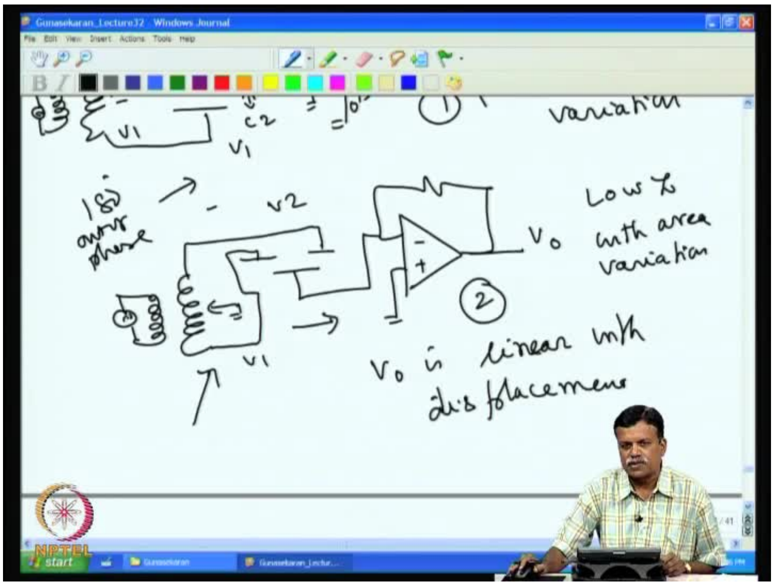

Area variation we had shown. So, output voltage is linear; this we had shown in the previous class. This is linear or non-linear that is what we have got a question. In the previous class, we had shown that this circuit, that is, number 2 low Z with area variation, v 0 displacement is linear, and we had shown the equation derivation also.

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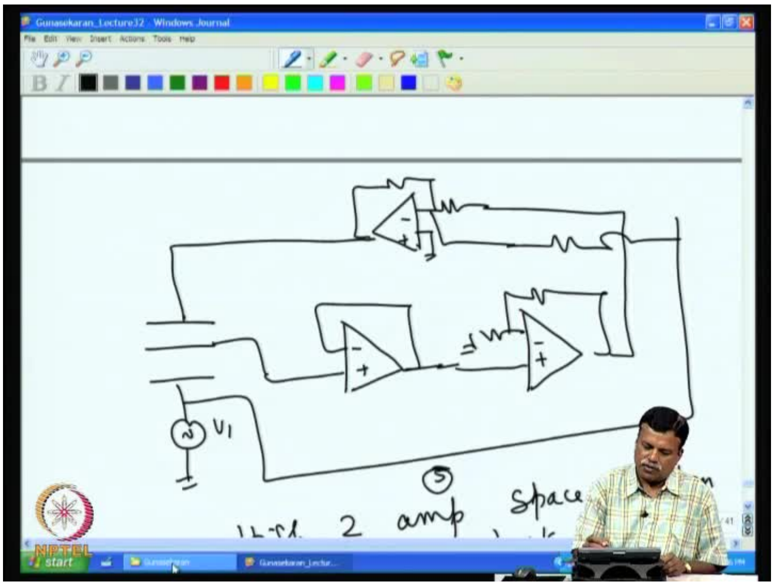

So, this error is advantage because output voltage is linear with displacement, of course, it is again depends upon frequency variation, because if the frequency of the source varies, then output voltage also changes, and even if the voltage varies, then output voltage also changes. Nevertheless it is linear but it is not comparable with a ratio transformer bridge. Then we had shown other circuit that is our number 5th circuit which is actually feedback because we want use a feedback and then design a circuit using a non-inverting input, because we had fed it to the non-inverting input the signal, and then, this output voltage whatever is come that we are amplified and then we inverted and giving back to the other plate.

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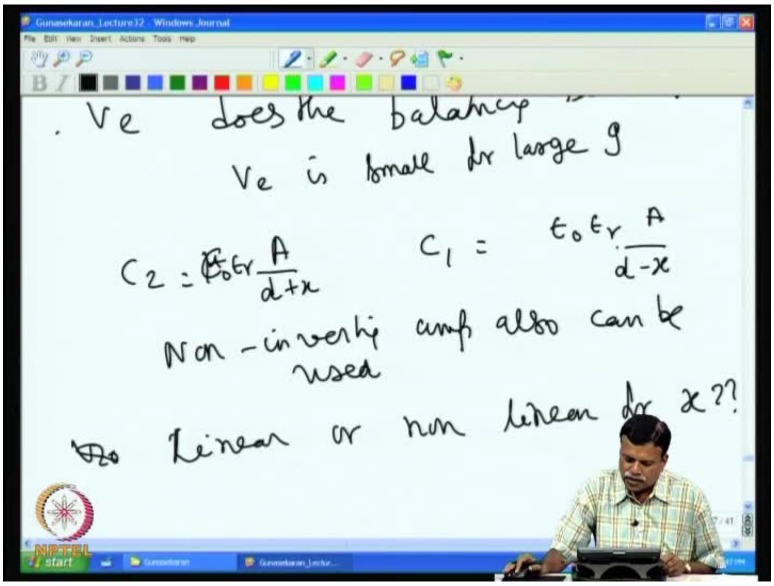

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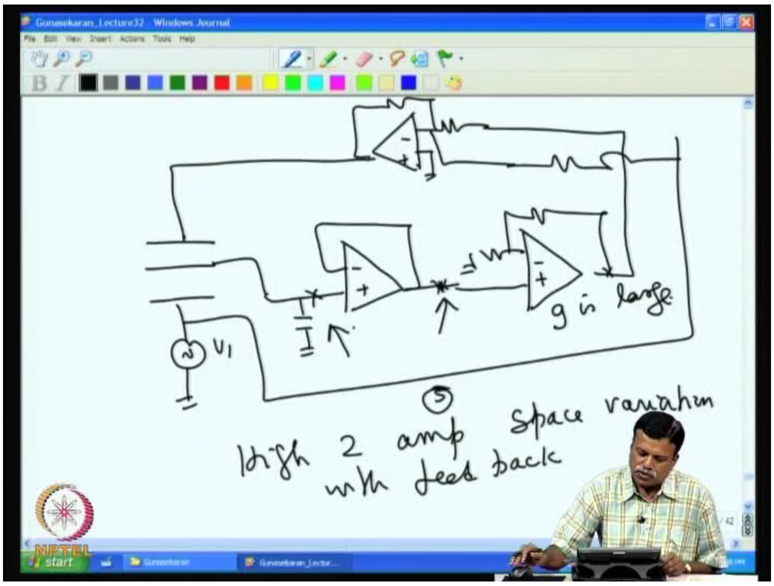

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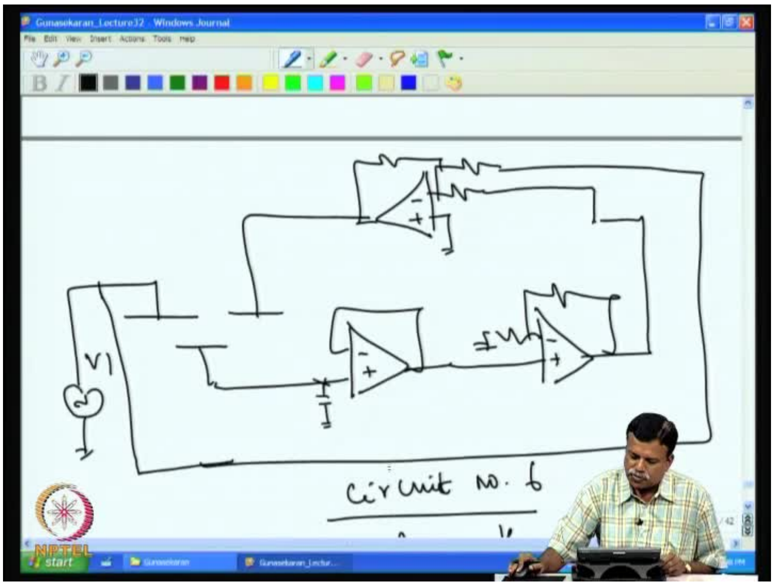

In this method, we had shown in the previous class that this derivation also was made in the previous class. We had shown that with this one, this is not linear and this is not linear because we had shown that C 1 plus C 2 if you take, because if you take this circuit number 5 and 6 which are actually with feedback. So, essentially what our aim is that we want make this voltage as small as possible, because if the gain is large, if the gain is, g is large, then the error voltage will be very small and this voltage will be very small. So, that is what our discussion. The aim is that if we have a stray capacitance here or the cable capacitance that should not have any effect means, the input voltage should be 0. That is a basis of a circuit 5 and 6. So, here also we assume that capacitance is there and this voltage is very small, and so, the output voltage will have no effect on the stray capacitance.

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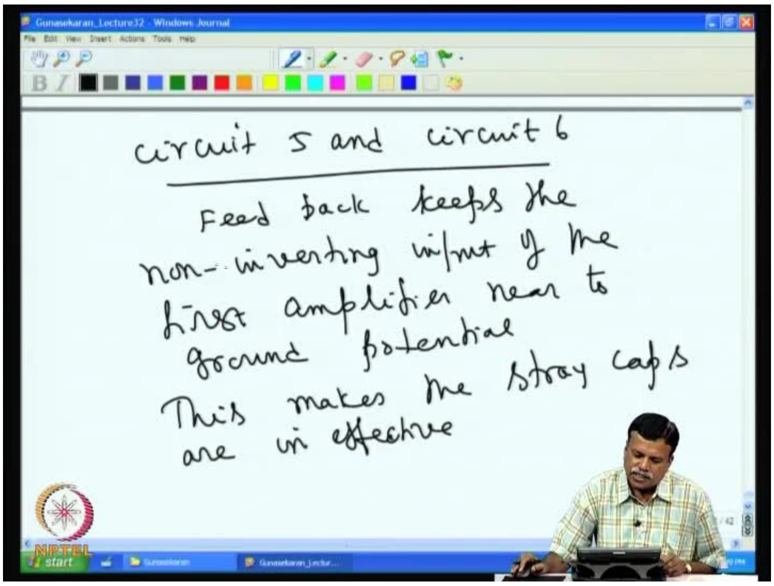

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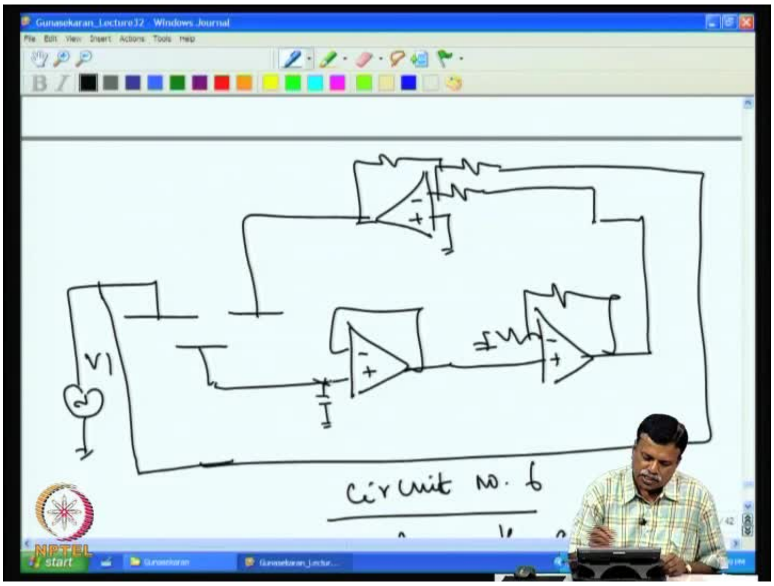

