Circuits For Analog System Design
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Lecture No. # 31
Capacitive Sensor Circuit Design Examples

Today's lecture we will discuss about, capacitive sensors. So, how to use the capacitive sensors? How to do the signal conditioning, for capacitor sensors and then various and it is various application also we can discuss in today's lecture.

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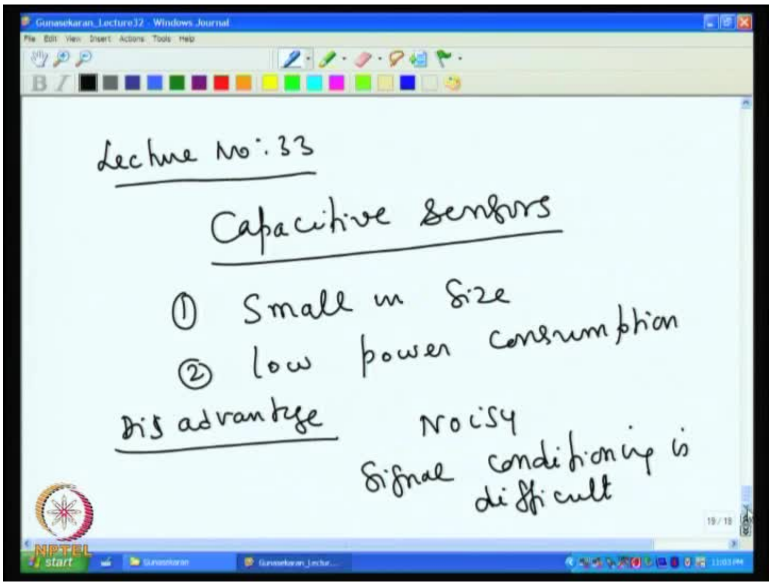

So, our topic would be capacitive sensors. Now, the capacitive sensors are very popular nowadays because, they are because of very its small size, small in size and then low power consumption. Because of these two reasons; they are very popular. Earlier, this capacitive sensor was not popular mainly because, signal conditioning is very difficult and they normally picks a, were picking a lot of noise. So, the disadvantage with capacitive sensors are, disadvantage is actually, mostly noisy and signal conditioning is difficult, signal conditioning is difficult. So but, nowadays these problems are overcome and now capacitive sensors used extensively.

For example, even our vernier caliper and all the capacitive sensors are used and then they finally, give a digital display of a displacement in the vernier caliper. That level of usage are come for capacitive sensor and capacitive sensors will be will be used more and more in future, because it is of low power consumption and of very small size.

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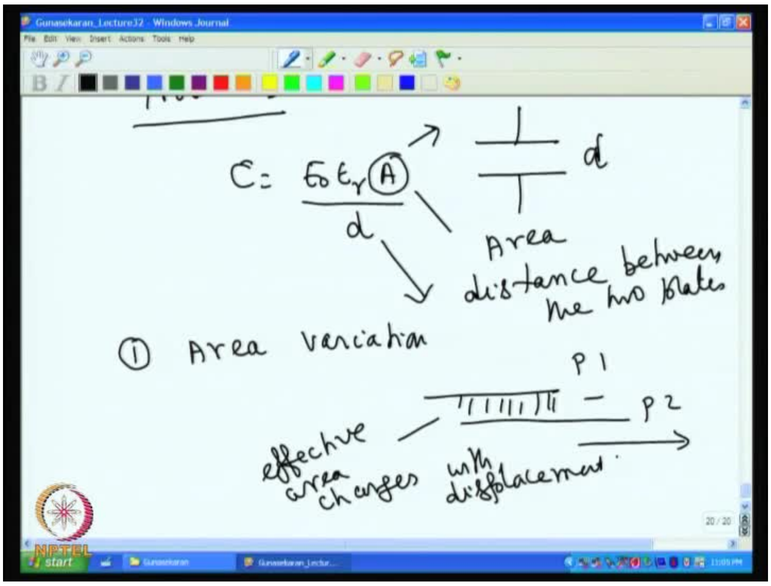

So, let us see, the problems associated with the capacitive sensors. Now basically, capacitance actually given by basically two plates separated by a dielectric, which already discussed. And here the distance is d, and then the c actually is given by epsilon naught epsilon r A by d. So that the; one can use this capacitive sensor, either for area variation because if, A varies then capacitance also changes, where A is a area of the plate, d is the distance between the two plates. Now, so obviously the two possibilities I can use as a sensor, either for area variations. That is, if I vary the area of the plate, then the area variation can result in a capacitance change and that capacitor can be used, for sensing. So area variation can be used.

Wherein, you vary the distance between the two plates, you have one plate here, another plate here. Plate 1, and plate 2, and then for example, one is move relative to the another then, the effective area what you have here, effective area varies. So, effective area changes with displacement. Other possibility is space variation, distance variation.

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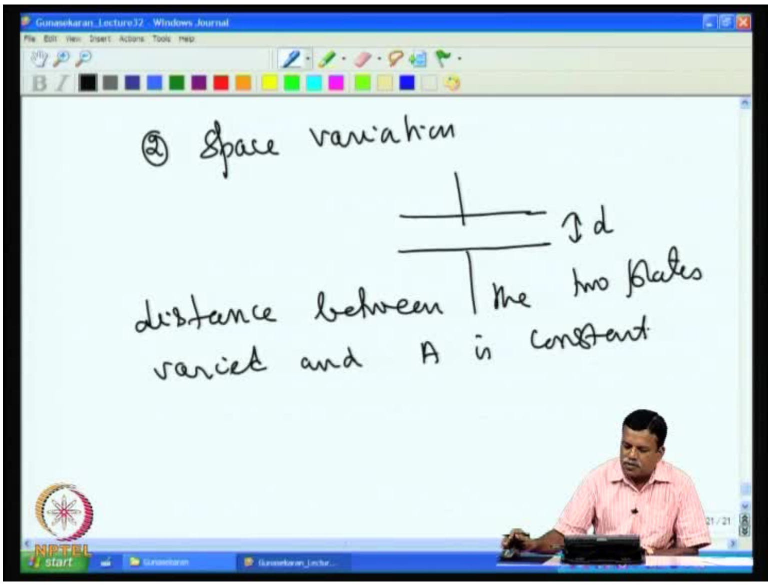

The second possibility is, space variation. That is we can have two capacitor plates. And keep the area same and vary the distance d, the distance between the two plates. So here, distance between the two plates are varied and keeping the area constant distance between the between the two plates varied and then A is kept constant. So, this is space variation can be also used.

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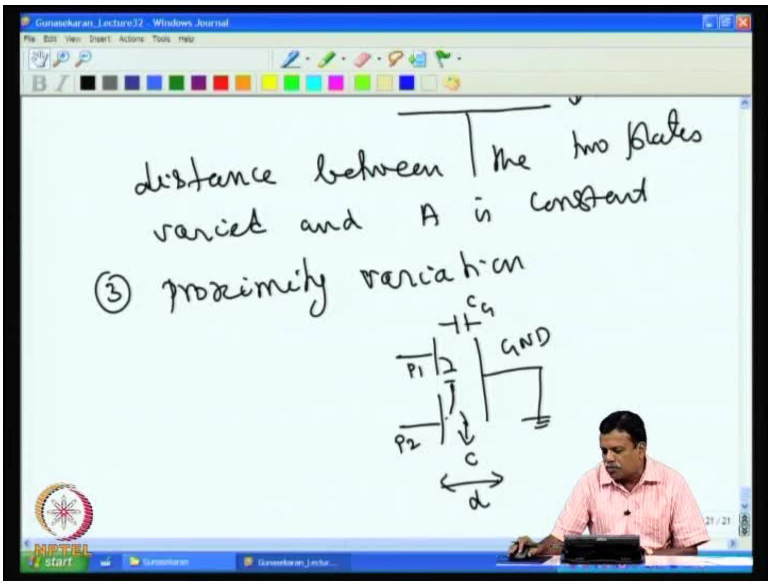

There is another, yet another method possible that is actually, proximity variation. We can also use this technique proximity variation. In this case what is normally done is that, you have two plates. Then it is another third plate, grounded plate. Now, I have a here one plate another plate, then you have a capacitor between these two, that is the C. Then you have actually capacitor between this and this C G. So, when the ground plate, this is a grounded plate. So when the ground plate this distance varies for example, this distance d, the distance between the the distance between the ground plate and the active plates, say P 1 and P 2. The distance between these two varies.

For example, I can move the ground electrode. If I come very closer and closer, you find that this capacitance is decreasing and if I go more, move away, then this capacitor is actually and also as I move away, this capacitor is increasing. So, this actually, this also can be used to sense the displacement.