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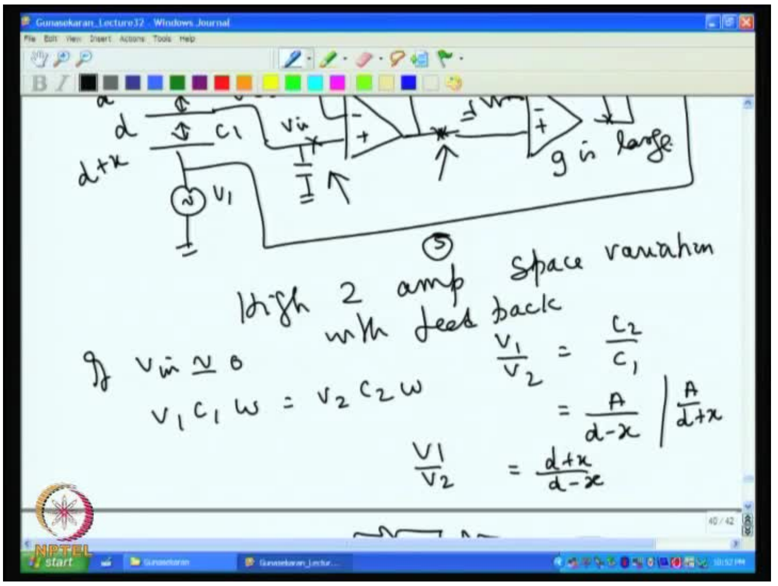

So, if we take circuit 6 and 6, 5 and 6, feedback, feedbacks, feedback keeps the non-inverting input of the first amplifier, first amplifier, first amplifier near to ground potential. This makes, this, this makes the stray capacitance, stray capacitance are in effective, in effective. So, this is, that is the advantage because, you know, the input capacitor have no effect. So, because of the, we are feeling the signal back and then making the input, at the input signal is 0. It is happening both circuit 5 and 6, both circuit 5 and 6. If, as long as the gain is high, the input voltage will be very small, so, the stray capacitance will have no effect.

But then, if you analyse the circuit whether they are linear or non-linear. So, we had seen, for example, the, for the space variation as well as, this is for space variation, so, our space variation, if you take. So, we had to take here, if you take d and the plate moves, then we have one side it become d minus x and the plates comes down. This from distance because d plus x. So, this distance and this distance varies in the case of space variation.

And the current actually, since these two voltages are 180 degree out of phase, so, the current at 0 we are assuming that V input is 0, V input is 0. if V in is nearly 0, then we can show that V 1 C 1 omega should be equal to V 2 C 2 omega. So, where C 1 is this capacitance, C 2 is this capacitance. There, they are to be equal because then only that this current is actually V 1 C 1 omega, and then, the current coming from here is V 2 C 2 omega and at for 0 they are to be equal. So, that actually makes the equation is simple.

So, we can write that V 1 by V 2 is actually C 2 by C 1, but then, if we write in terms of d, that C we can write it as C 1 C 2 minus C 1, we can write it as C 2 will be A by d plus x, d minus x in this case. The C 2 is this capacitor, so, we had taken as d minus x. Then, divided by A by d plus x because A also goes off. So, eventually, this will be simplified as d plus x by d minus x. So, that is the voltage V 1 minus V 2 will come which shows that the voltage clearly non-linear circuit, and apart from removing the stray capacitance effect, this circuit is not advantageous even for space variation measurement.

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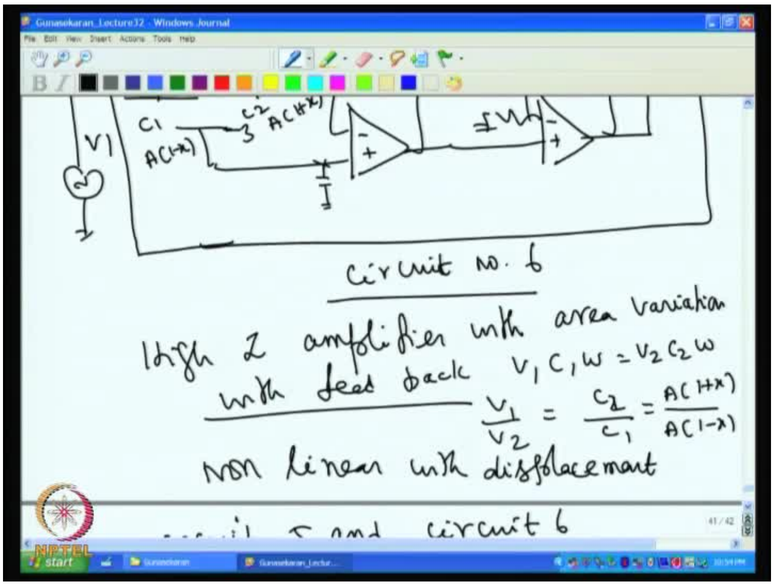

Similarly, if we take the other circuit that is say 6, that is, wherein, we are using high Z amplifier, and then giving the feedback, such that, this voltage becoming more nearly 0 by giving a high gain, but again, this is for area variation, because we are moving the plate, you know, they are 3, this is area variation. So, if by moving the plate 3, we are varying the area increasing. So, assume that this is having A into 1 minus x area and this is actually applied to area increases we take A into 1 plus x as this area.

So, if you again write the equation for the current. So, one current will be V 1 C 1 omega, that is, if I take this as C 1 capacitor and this as C 2 capacitor, then V 1 C 1 omega will be equal to V 2 C 2 omega. So, again we will get a V 1 by V 2 as C 2 by C 1.

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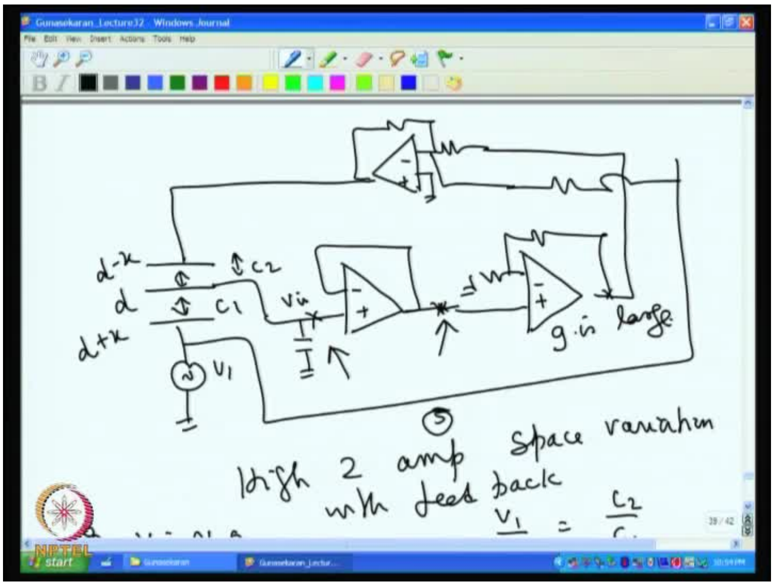

Then C 2 can be written in terms of area that actually will come. So, C 2 will be A into 1 plus x. Here, it will be A into 1 minus x. The other parameters actually goes off, but again you find that, this is again non-linear, that is V 1 V 2 is non-linear with displacement, but interestingly this is not depend upon the dielectric constant variation and the frequency variation. This is true for circuit number 5 also. Circuit number 5 again is independent of dielectric constant variation and the frequency variation, of course, it is non-linear. Otherwise, this circuit is excellent proposition, because we can give the feedback around and make the input, bring the input to the near to 0 potential. So, we will not have any problem due to the stray capacitance.

Nevertheless, the circuit 5 and 6 actually become, actually a non-linear circuit, and in some applications, it can create a problem, because at the extreme ends, the signal strength might come down. Other than doing a computation using, probably, today it can be done easily with microcontrollers.

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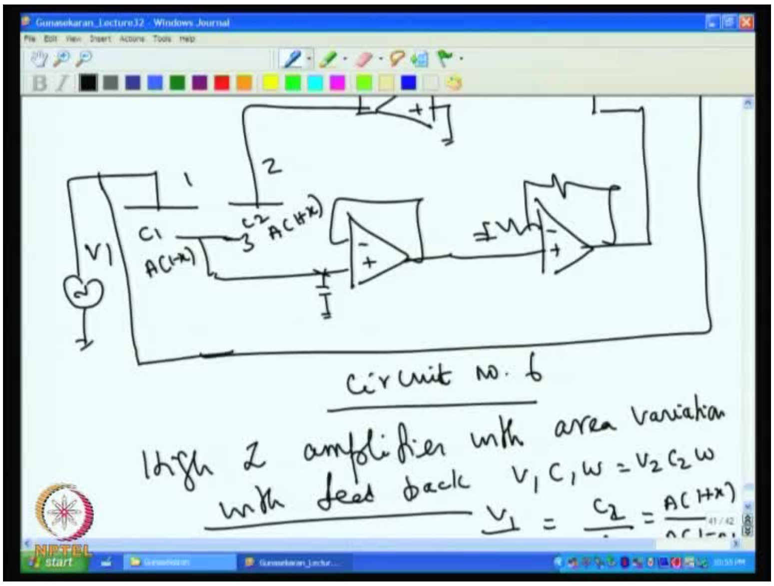

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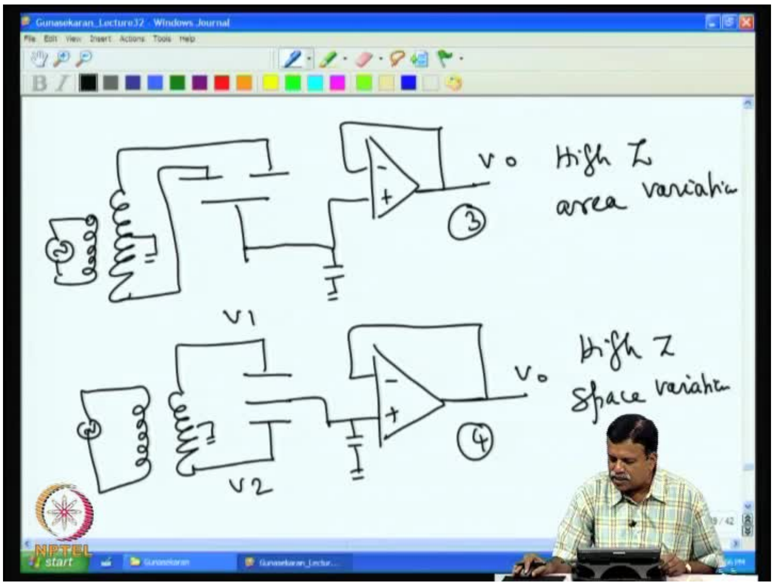

So, if you see this out of the 6th circuits, that 5 and 6, even though input is 0, we are using a non- inverting amplifier. They are not effectively good because they are non-linear, and then, if you look at circuit 3 and 4, that is, we will let us not make the output 0 but we will not give a feedback but we see what effect you will get if I use high Z amplifier for area variation, that is the circuit 3 we use, what happens? And then, if I use this circuit 4, again circuit 4 is for, this is for space variation, this is for area variation. In this case, what advantage we get? Obviously, if the output is not 0, we can see one disadvantage that this is also not the input also not 0.

So, same thing if this is not 0, input also not going to be 0. That can create problem because you will have a stray capacitance here to ground and you can also have a stray capacitance here to ground. So, stray capacitance will have severe effect on the signal. So, these two circuits we analyse little more in detail separately now.