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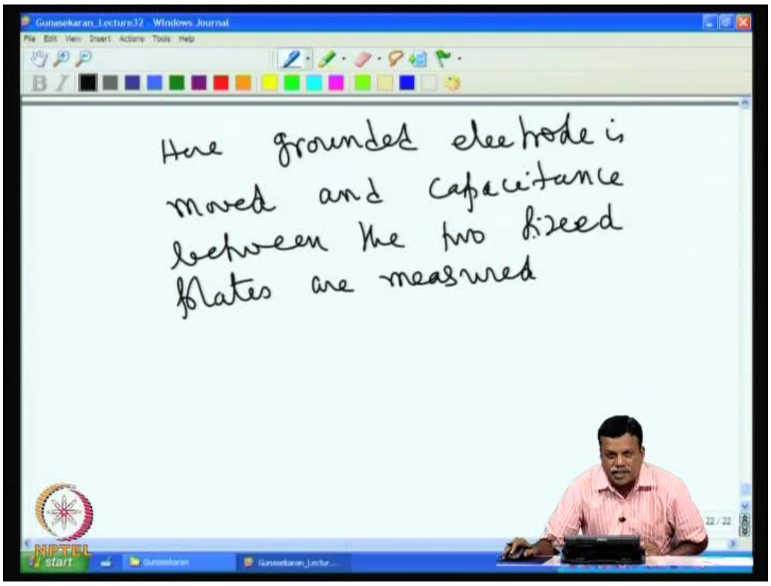

So here, in here grounded electrode is moved, grounded electrode is moved, is moved and capacitance between the capacitance between the between the, two fixed plates are measured fixed plates. So, this because of proximity effect, this happens and then here are this technique also can be used to measure the displacement. So essentially, we can vary the measurement displacement either by area variation method or space variation method or the proximity effect; using the proximity effect. Now we will see in each of this, how that can be used for different purpose.

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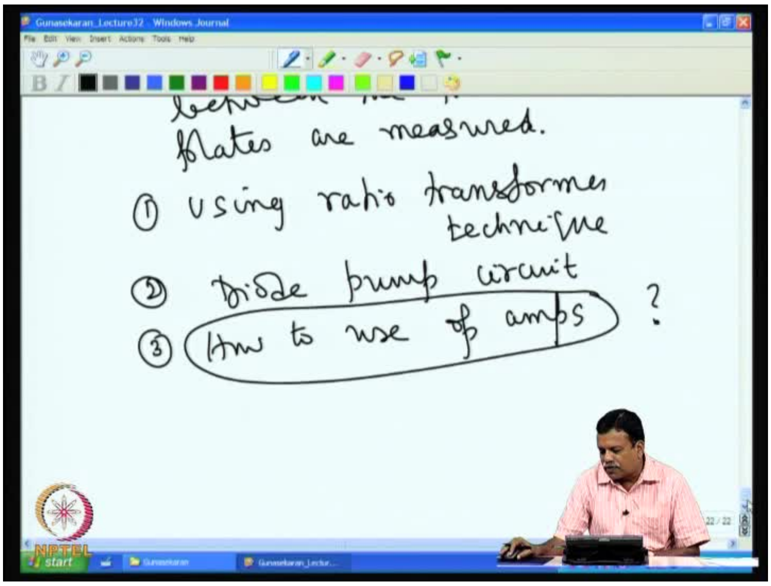

Now, let us see a general capacitive measurement technique. First using op amp, because earlier we had discussed capacitive measurement, using a ratio transformer technique that is, that earlier discussions were about using ratio transformer technique. Then we also discussed about diode pump circuit. Now we discuss about, how to use op amp effectively, how to use op amps effectively for capacitive measurement. Because, this is what now we going to discuss more in this lecture, how to use op amp effectively for capacitive measurement.

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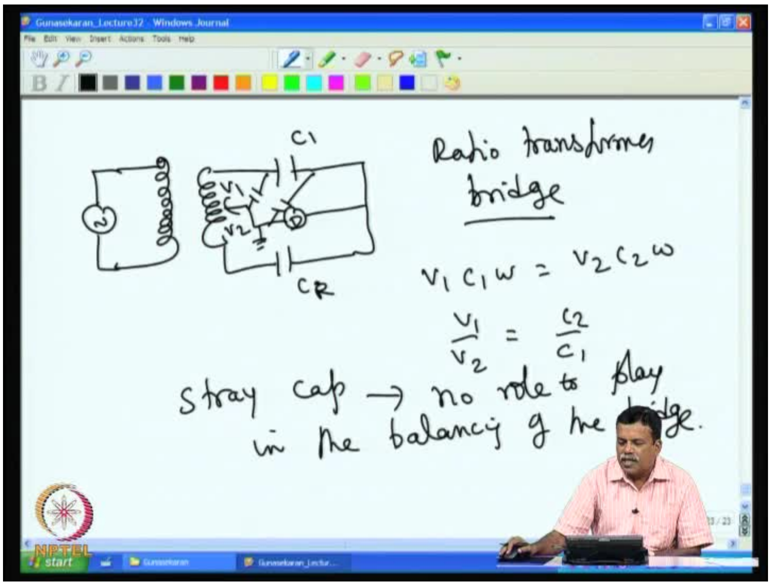

So, if you recall our earlier technique; that is a ratio transformer technique. There we could able to measure the capacitance accurately. Mainly because, we were able to remove the ground capacitances. Because, if we have a capacitance like this and then we had shown that, we can have detector here and if the detector is detected here. Then, this capacitance is C 1 and C 2. C reference is here, then, you have a detector here and this is energized with the AC source. Now this actually V 1, V 2 you had and then normally what was done in the in this circuit was, this is a, this is a ratio transformer bridge, this is a ratio transformer bridge. In this case, we varied the center tap, such that you get a null at the detector.

So for example, if C 1 and C R are equal, then you will get V 1, V 2, are equal. Because, the current actually flowing like this and this current actually flowing like this. So, if both the currents are equal, then it will actually balance out and that way V 1 the current comes as V 1, C 1 omega will be equal to V 2, C 2 omega, that is what, we get. And V 1 by V 2 will come as C 2, by a C 1. And in this method the stray capacitances were removed actually, this stray capacitance which we which, we had at the two ends; this is kept as an measurement. So it has this stray capacitance 1 and then stray capacitance 2 these; they do not contribute for the balance because, this capacitor is actually powered by the source and the source is the low impedance.

So, it has no effect and this capacitor actually sends only the detector. So, at null point there is no current through this. So, the stray capacitance has no effect in this method. Stray capacitance has no effect. Capacitance no role to play in the balance, in the balancing of the bridge, so it is very accurate. However balancing the bridge is the main issue, so that is why this is the not very convenient for instrumentation work.

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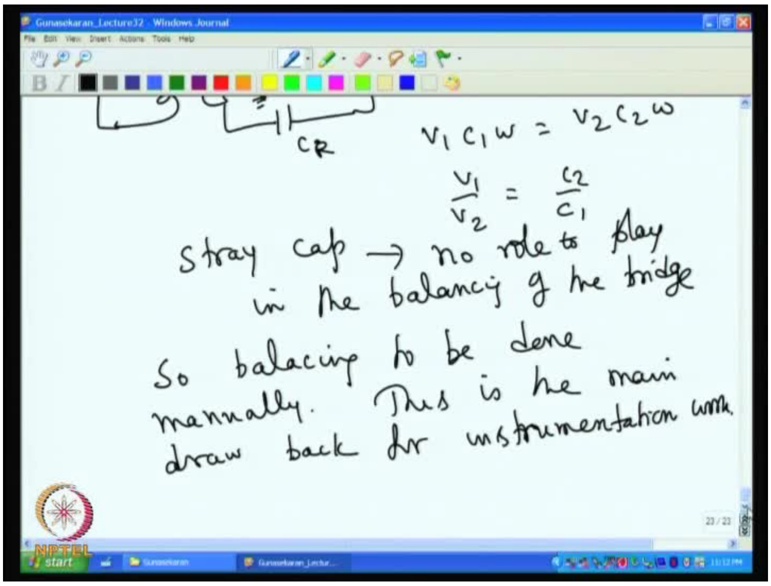

So balancing, so at balancing is a balancing to be done to be done manually. This is the main draw back of this circuit. Main drawback for instrumentation work. Now, so people are not using this very much except that standard equipment is there. We can manually balance the bridge by varying the center tap. We also discussed about this earlier.