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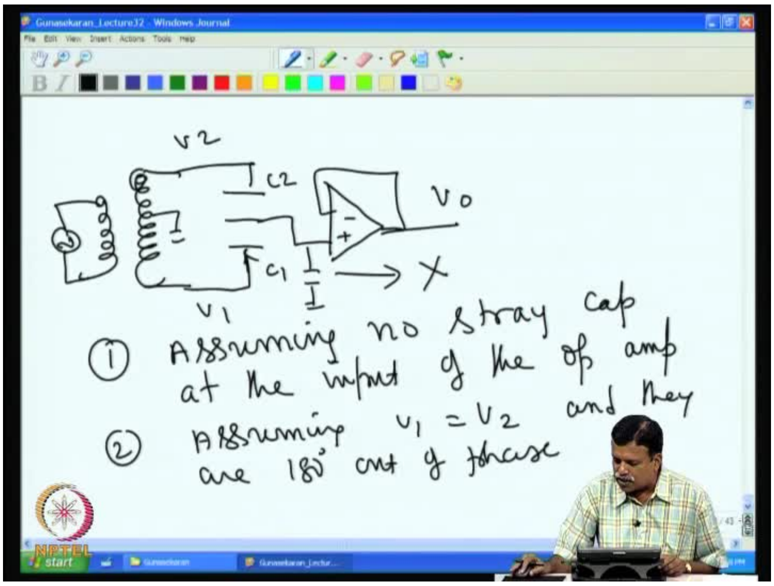

So, let us get into, the, these two circuits for detailed analysis. Now, let us take this transformer secondary and then I connect the input here, that is a AC, then I will use. First we will take high Z for space variation, so, space variation I will put that three plates. Then I connect one of them here, and that is the output voltage. If need, gain also can be given. So, I can connect one of them here, another one here. So, we will have, this is actually V 1, V 2 and then C 2, C 1 can be taken and the output is 0. Assume, there is no stray capacitance effect as assumption first.

So, one assumption is assuming no stray capacitance is present here, that is, this is 0, no stray capacitance, capacitance at the input, input of the op amp. So, we will analyse assuming there is no effect due to this, and similarly, V 1 second assumption is assuming V 1 equal to V 2, V 1 equal to V 2, and 180 degree, and they are one 180 degree out of phase, because this anyway transformer that actually 180 degree out of phase automatically happens. So, there is no problem with that.

If this assumption is made, then we can show that, we can show that the input current that is coming from here, that actually goes here, and the input current that is coming here, goes here. Now, if I, since it is not 0, so, we cannot take the currents as it is. So, we have to analyse in terms of voltage. So, we can write it what is the output voltage in terms of C 1 and C 2. That is what we have to write now.

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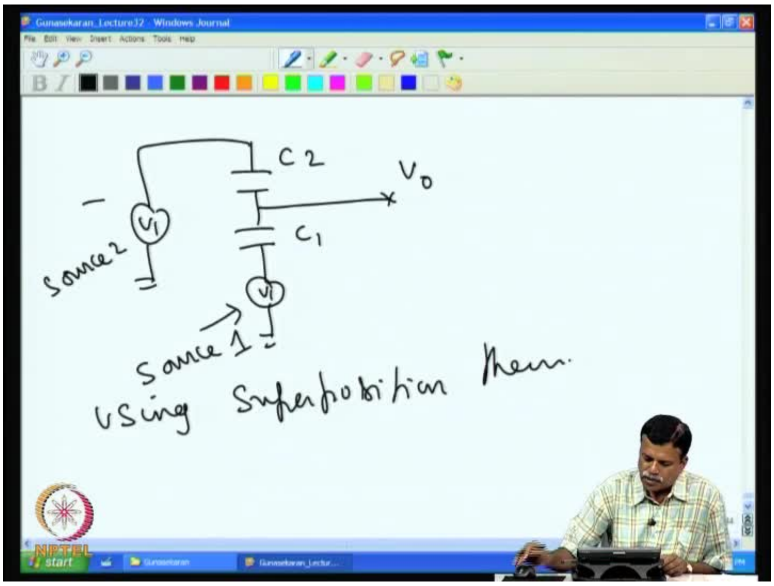

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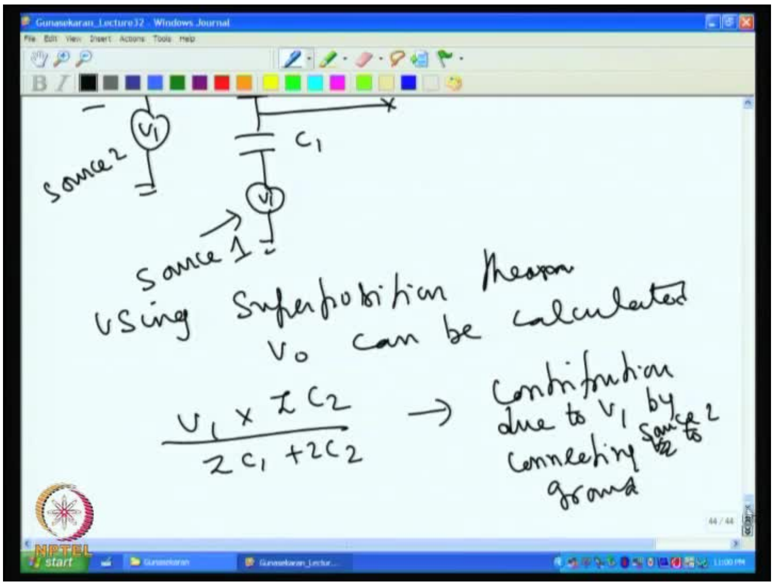

So, if we take that, then the equivalent circuit becomes like this, that is, I have two capacitors - one is with V 1, another one is with minus V 1, and then, here is the voltage V naught, that is, C 2 and C 1, that is C 2, that is C 1. So, we had find out what is the voltage V naught. Now, we can write using super position theorem what is the value of

V 1. So, contribution due to source 1, I take this as a source 1, source 1; that is a source 2. So, using super position theorem, one can find the value of V 0, using super position theorem, we can find the V 0 can be calculated. So, that is actually V 1 into Z C 2 divided by Z C 1 plus Z C 2. That is the contribution due to, contribution due to V 1 by connecting V 2 to ground, source 2 to ground.

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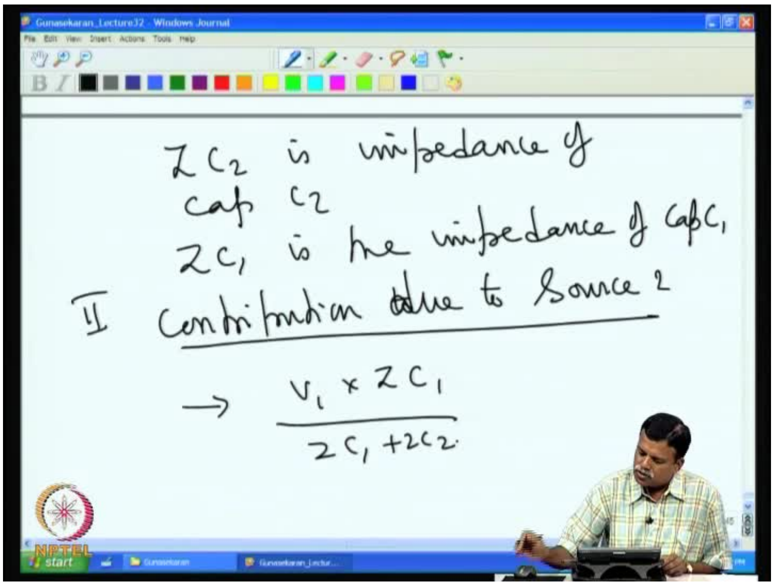

So, well, Z 2 is the impedance of capacitance 2 and Z C 1 impedance is the impedance of capacitor 1. So, Z C 2 is nothing but impedance of capacitor Z C 2 is impedance of the capacity C 2; Z C 1 is the impedance of cap C 1.

Similarly, we can find the contribution due to source 2. So, second part is contribution due to source 2, contribution due to source 2. Here, actually we will get the contribution due to source two as V 1, V 1 is the excitation voltage V 1 into Z C 1 divided by Z C 1 plus Z C 2.

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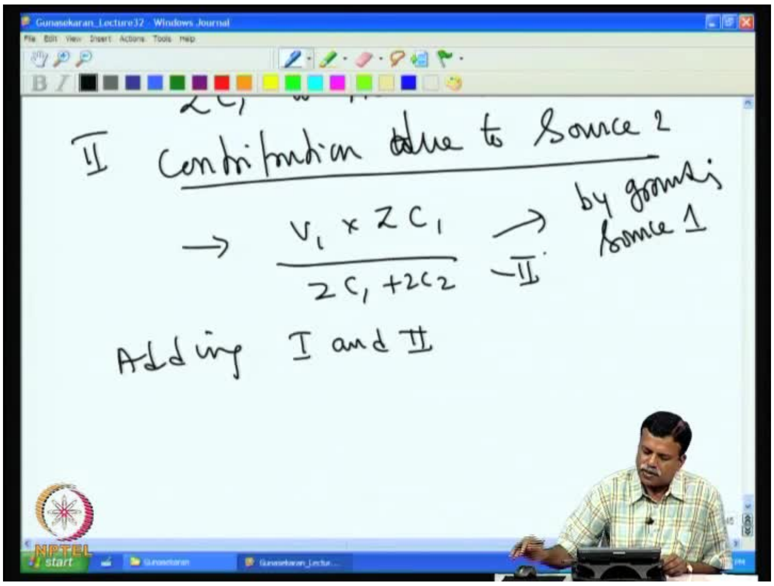

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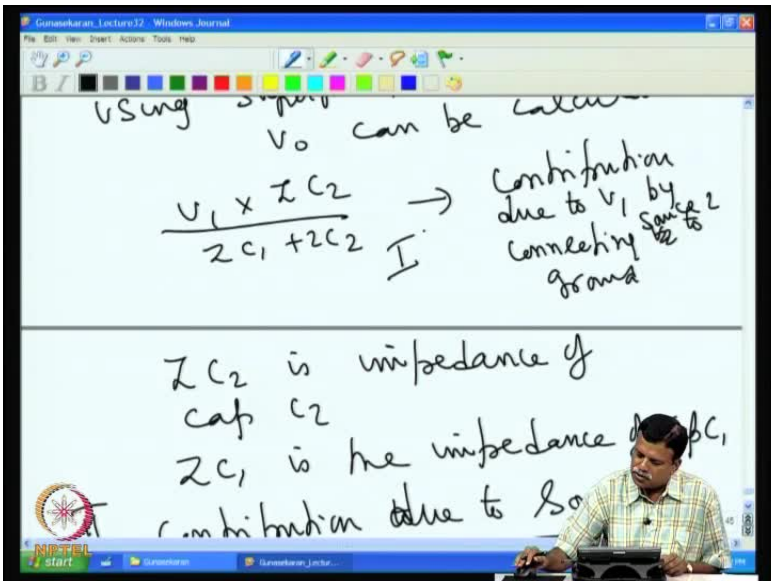

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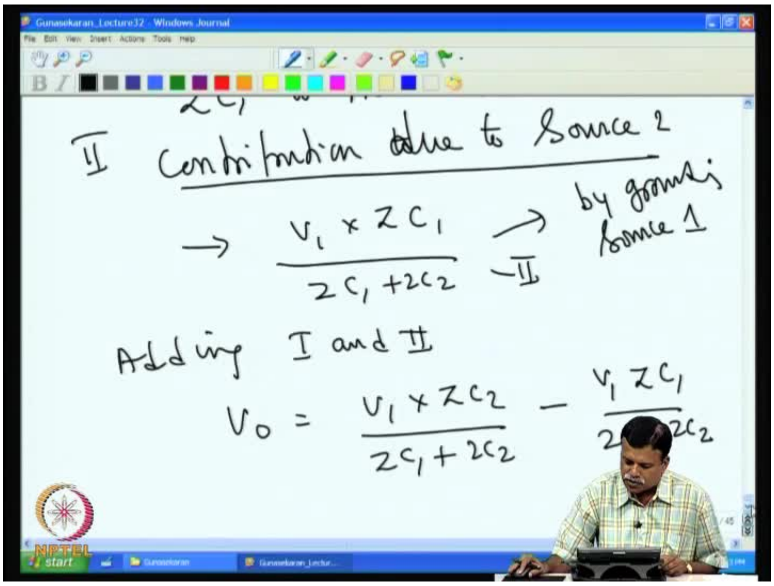

So, adding these two you will get the net voltage V 0. So, adding 1 and 2, this is then by grounding source 1, so, adding 1 and 2. So, this equation 2 and then we had the equation 1. So, adding 1 and 2, we can get the output voltage V naught. So, V naught actually become, so, V 1 into Z C 2 divided by Z C 1 plus Z C 2. Then since other one is minus, I can actually we have to add. Since the polarity is reversed, I can write it as V 1 into Z C 1 divided by Z C 1 plus Z C 2. So, that is the equation that we get for output. This output is obviously not 0. Now, the question is whether it is linear are not, because this is the space variation. You will show that it is actually linear, because even though this is the disadvantage that it is sensitive, it is sensitive for input capacitance. Nevertheless, this is gives you linear output. That is the advantage of this circuit. Now, that we can so like this, since V 1 can be, now it can be simplified V 0 can be shown as V 1 divided by Z C 1 plus Z C 2, and then, we can, so, Z C 2 minus Z C 1.