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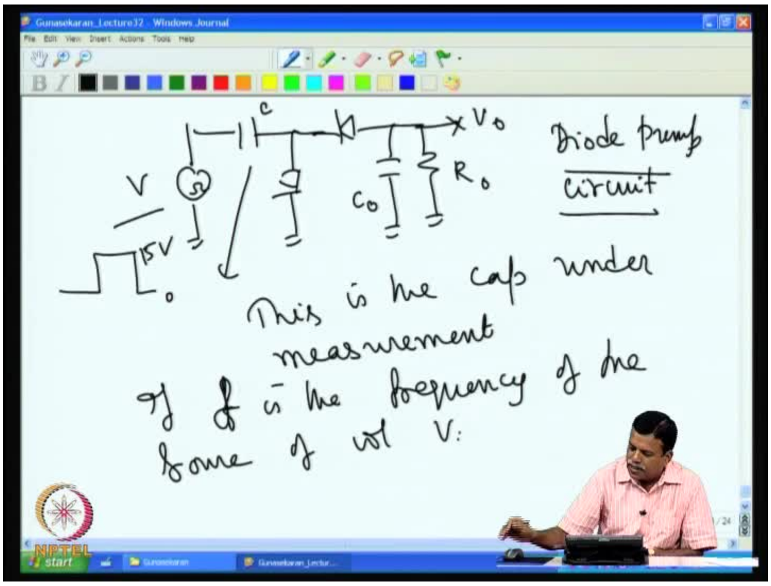

Now, the next technique that was came was that, diode bridge pump circuit there wherein that you have a square wave and connected to the capacitor like this. And then we had a voltage coming here and then output is, this is the output voltage. And you have

R output, you have resistance here the capacitance; this is capacitor under measurement. So this is the capacitor under measurement. This diode pump circuit, this is the capacitance under measurement. Now in this case, the square wave source of voltage V actually goes 0 to say, 5 volt or 15 volt. So if you have this one, then initially you look this source when it is going positive charges up this capacitor.

And then, when it drops to 0 then this capacitor discharges to this. So it finds a path like this and discharges. So the energies when it is high the capacitor charge, it goes to 0, the capacitor discharges the charges to the output capacitor. And then the output capacitor voltage builds up that also leaks through this R naught.

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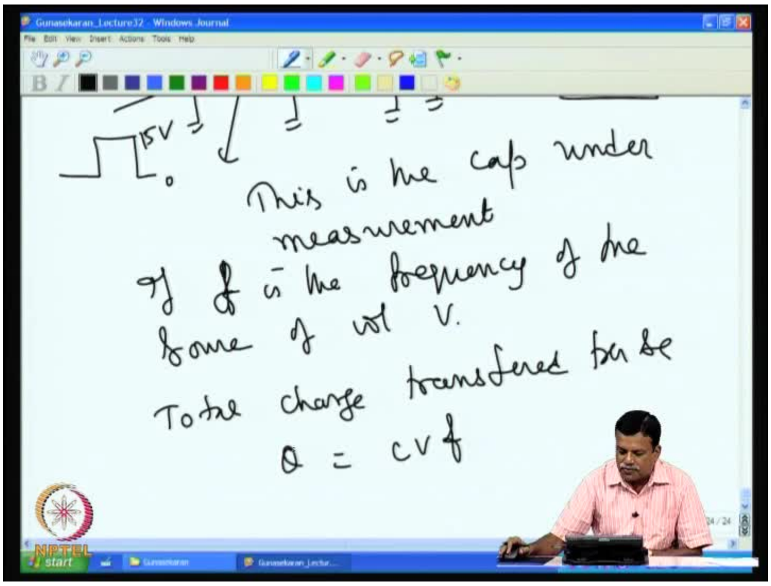

So we were shown earlier, the total charge transfer if frequency is f, the frequency of the source is f, if f is the frequency of the source of voltage V, then total charge transferred, total charge transferred per second would be C into V into f. Because, C is the capacitor measurement and it is charged to V. So quantum of charge that its one cycle is C into V and the total quantity become Q becomes, CVf. And if the, if the so it continuously delivers the charge to the output capacitor. So this much of charge is delivered, continuously to the output capacitor C naught.

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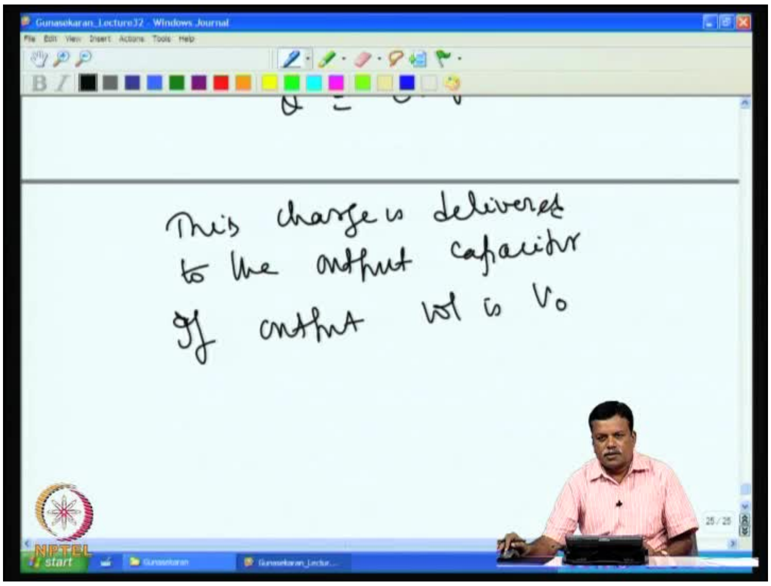

This charge is delivered to the, charge is delivered to the output capacitor. If output voltage is V naught, if output voltage is V naught, V naught then the amount of charge leaving the leaking through R naught would be the amount of charge leaking through R naught would be...

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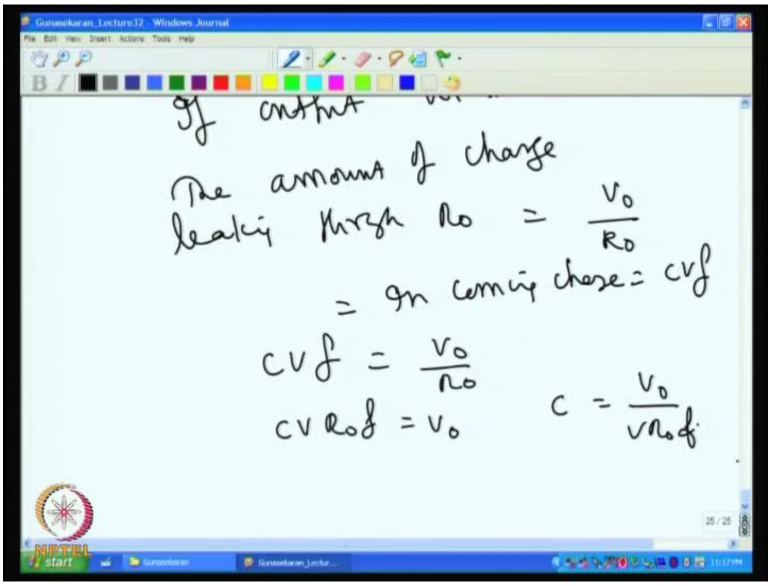

The quantum of amount of charge leaking through R naught would be equal to V 0 by R naught. So, this must be equal to the, this must be equal to in coming charge, in charge that is equal to CVf. So, essentially CVf is actually become V 0 by R naught. So, you will get output voltage in terms of capacitance.

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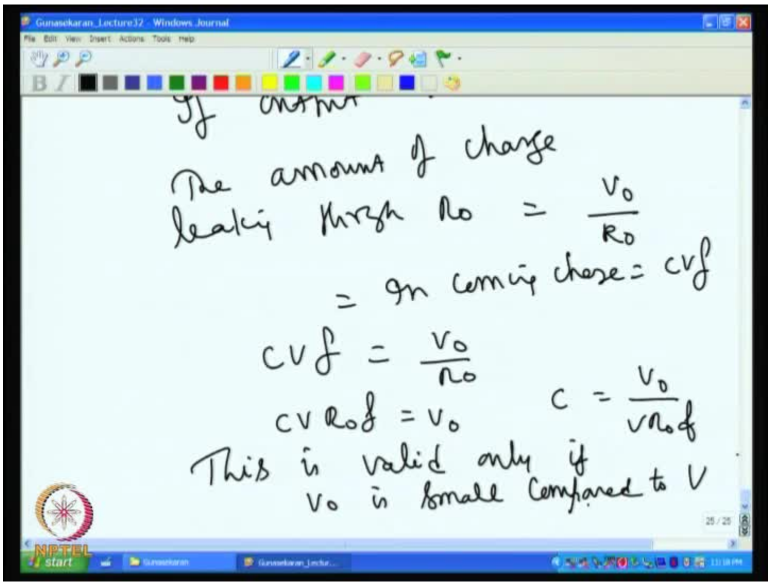

So, CVR naught f becomes, V naught. So C actually can written as, V naught by V into R 0 f. So, the capacitor output from V naught, we can find the value of the capacitance. So, this circuit works well. But, not good, for very low capacitance. Because, few 100pf it is good, because the capacitor is getting charged. And then, as it discharge to this, this voltage rises up. The output voltage rises up and then this capacitor does not discharge fully, because the whatever voltage that is here that much voltage is lost. So, ideally it is it assumed to be linear. But, in reality that since, this voltage slowly increasing its non-linear provided it can be made linear, only if V 0 is kept very small. So, this is true only if V 0 is small, compared to V. So, this is valid this is valid only if V 0 is small compared to compared to compared to V. So, normally we can select R naught to keep V 0 few mille volts.