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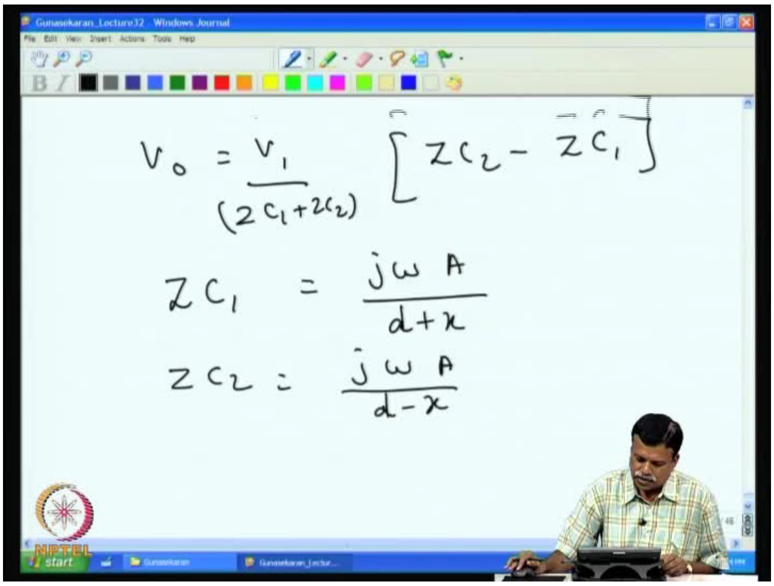

Now, if you write Z C 1 is coming as j omega A by d plus x I can write, and Z C 2 can be written as j omega A by d minus x, and of course, mu naught, epsilon naught, epsilon r are also there. That one need not worry about that because that anyway we will show that it is getting cancelled.

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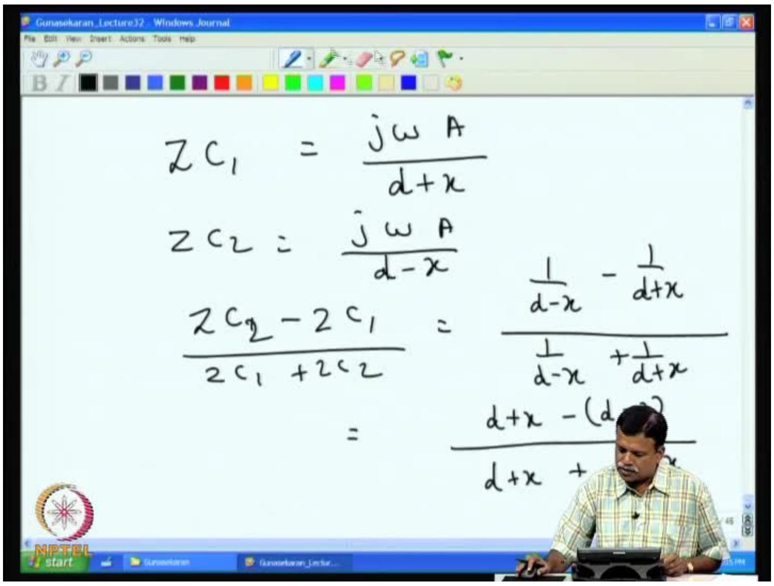

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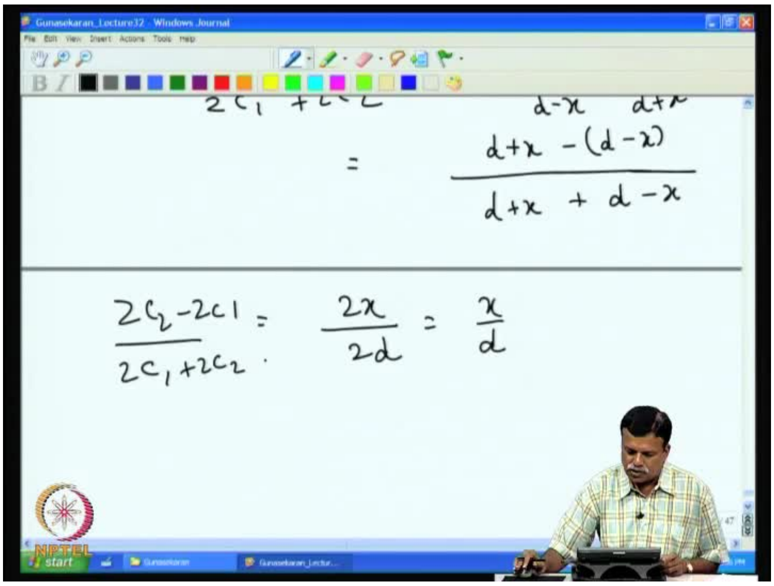

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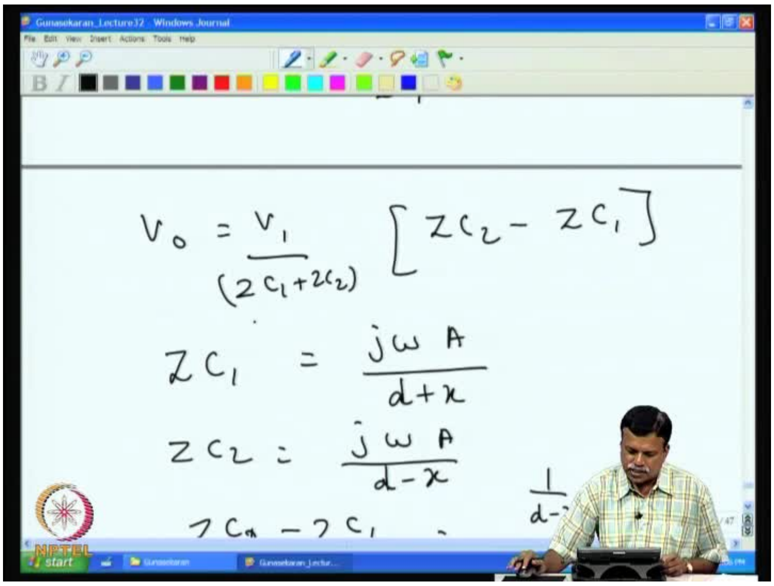

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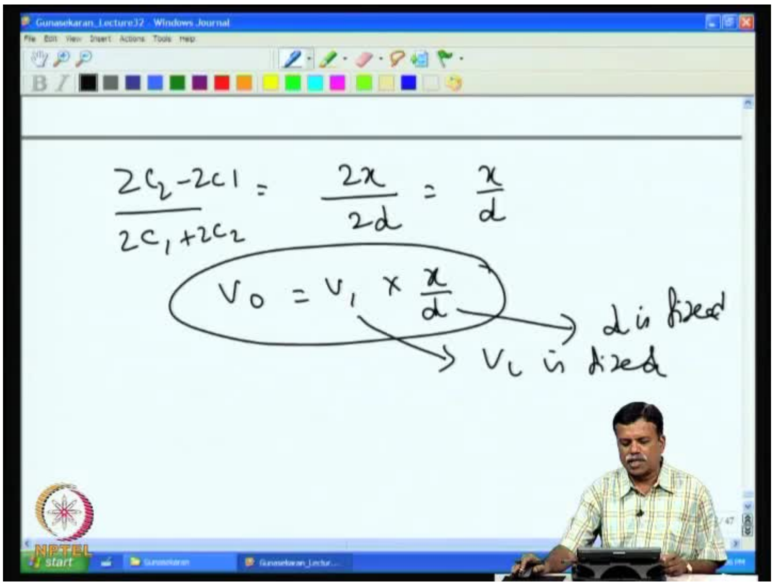

Now, if I simplify Z C 2 minus Z C 1 divided by Z C 1 plus Z C 2, that is coming as we can show that that will be C 2 minus C 1. That will come 1 plus d minus x minus 1 by d plus x divided by 1 by d minus x plus 1 by d plus x. That is what the terms comes out. So, that actually if I, if you simplify this, then you will get the bottom terms are actually constants. So, you will show that it will come as d plus x minus d minus x divided by d plus x plus d minus x, because, the, if you can take common factor that it goes off. So, you will get the net result as this is. Now, if simplified this, that comes out as 2 x divided by 2 d, that comes as x by d, that is the, that is Z C 2 minus Z C 1 divided by Z C 1 plus Z C 2. So, then, V 0 will be come, because V 0 is shown as this, so, V 0 will be V 1, V 0 will be V 1 into x by d which is actually linear because d is fixed, V 1 is fixed. So, V 0 is proportional to x; so, it is linear. So, even though this amplifier is not could in terms of stray capacitance effect, this is could because it is linear.