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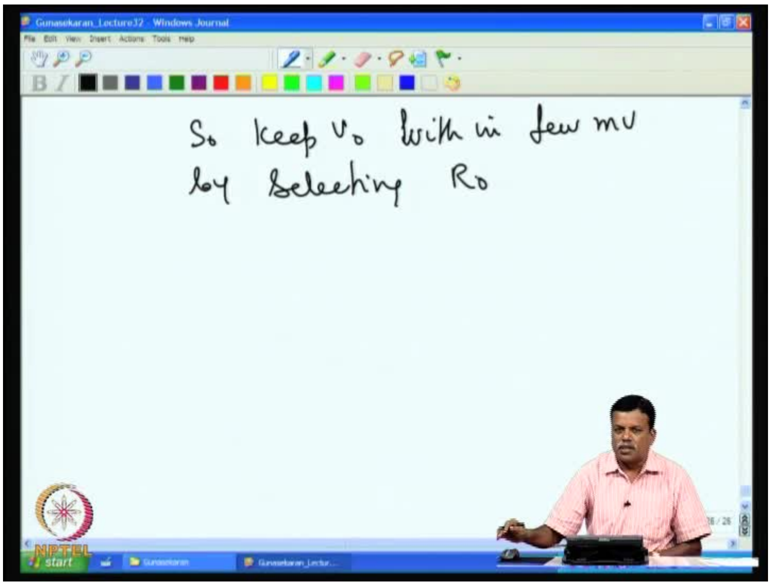

So, keep V 0 for within few mille volt by selecting R naught.

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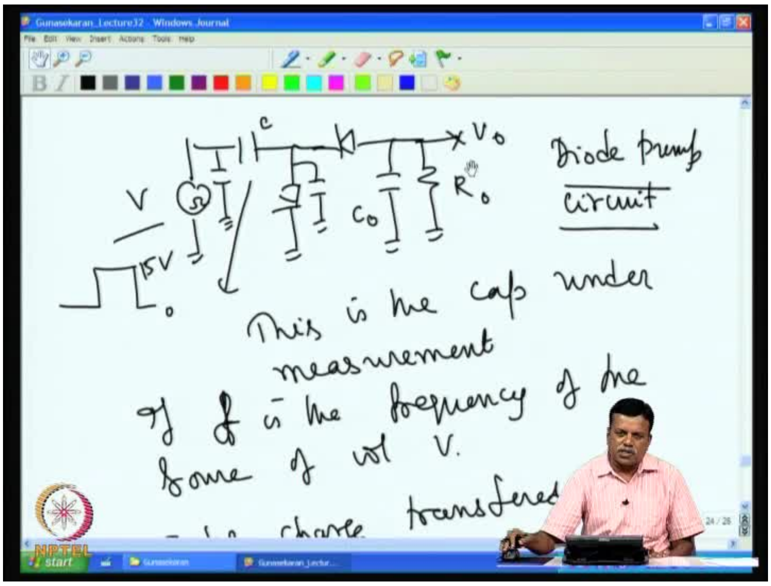

So, this error plus there also other errors because, you have the diode is conducting and then if you have a capacitance at the other ends. For example, if you have a capacitance from here to ground. Now this is charged and discharged through this one only. If you have capacitance here, capacitor that is under measurement that is, this capacitor may have capacitor both the sides to ground. And this capacitor contributes little to the output because, when it is conducting this capacitor discharged and then, this capacitor getting charged along with this. And then it goes 0 this also discharge, discharges and even this capacitor also discharges. And this contributes little to the output. So it is not very accurate but, nevertheless this is for purpose of 1 or 2 percent accuracy.

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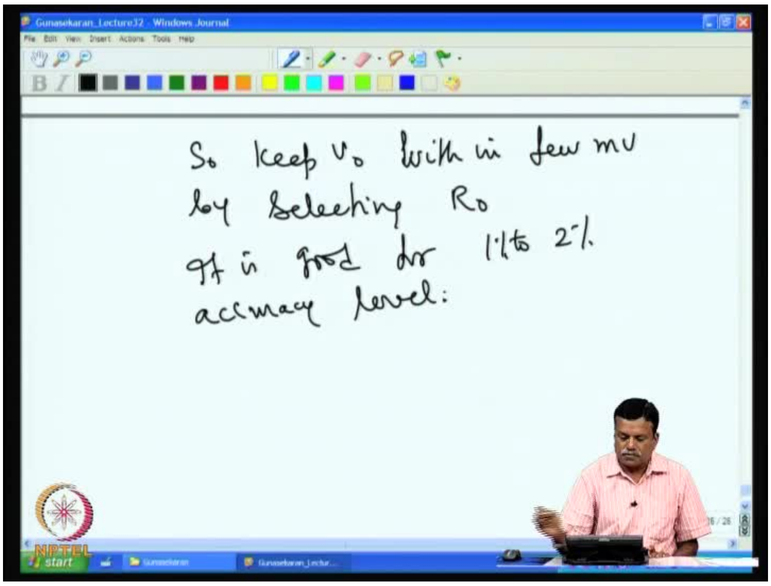

It is good. It is it is good to have good for 1 to 2 percent, 1 percent, 2 percent accuracy level. So, how to tackle the how to make measurements using a op amp.

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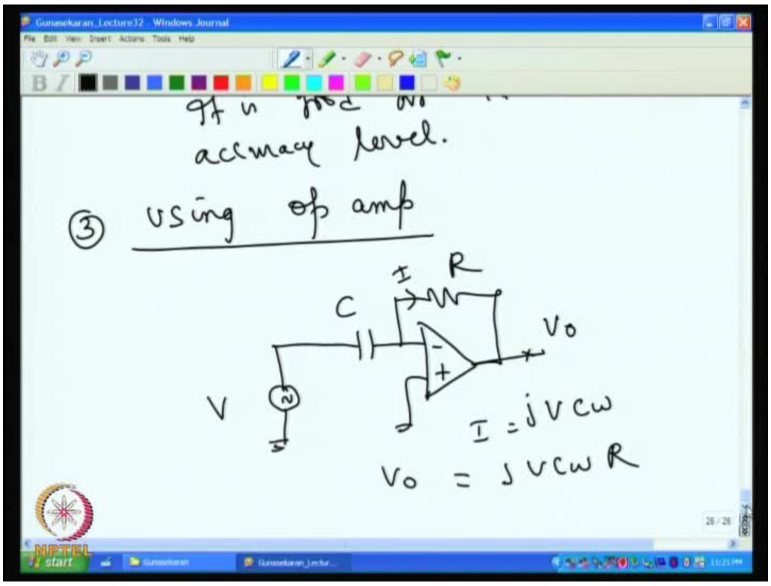

So, third technique at that what we going to discuss in detail would be, using operational amplifier. Now, if you want to measure the capacitance in operational amplifier, then one possible solution would be that, I can have a ground then I can have a capacitance here. Then I can have a say sine wave source connected here, then have a output feedback resistance R and C and the output voltage V naught. In this case, the current that is following through that, the AC source actually drives this capacitor, and current flows through that and that actually flows through this R and then return backs to the ground. So, that develops a voltage V naught, so the current I into R gives you the output voltage. So the current I actually is given by, if this is V then V into C omega of course, with j and then multiply by R output voltage that is comes jVC omega into R

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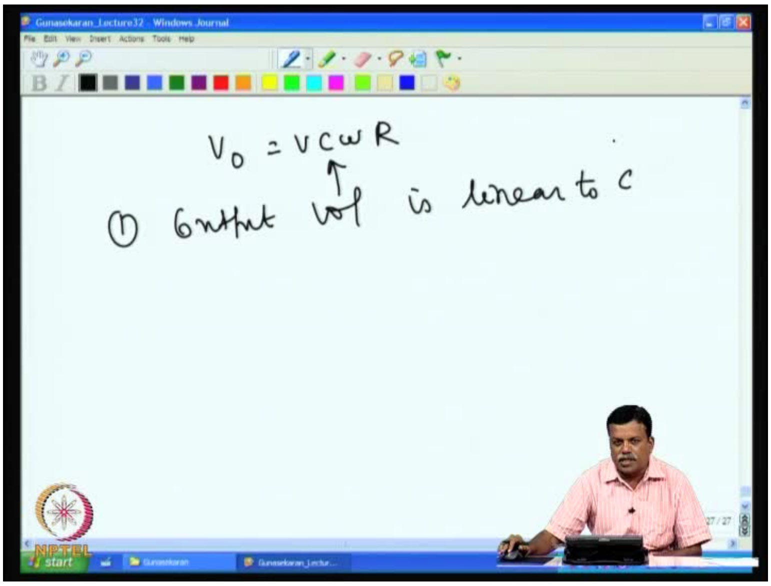

So, if you take the magnitude that actually comes as, the output voltage comes as V C omega R. That means the output voltage proportional to capacitance C, so output voltage is proportional to output voltage is linear to C linear to C.