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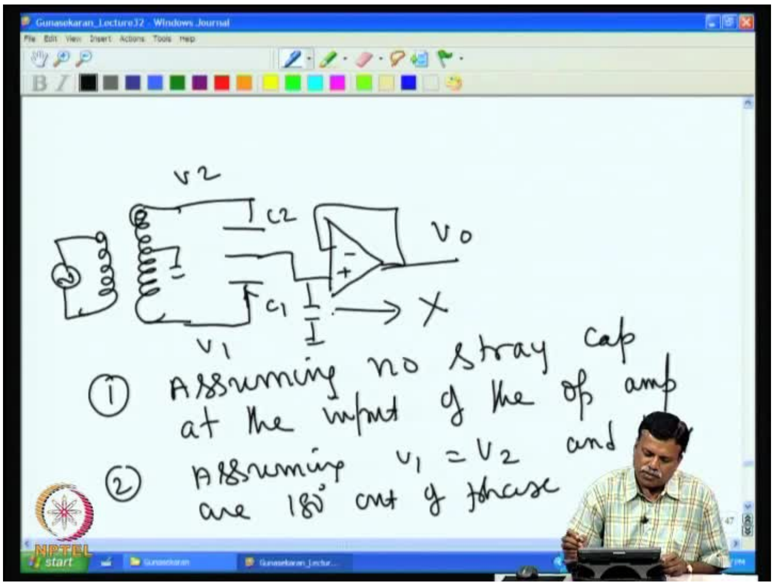

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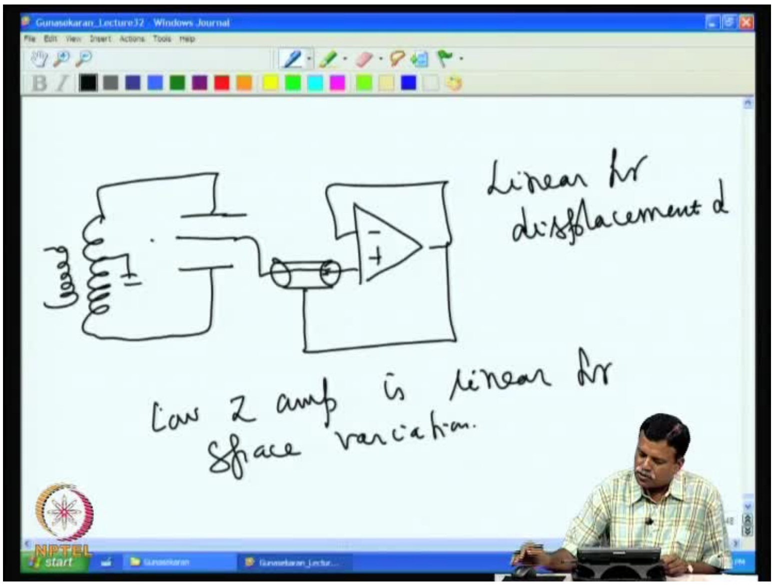

So, that is the reason that this amplifier also popular. Now, the difference of this capacitance can be solved by giving a guarding the input. So, normally what is done is to solve the input impedance, input stray capacitance problem, one can guard the input electrodes. So, using the following technique that is we can have the input, and then the 2 space variation. So, we will have in this input can be use ground capacitance and can be connected this. This partly nullifies the input capacitance problem but not completely, but nevertheless, it is linear, linear for displacement d.

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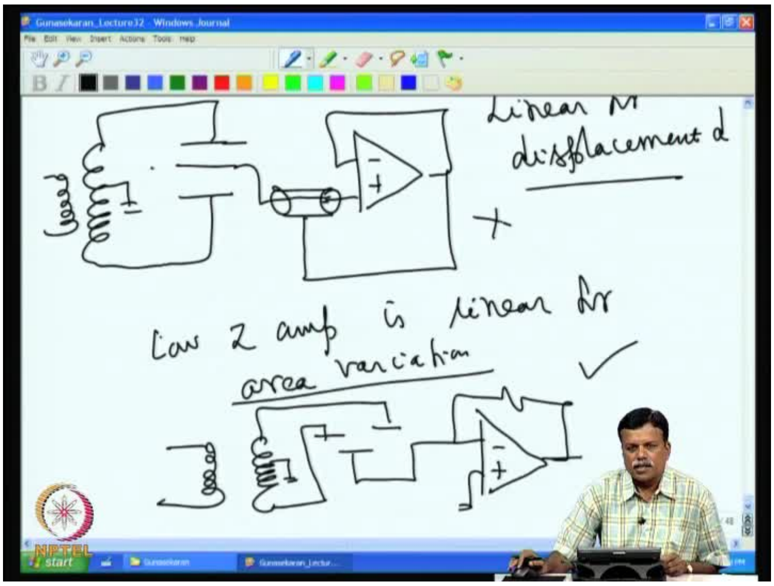

So, this is a, that is way it is very popular because non-inverting amplifier was linear for area variation. Whereas, you know, this non-inverting amplifier is linear for displacement d, and then this invert low Z amplifier, low Z amplifier is linear, linear for space variation that if you recollect the circuit, that is this. So, we have the output voltage here and then the same centre tapped transformer that go for area variation. So, we have the two plates and then that is connected to this, and one actually connected to this plate, another voltage connected to this. So, again this is also linear for space variation, linear for area variation, sorry, this is for area variation.

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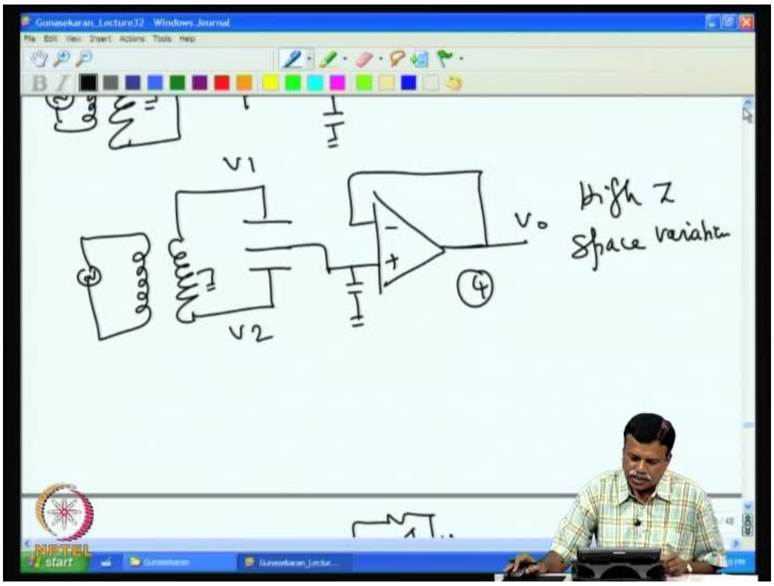

So, linear for displacement d, and then, this is linear for area variation. So, these two amplifiers are actually I used in real life so that you get linear output for the given displacement or that is in the, since at by using area variation in come as the displacement here. We can using the space variation you can measure the displacement. Nevertheless, this amplifier is good in terms of stray capacitance effect; this is not very good in terms of stray capacitance effect.

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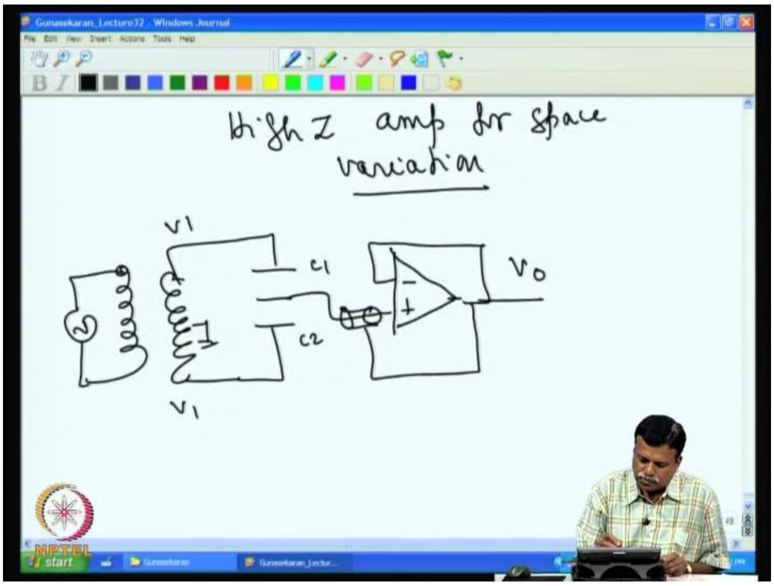

Now, that, what is remaining is the circuit number 6, what is the effect of circuit number 6? Now, circuit number 6 is actually, sorry, circuit number 4, circuit number 6 we already discussed. Circuit number 4 if you see, here actually high Z amplifier for space variation. So, how the, this amplifier behaves we can see now. So, we take this high Z amplifier for space variation. Here, actually, we have the input high Z amplifier for space variation. So, we can have this, and then, input is energised with this, the centre tapped transformer. So, we have space variation, we have to bring in here. So, we will have that two, three electrodes here.

Of course, again, we will had to put guarding technique here to avoid the stray capacitance problem that is coming as V naught, and then V 1, that is V 1, and then we will have C 1 here, and C 2 here.

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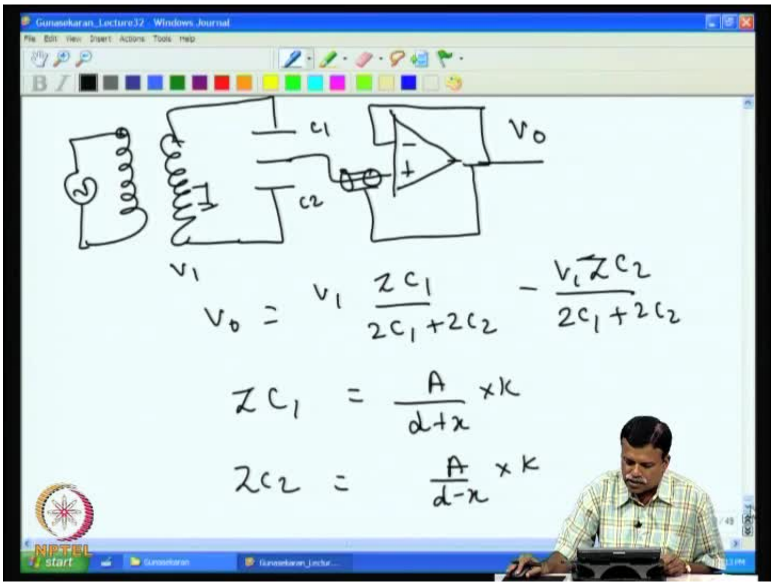

Now, this also can be analysed in the same form, and then, we can show that it is also not linear because we can write the same voltage equation using a super position theorem, and then, if you look at the super position theorem equation what we are written, so, we will get V 1 into Z C 1 divided by Z C 1 plus Z C 2 plus that is the inverted, so, we have to have a minus voltage. So, you will have minus Z V 1 Z C 2 divided by Z C 1 plus Z C 2 we will get.

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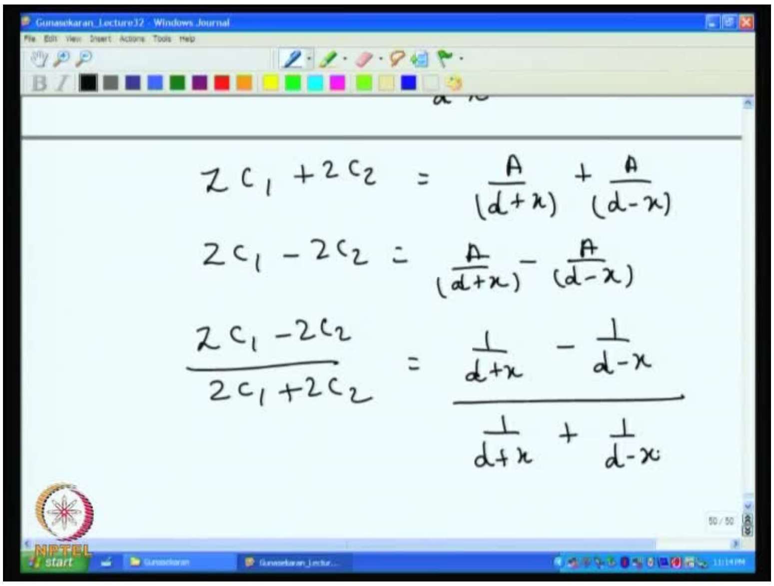

Now, the, it is similar to what we had but except that Z C 1 C 2 that is the V naught. Now, we can show that, you know, this is also non-linear. For example, Z C 1 C 2, Z C 1 will come as, here it is space variation. So, will have A constant and we will have one is d plus x and Z C 1 will come in terms of this constant K is there. The Z C 2 will be A by d minus x into the constant K which is actually consist of mu not epsilon naught and epsilon r. So, that, at this point of time, we keep it as constant. Then, if you find out Z C 1 plus Z C 2, that comes as A by d plus x plus A by d minus x, and then, Z C 1 minus Z C 2, Z C 1 minus Z C 2 comes as A by d plus x minus A by d minus x.

So, if you can, if you again we write by Z C 1 minus Z C 2 divided by Z C 1 plus Z C 2, if we write, that actually terms of the A goes off.

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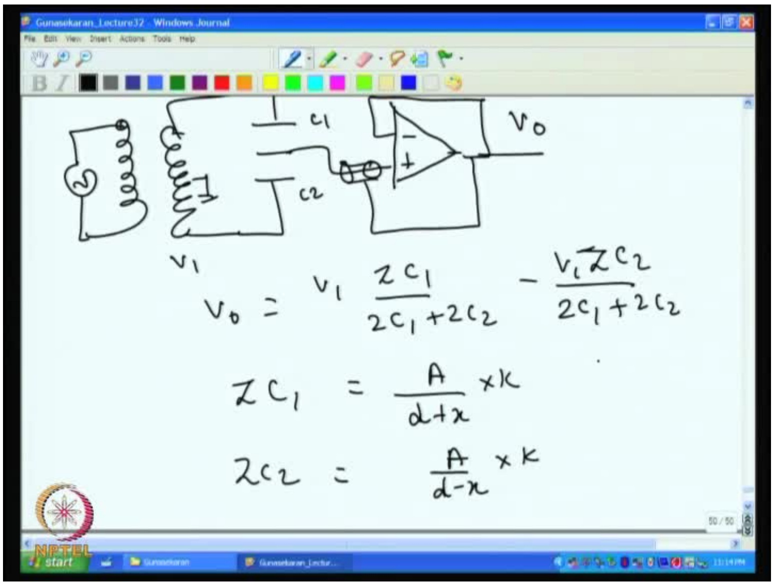

So, you will have at the as a upper term 1 by d plus x minus 1 by d minus x divided by, you will have 1 by d plus x plus 1 by d minus x, that is what it turns out. That is the effect of this one, only then we have to take V 1 factor to get into V naught.

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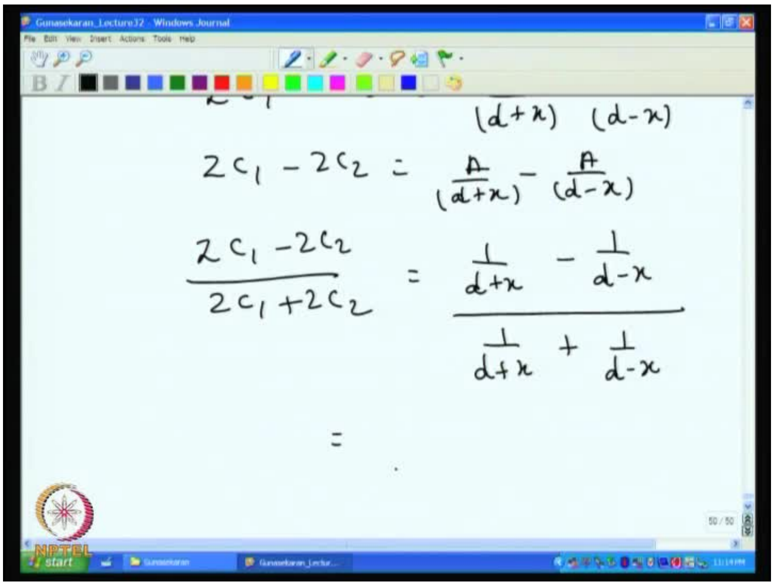

So, if we simplify this, you will get similar terms. Actually we had A, in the previous term, that is in the previous equation, we had A plus 1 plus x and A minus 1 minus x we had. Here also we come it is space, we have written as, to it is, this, here we have written as space variation.

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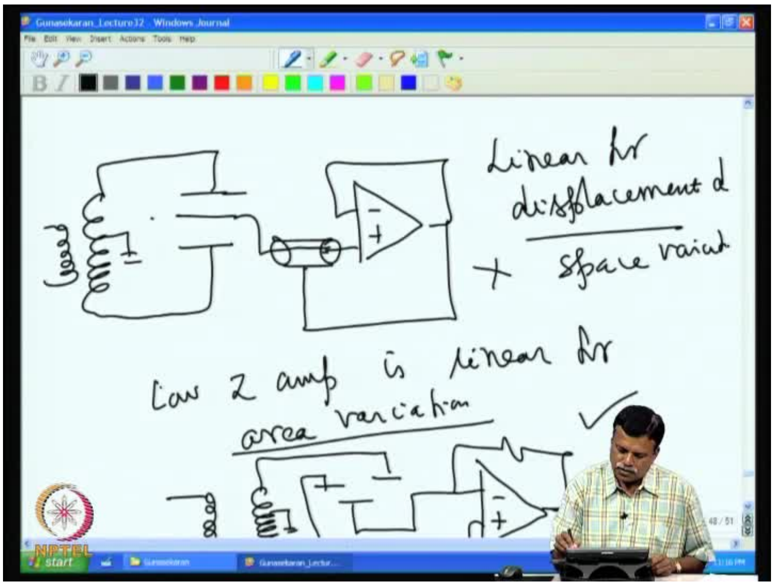

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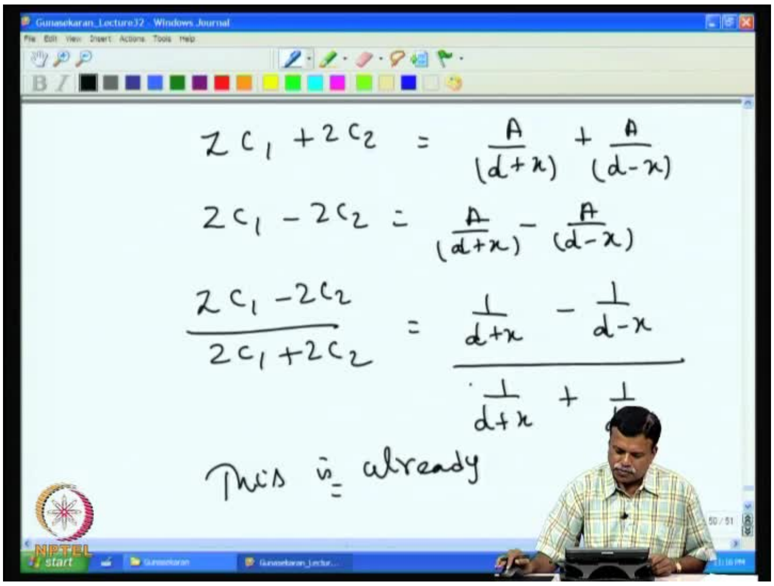

So we are taken this as area variation, so, that is a small correction. So, what I do is that the second equation, then take it as area variation, not as a space variation. So, this is anyway linear, so, if I had to take area variation here, I have to connect as Z amplifier for linear for displacement d. This is for space variation, this for the area variation. Then, high Z amplifier for space variation, we are already done this. This is already done, this is already done.

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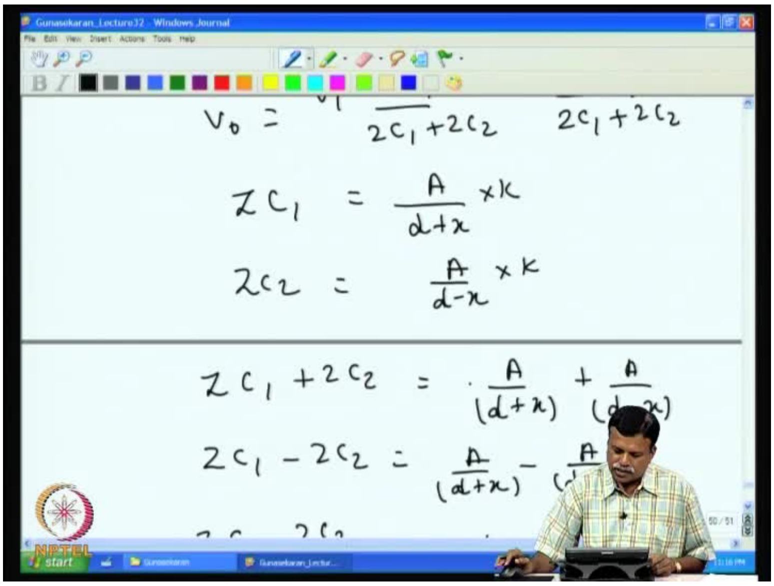

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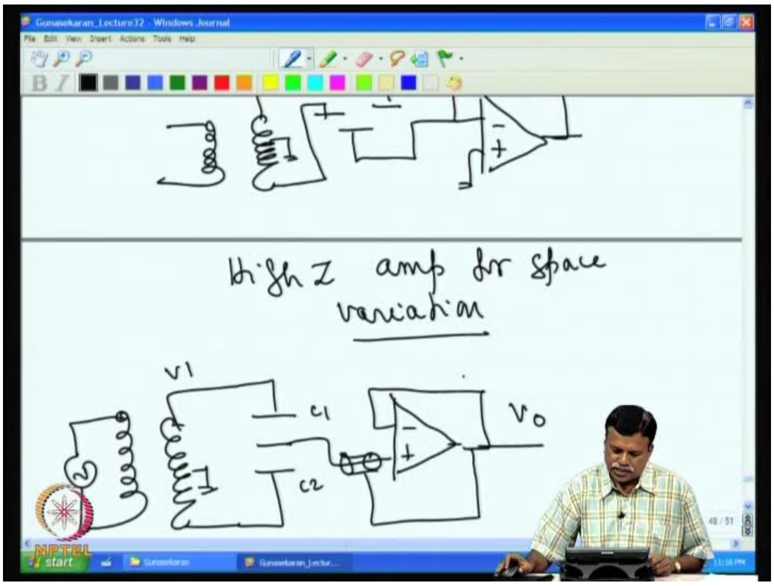

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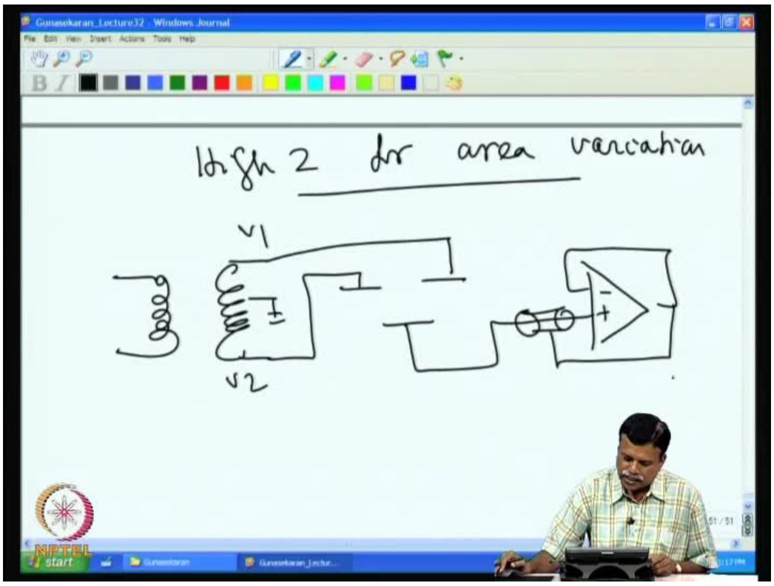

So, we take next area variation. So, if it is area variation, then we had to take it as A into 1 plus x into A into 1 minus x. High Z space variation is already done, high Z, high Z actually space variation is already done. I will do now a high Z for area variation. This is already done. So, high Z for area variation I do it, high Z, high Z for area variation. Here, actually we will have a source. We can have two voltages - V 1 V 2, so, we will have.