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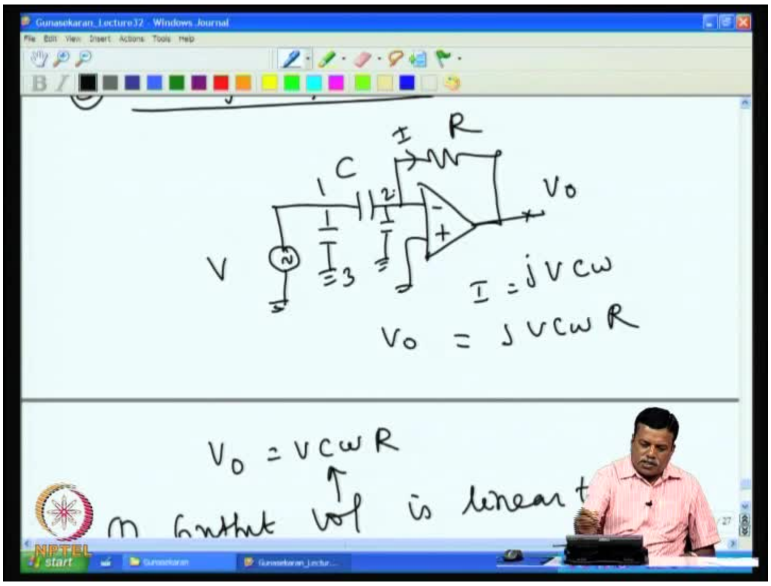

Now, if we see our other earlier discussion that, the stray capacitor is always associated with any measuring capacitance. Because, you will have a capacitance from this point to ground that mostly shield capacitor. And other if you using shielded wire, then we will always have these two stray capacitance with any capacitor. That is why the capacitor measurement is always considered as a 3 terminal measurement. That is you have a ground terminal 3 and measurement terminal 1 and measurement terminal 2.

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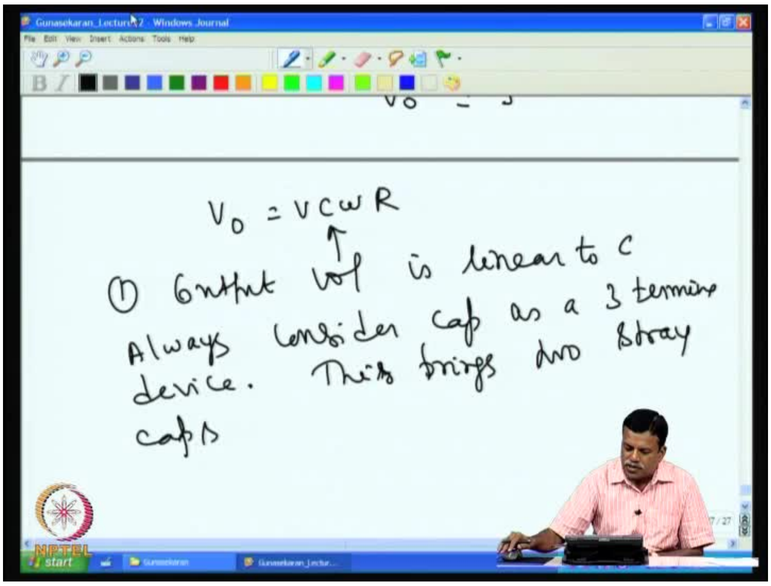

So, if I consider capacitor 3 terminal device. So, output voltage is linear to C then, always consider, capacitor as a 3 terminal device, capacitor as a 3 terminal device. This brings this brings two stray capacitances, two stray capacitances, C 1 and C 2 that is a C 1 and C 2. Now C 1 and C 2 are not producing any appreciable voltage at the output. This is because, if you see the C 1 that C 1 is actually only loads the source. As long as source impedance is low this C 1 has no effect on the output. Similarly, this point is actually at virtual this is 0 so this also 0. So, no current actually flows through C 2, so C 1 and C 2 has no effect at the output. So obviously operational amplifier is a good device to measure the capacitance. Invariantly it removes the stray capacitance effect.

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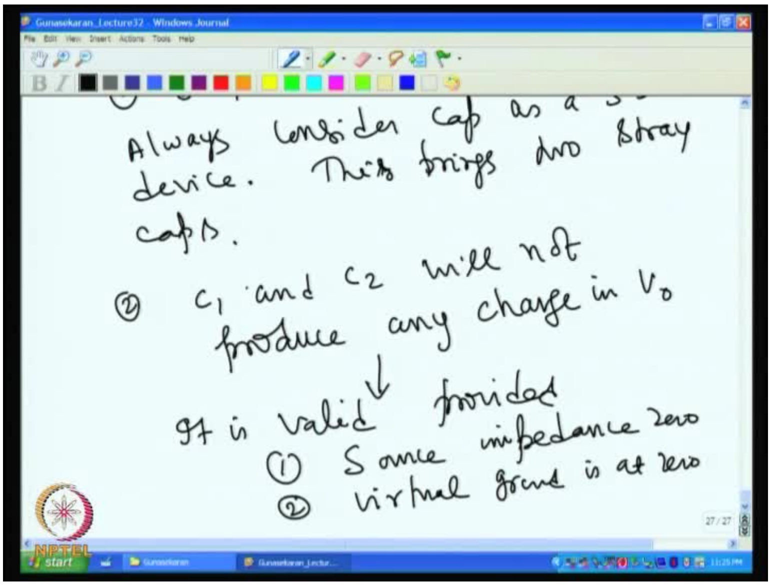

So, this two the two stray capacitance the two that is the C 1 and C 2 C 1 and C 2, C 1 and C 2 will not affect, will not produce any change in the output voltage, change in V naught. This is good this is ideal case but, which is very nearly true. Because, as we the main assumption is that here this has a zero impedance source, zero impedance source and this is also at ground potential. So, the validity of this assumption depends upon the source impedance, and then the gain of the operational amplifier. Since, the gain of the operational amplifier is very high that invariably this is always true. So, it will not produce any change in output.

This actually comes this is valid provided it is valid it is valid provided, source impedance is zero source impedance is zero, and virtual ground is really at zero, virtual ground is at zero which is invariably the case. So if you look at this then, the output voltage will be, will give you a capacitance value. Now if I use this capacitor for displacement measurement, this technique for displacement measurement. Then what is the issue that we will encounter.

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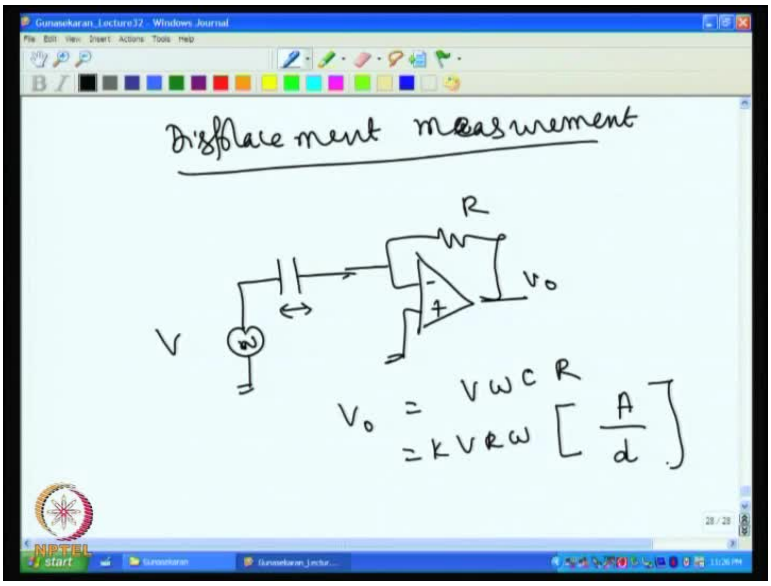

Displacement measurement for, so if you take a displacement measurement then, we will be using we will be using this capacitance here. Then another side, we will be so connecting here the source of voltage V, and then we would be moving the distance. So now, the output voltage which is actually V naught, and this is V, this is R and the V naught actually is given by V omega, V omega C into R. So, if we take this is constant V R omega, then C actually can be written as, A by d. And that constant we can write epsilon, naught can be used.