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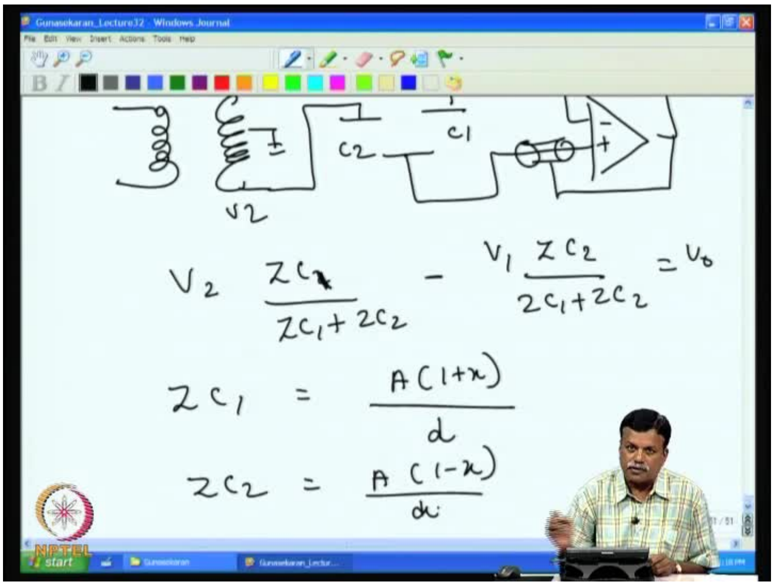

So, again we will have our guarding technique. So, if you write the same voltage equation for this point, you will get V 2 into V. We take it as C 2 and this is C 1, V Z sorry, V 2 into Z C 1 divided by Z C 1 plus Z C 2 plus that is the other contribution due to the other source that we take it as V 1 into Z C 2 divided by Z C 1 plus Z C 2, that is equal to V naught. Now, we can find Z C 1 and Z C 2.

So, Z C 1, actually comes out to be, we have to try for, suitable for area variation. So, that will comes as A into 1 plus x divided by d, and then, Z C 2 will come as A into 1 minus x divided by d.

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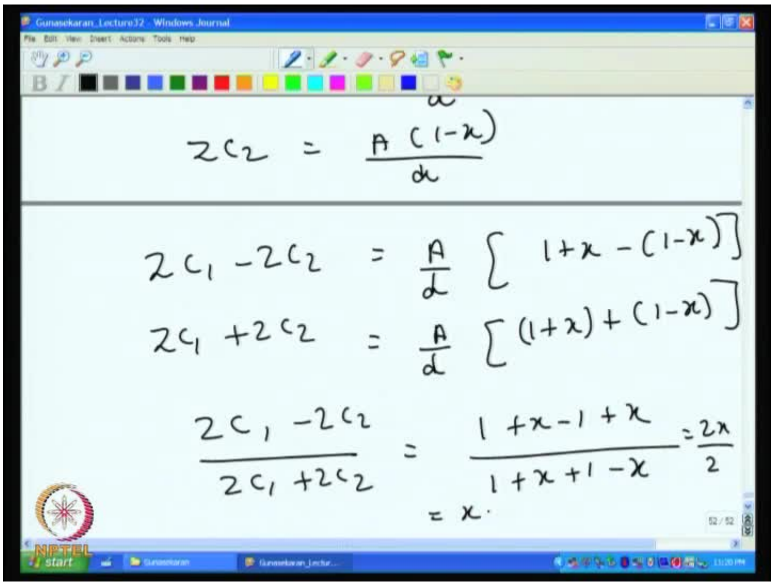

So, that, if you simplify, so, that comes Z C 1 minus Z C 2, that will turn out to be A actually by d is common. So, will have 1 plus x minus of 1 minus x, and then, Z C 1 plus Z C 2 will turn out to be A by d is constant. Then, you will have 1 plus x plus 1 minus x.

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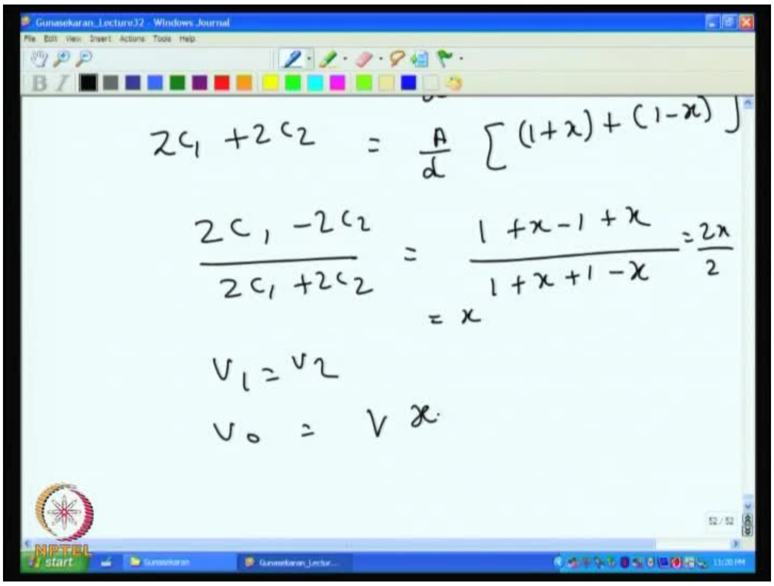

So, we can find now Z C 1 minus Z C 2 divided by Z C 1 plus Z C 2 will turn out to be 1 plus x minus 1 and plus x, and then, the bottom 1 turned out to be 1 plus x plus 1 minus x. That turns out to be 2 x by 2 that comes as x actually. So, Z C 1 minus Z C 2 comes as

x. So, that will give, that output voltage V as, if V 1 is equal to V 2, V 1 is equal to V 2, then V 0 will come V into actually x. It is again, it is linear actually.

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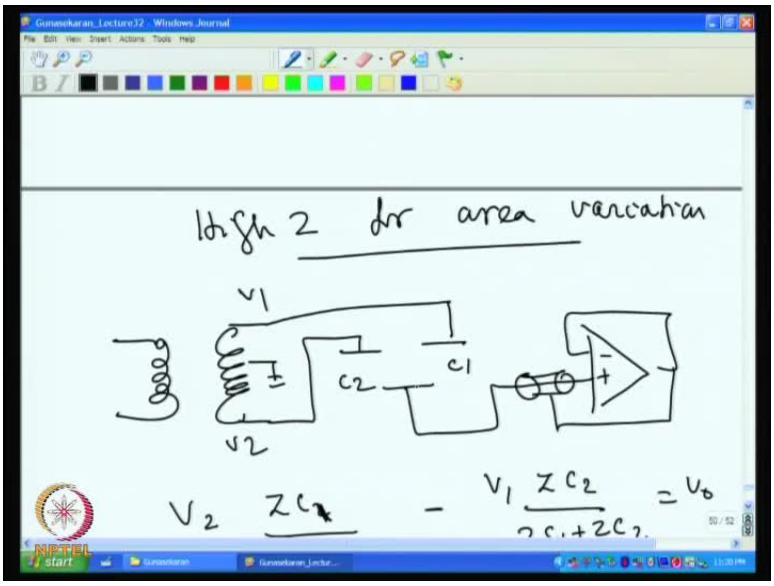

So, high Z for area variation is turns out to be again linear. High Z for space variation, for space variation, it is a linear. So, now, we are seen all the 6 circuits, how each one is the behaving for displacement. So, high Z for area variation turns out to be linear.

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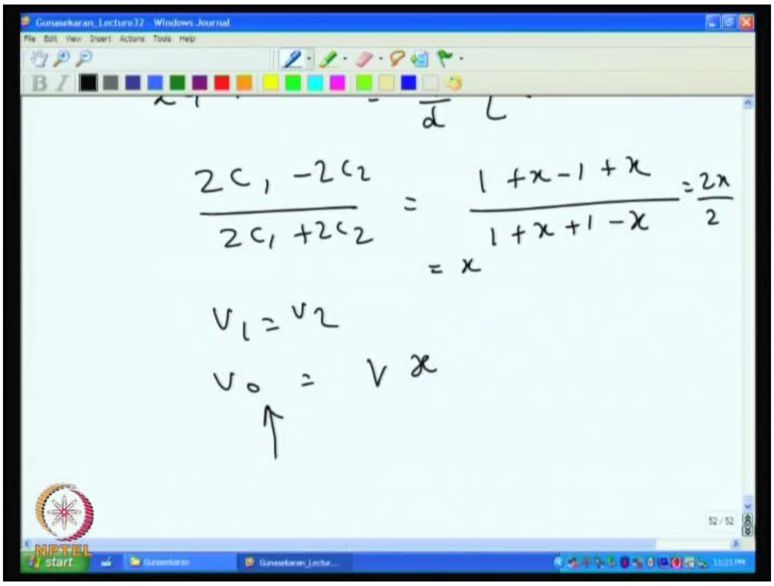

Now, we can select a circuit which is actually suitable for given application. Of course, when the output voltage is not 0, we had to worry about the stray capacitance problem.

So, these 6 circuits can be selected for the any particular application. Now, one may wonder that why the feedback is not given for low Z amplifier and made the output 0. One can try that also, so, that will give you 8 different circuits and that is to be analysed in a systematic manner.

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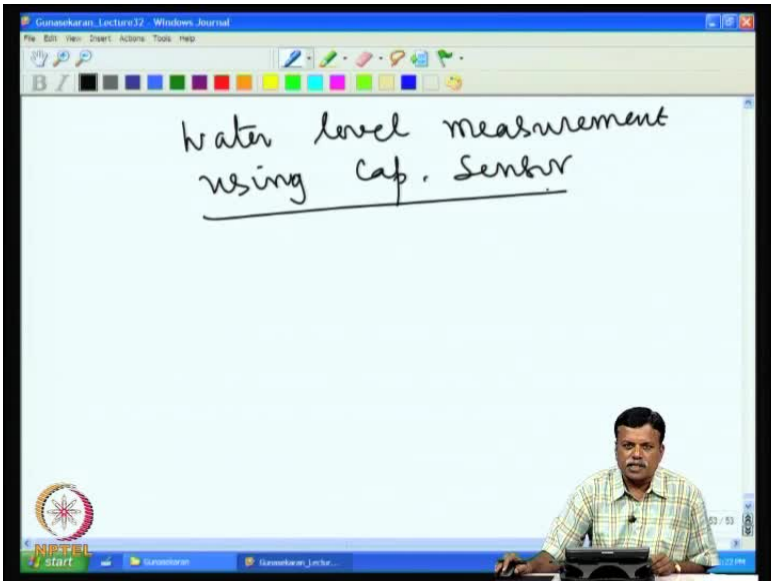

Now, let us turn in to another application, that is, how to, how to make a water level measurement, water level measurement using capacitance sensor.

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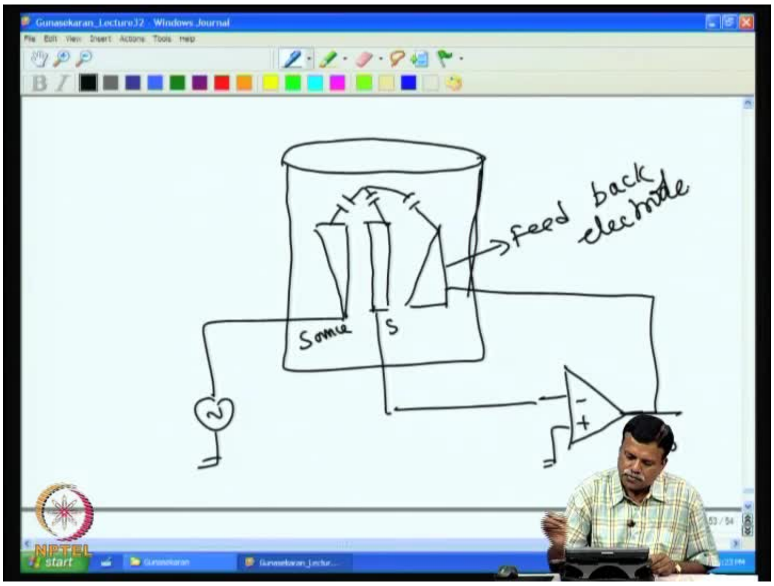

Now, this is a technique that is used to measure the overhead tank, the level of the water. So, what is done is you have this and then put the two plates. One plate like this, then another plate in an inverted manner, then another sense plate which is in between these two, which is pasted outside the tank actually, and then, this is connected directly to the amplifier.

So, the amplifier is done like this, that is, you have amplifier, then this is actually we have a ground here. Now, the output minus, now, this is connected to this; then, sense amplifier is connected to this, and this is connected to the source.

Now, this output now depends upon the water level, and it is a wonderful circuit which has very less effect due to the stray capacitor and so on. Now, if water is there, essentially we have a capacitance formed from here to water and water to here, and then, from here to water, and then, to the sensor electrode. This is sensor electrode; this is a source electrode; this is feedback electrode. (Refer Slide Time: 51:40)

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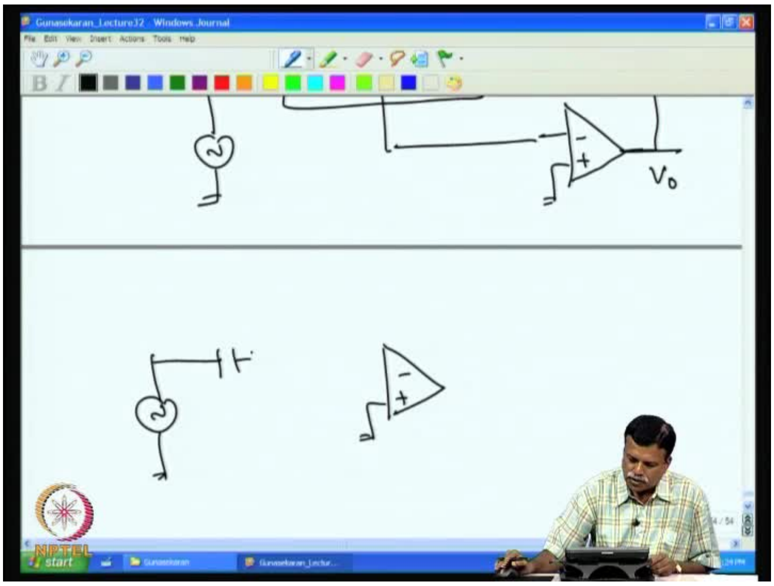

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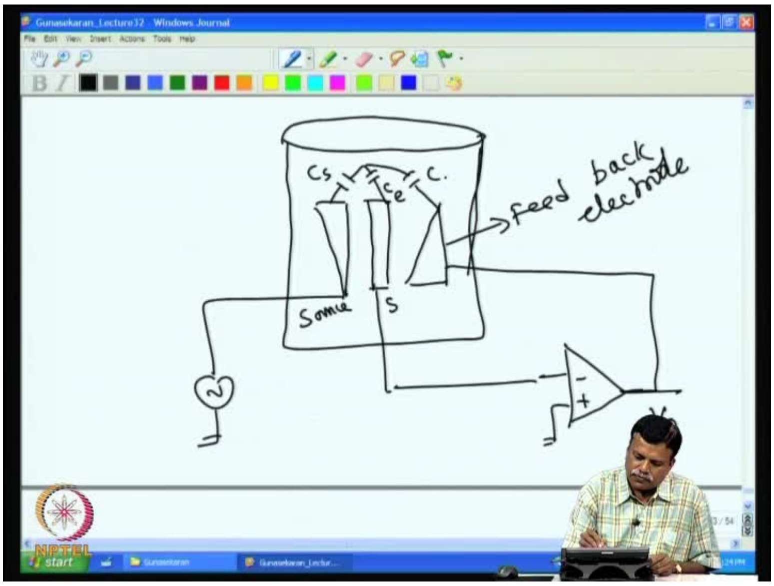

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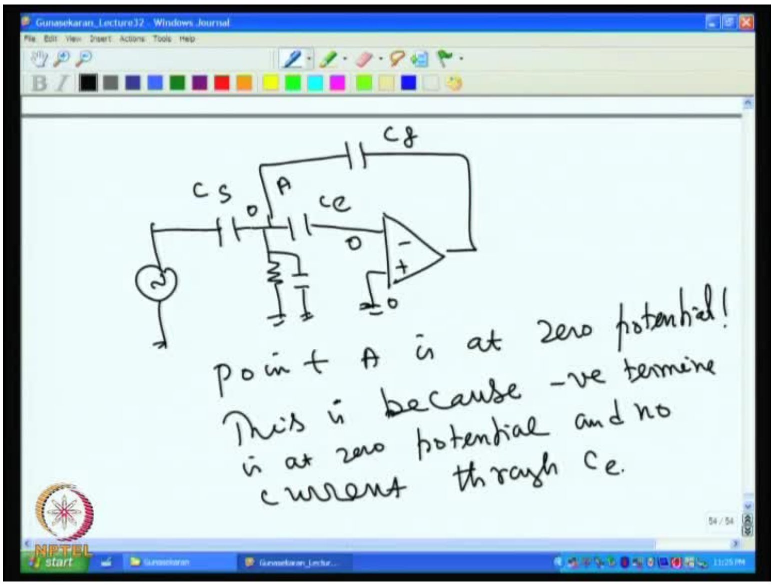

Now, if you draw the equivalent circuit of this, that turns out be like this that we have a source. The source is connected to the input through two capacitances, that is, we have one capacitor that is the C s and then C electrode and C feedback.

So, we have C s and C e coming in series to this, and the feedback capacitor comes like this, and then we can also have, we may also have leakage current to the ground from the water. So, that can be shown like this.

So, the equivalent circuit for this turns out to be C s here, and then this is C f and then C e. Now, but we know that this is ground potential, this is also 0. So, one can assume that this is also 0 potential, because when this is 0, there is no current flowing here. So, this also has to be 0 only. So, that is this we call point A, so, point A, point A is at 0 potential. That is the crux of the controller here. In that case, this is because, this is because negative terminal is at 0 potential and no current, no current, current through C e.

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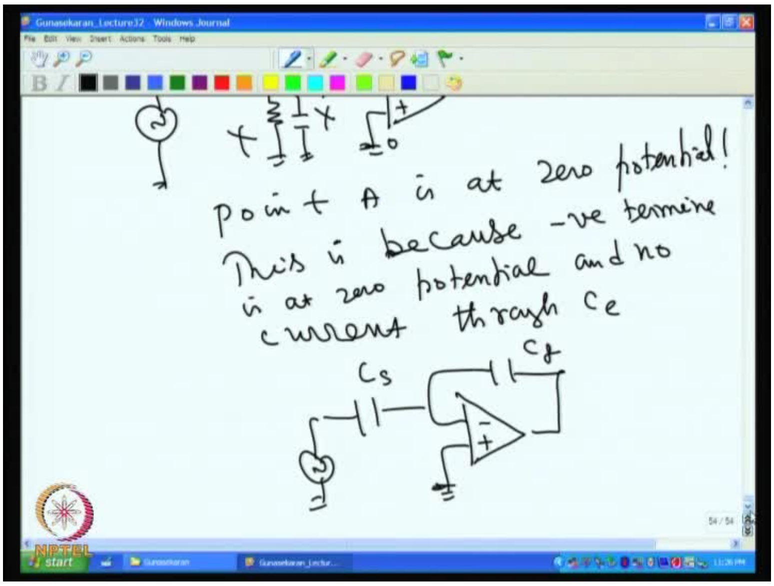

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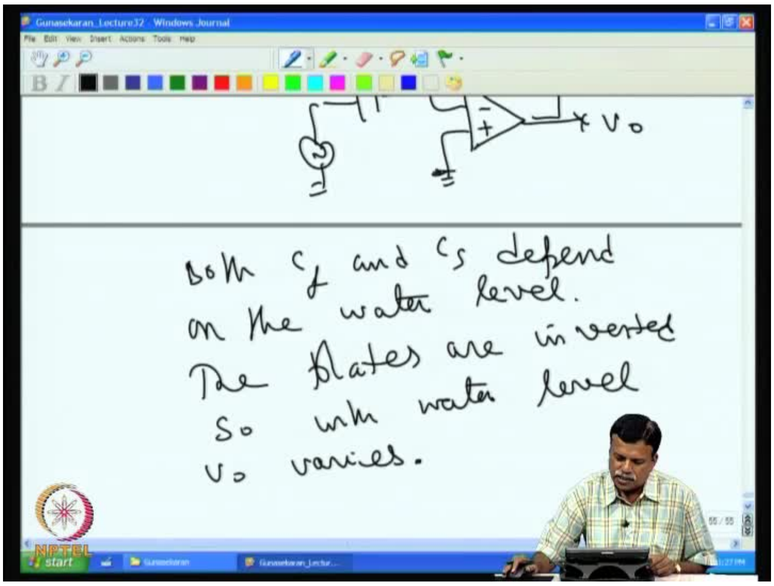

So, we can now, the, draw the equivalent circuit as like this. That is I can have circuit like this and then have this. So, if this is 0 potential, I can ignore this and this and as well this, because there is no current through this, so, all these three parts can be ignored. So, the equivalent circuit become simply the two capacitors, and both of the depend upon this is C f and that is C s, both C f, C s and C f depend on the water level, both C f, both C f and C s depend on the water level. The plates are inverted, plates, plates are inverted. So, with water level, output V 0 varies, that is, V 0 varies.

So, this is a wonderful circuit, wherein, the stray effects are actually removed. So, we had seen now different circuits to for capacitor measurement. Essentially there are eight different combinations possible but it is better to use inverting amplifier configuration. So, the stray capacitance effect is not there. So, of course, the basic circuit one can think of for capacitance measurement would be Ratio Transformer Bridge.

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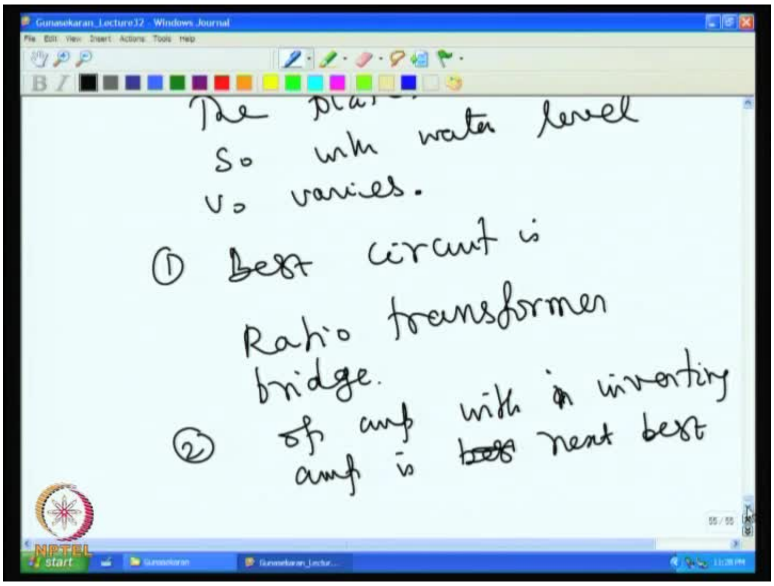

So, the best circuit is, the best circuit is ratio transformer technique, but then this cannot be used on today’s world, because one need to have a manual balance but op amp circuit, op amp with non-inverting amplifier, inverting, with inverting amplifier, inverting amplifier, amplifier is the alternate option inverting amplifier is best, next best.

So, with this, I will stop the capacitance measurement technique, and in the next class, we will see A to d convertor and d to A convertor construction, and then, usage details in detail. Thank you.