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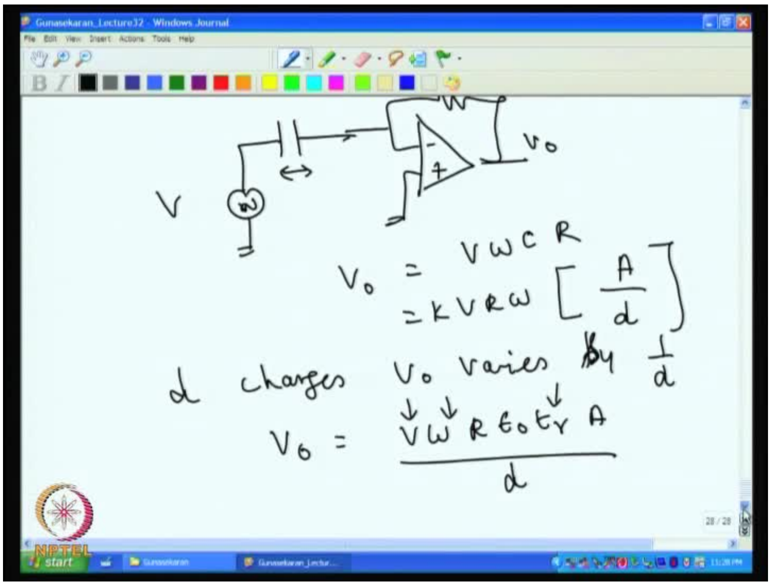

So if d is varied if for, d changes, d changes V naught varies by varies by 1 by d fashion. So, this is not going to be truly linear for displacement because, as you vary the more and more d is varied and this is going to vary in the 1 by R fashion. So, even though C varies actually even though C is varying but, the output voltage for large distance output voltage will be very small. So, another issue is that, if you take this one true formula, you will have V into omega R and then, epsilon naught epsilon r A divided by d that is what you will be having it actually. Now, epsilon sorry it is epsilon naught not mu r. So, this is epsilon naught, epsilon r. So, in real life if you compare this output voltage with respect to ratio transformer bridge.

Here, if V is varies that is, the supply voltage varies also output voltage will changing when the frequency of the source varies also output voltage will be changing. And then if epsilon r, epsilon r is relative dielectric constant for example, if there is some moisture in between the two plates, then also you will have a output voltage will give a error. So if you compare this output voltage with respect to ratio transformer bridge, that this is not as accurate as ratio transformer bridge because...

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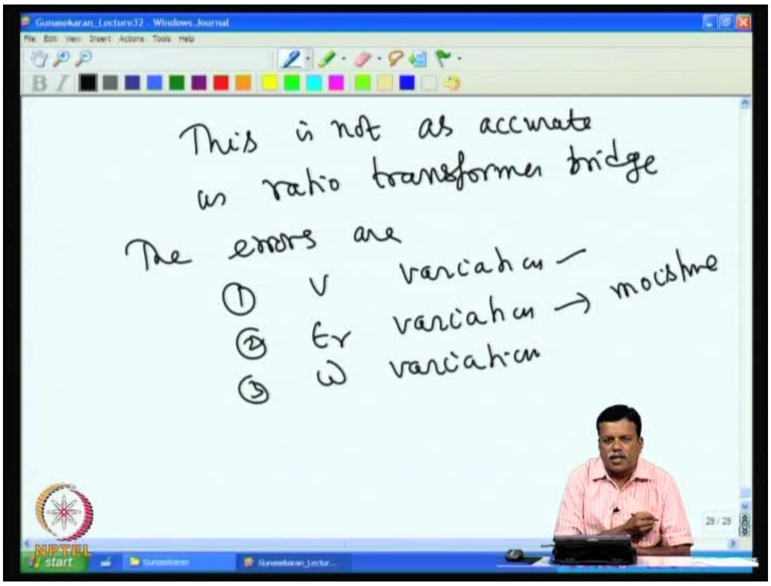

So this is not as accurate as ratio transformer bridge, as accurate as ratio transformer bridge. This is because, the errors are the errors are 1, V variation, epsilon r variation, omega variation. These are very serious problem because, the epsilon r can vary because of moisture can create problem and then source voltage can vary, frequency can vary. So this, these problems are not there in the earlier circuit that is the ratio transformer bridge circuit. So, we have to see how to minimize these errors.

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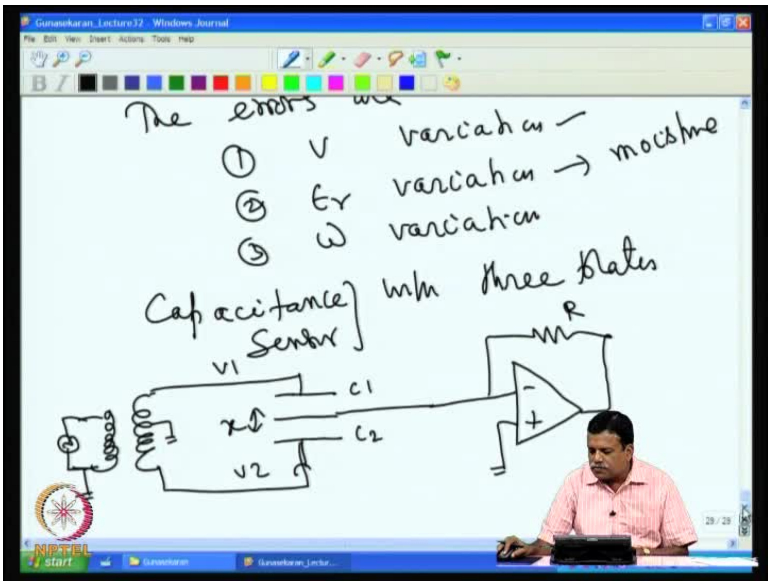

So, one possibility is you can go for two plate method actually that is what that done in industry. So, two plate vary method two plate that three plate sorry, that is the three plate technique capacitance with capacitance with three plates capacitance with capacitance sensor with three plates. What is done is that, we can have this operational amplifier. We can have one plate, and the second one, and third one. Now this plate can be attached to our inverting terminal. Inverting terminal can be connected and we can energize this with for example, we can have simple transformer with a center tap. So, you will get equal voltages here and opposite voltage here.

For example, we will have V 1 here, V 2 here and the displacement actually moves the center plate back and forth x. We move the center plate here so, you have for example, the between these two you have capacitance C 1 between these two you have capacitance C 2 and you have the resistance R. So, here this is energized with AC source. Now if you see this method, if you see this method, you will see that the, this actually sends a current like this and then it goes like this. Then this current is reverse opposite, this voltage and this voltage V 1 and V 2 are 180 degree opposite. So, the current through C 1 and current through C 2 are 180 degree opposite.

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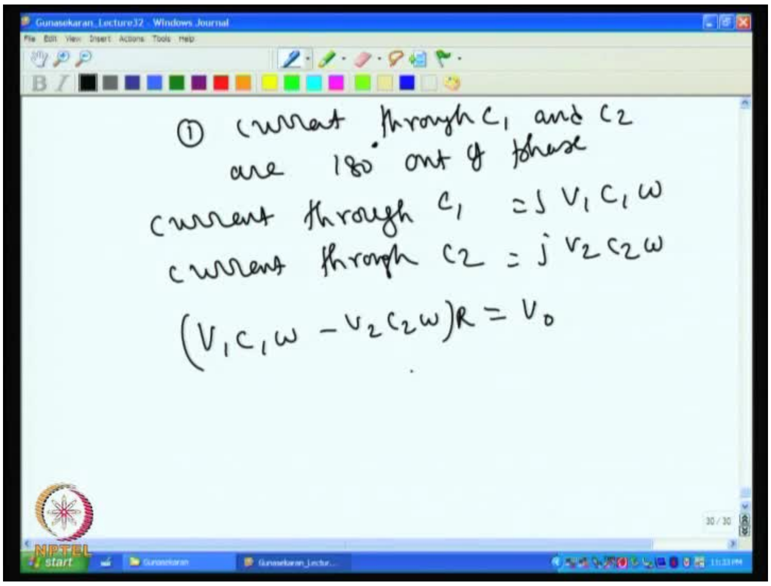

So basically, the current through C 1 current through C 1 and C 2 are 180 degree out of phase. So, if the two currents are equal, then you will get the output 0-th 0, otherwise the net result would be, so the current through C 1 it will come, current through C 1 is actually V 1, C 1 omega with j component. And then current through C 2 will be V 2, C 2 omega, and if you add these two currents then what it is summed up. So, you will have V 1 C 1 omega minus V 2 C 2 omega is what actually comes as a output voltage. So, that is the output voltage that you get here into R of course, into R is what is following through this.

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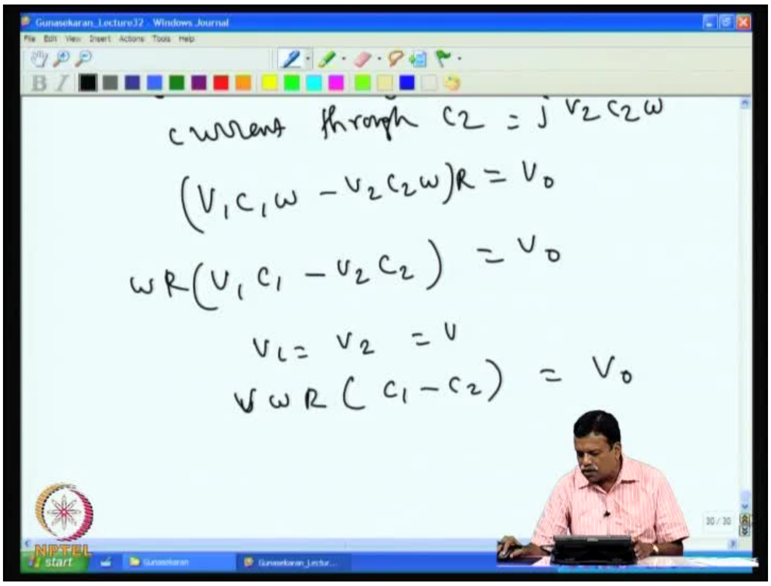

So, if you simplify this that it comes as we know V 1 C 1 minus V 2 C 2 into omega R. If we want equal to V 2, then we can write V 1 it is equal to V 2, because the minus in already consider. So, that makes it V 1 omega R, V into omega R equal to C 1 minus C 2. That actually becomes V naught but, then C 1 is coming because of one capacitor with respect d.

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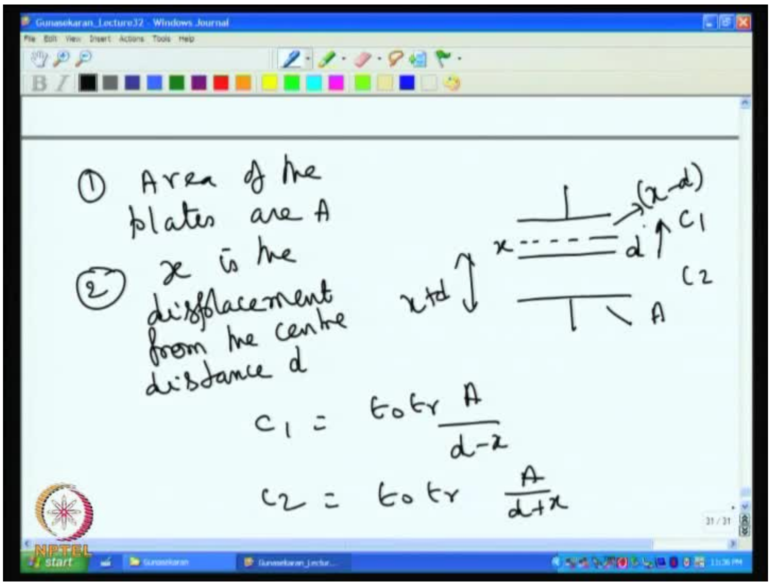

So if I take for example, the capacitor movement like this, if I take the center plate at the midpoint at d. If it moves to d plus x, then this distance plate moves like this the center plate moves like this by x. Then this distance x plus d, this becomes x plus d, and then this distance becomes x minus d. Because, if I move the plate by a amount x, then the distance per one plate to another, this becomes x plus d and other becomes x minus d. So, consider and then the area of the plate is A, so this area is A. So, considering area is A, area of the plates are A and then, the second one is, x is the displacement with respect to the midpoint, x is the displacement from the center distance d. So, if I take this then C 1 can be written as this is C 1 and this is C 2, C 1 will be epsilon naught epsilon r A by d minus x, and C 2 will be epsilon naught epsilon r A by d plus x.

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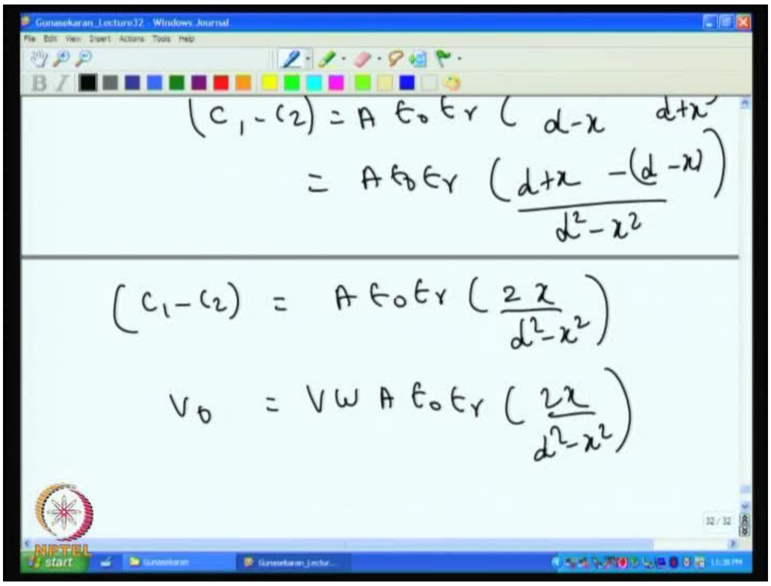

So, that gives C 1 minus C 2 as, C 1 minus C 2 as give epsilon 0 epsilon r into A so, you will get 1 by d minus x minus 1 by d plus x, which actually can be shown as epsilon naught, epsilon r and then you have d square minus x square, then d plus x minus d minus x this comes at C 1 minus C 2 as so that makes, C 1 minus C 2 will appear as, a epsilon naught, epsilon r into d of course, you will have 2x by d square minus x square. So C 1, then the output voltage, if you take it to the output voltage, that is in this formula we are seen that output voltage V naught is given by V omega R, C 1 minus C 2. So, output voltage can be shown as V naught, V naught will be V omega into A epsilon naught, epsilon r into 2x by d square minus x square. Even though it is a linear with x but, then only for smaller distance x is small only it will be linear x, V naught will be linear with displacement.

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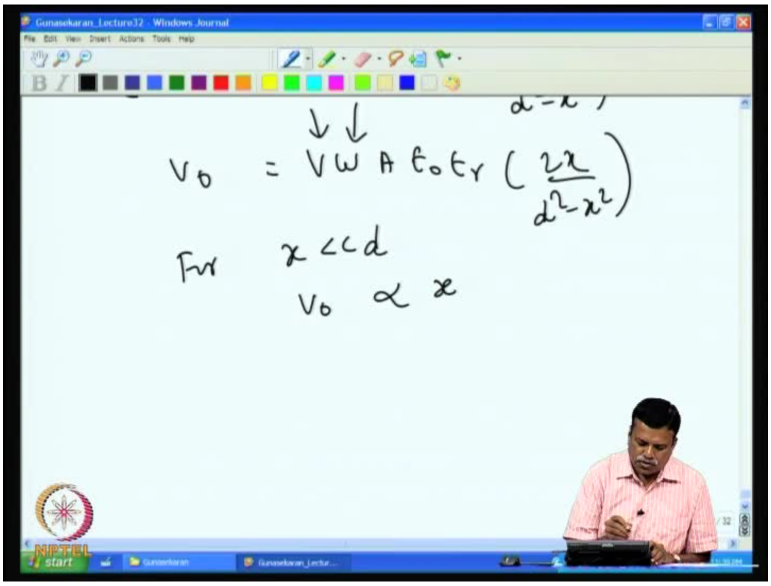

For small values of x, for x much smaller than d, then V naught is actually proportional to x. But then, here again you find that it is sensitive to omega, it is sensitive to variation V, it is sensitive to actually, that epsilon r variation what we planned when the moisture varies, then supposed to cancel of both. That is not really happen because, our capacitor currents are still there only if it is a null method, then it can be canceled. But, then here all this things still have a effect so even this is not vary I create it has not it is not very linear. So, is there any other method by which we can make it linear. Now one possibility if you go for area variation, then this circuit appears to be linear.

So, let us see what happens for by use the displacement measurement, using area variation. Suppose, if I arrange the capacitor such a way that given displacement area occupied by the, common area occupied by the two plates are varying, then we see what happens.

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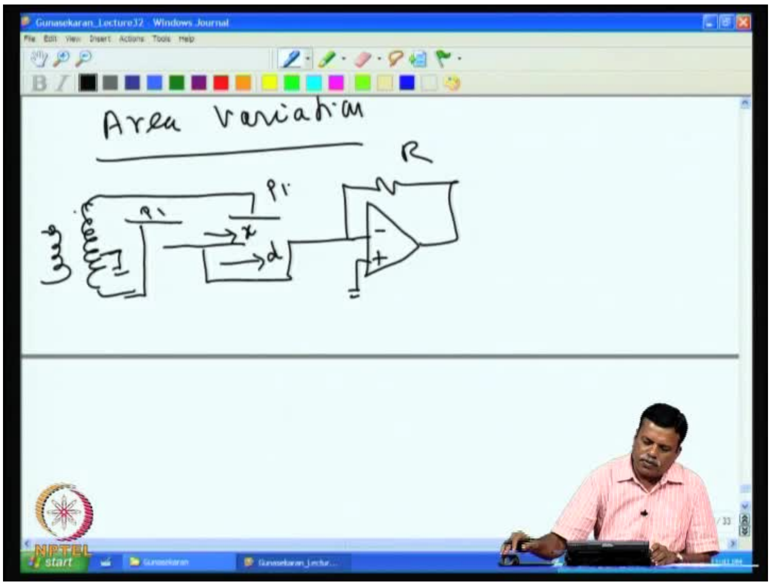

So area variation, this case what you do would be that will take the, same capacitance sensor and then, here we take the two plates. Then, I take the third plate like this, then connect to this the third plate, then have this resistance R. And this two are actually similar to last time we will connect to two sources that is I can connect a center tap here and connect one to this, and another to this. Now, this is the moving plate remove this displacement d is moving. So when you move the, when you move this plate, then automatically for example, if I move like this by x then area under this is coming down area under this is increasing. So you have two plates P 1 and P 2.

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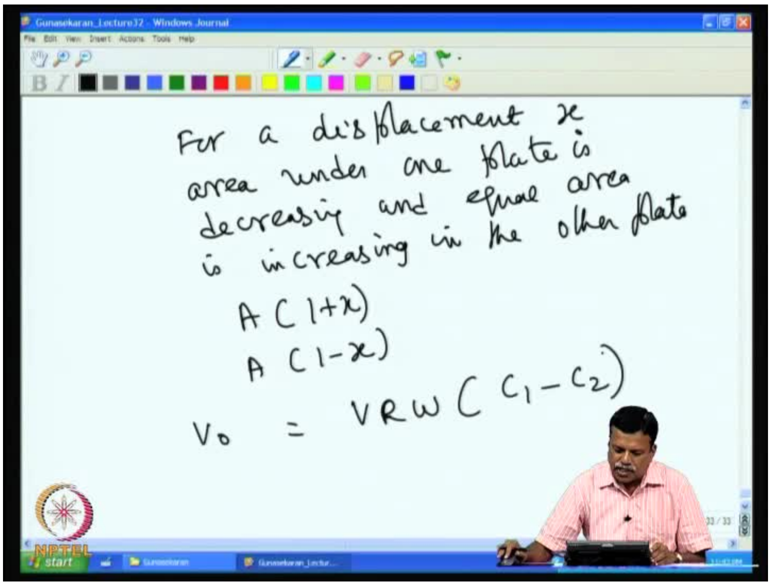

So, when for a displacement x for a displacement x, area under, one plate is decreasing, and equal area equal area is increasing in the other plate the other plate. That is if area is A, then one plate becomes A into 1 plus x the other plate it becomes A into 1 minus x. So, area with that is how area variation is taking place that makes the capacitor corresponding to the capacitance of the two capacitors also vary and the current that is contributed by the two plates also will be varying. So if you look at the current then this actually sends one current through this capacitance, and this sends a reverse current through this other capacitance. So, net resultant current will be following through this.

So, if you see the output voltage V naught here, output voltage V naught. So, if I see the output voltage that actually, will be the resultant of this one. So if I have a VR omega into C 1 minus C 2 is what actually you will get as a output. Similar to the last C 1 minus C 2 if you try to find that is where the different coming.

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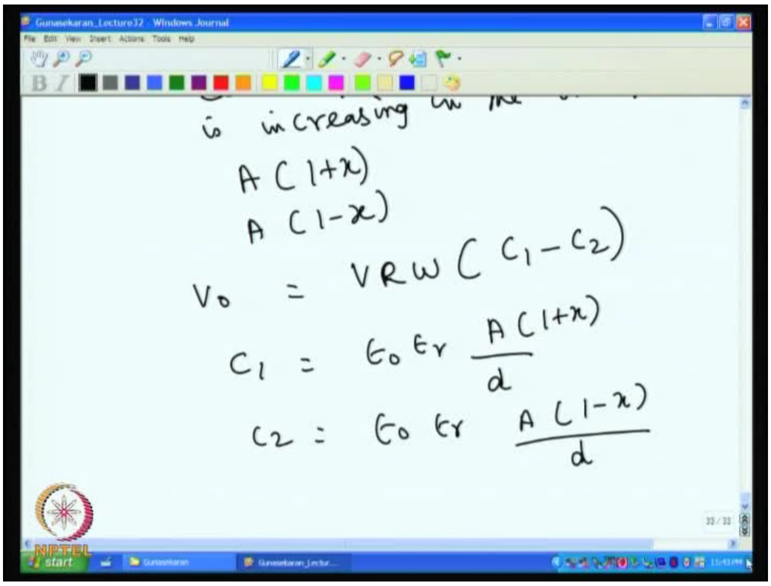

Now the C 1 would be C 1 will come as epsilon naught epsilon r, A dived by d and then C 2 would be A, A is actually 1 plus x I can make other ones epsilon naught A by into 1 minus x, dived by d.

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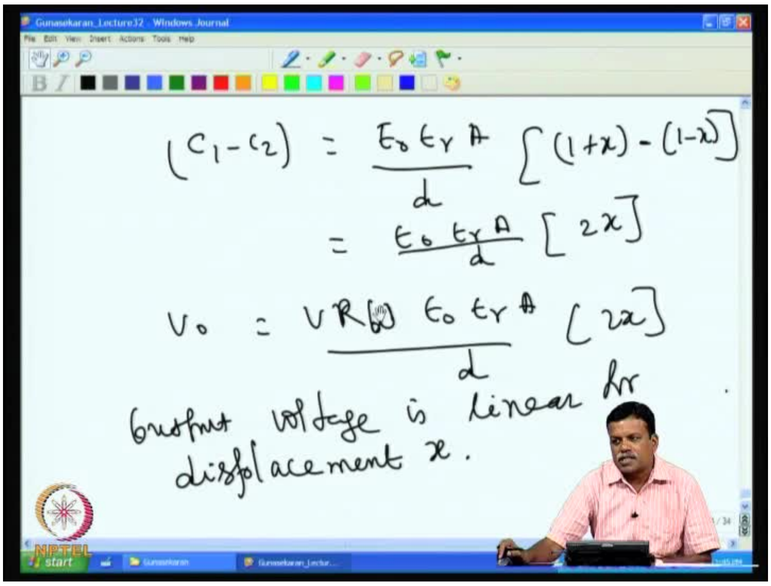

Now if I calculate C 1 minus C 2, so you will have a C 1 minus C 2 will appear as epsilon naught epsilon r and then you have A, and d is constant is coming. So we will have 1 plus x, then minus 1 minus x. That actually will work out. That comes as you will have 2x. So it is a wonderful thing because, C 1 C 2 that come linear with displacement. Because, now if find that C 1 C 2 is linear with displacement. Now if I put this one in our equation for output voltage V naught that is here, so this is the, our equation for output voltage V naught. So, if I do this, then V naught will come as, V naught will as VR naught, VR omega into epsilon naught epsilon r A by d into 2x.

So, output voltage linear with displacement, output voltage linear for displacement, this is the, so output voltage is linear for linear for, linear for displacement x. This is good because, we can have our output voltage, measuring that displacement linearly. Of course, it is still sensitive to all the parameters that we can think of, you have your V variation, R variation, omega variation everything still has a problem. So, it is also not as accurate as our ratio transformer bridge that we have discussed.

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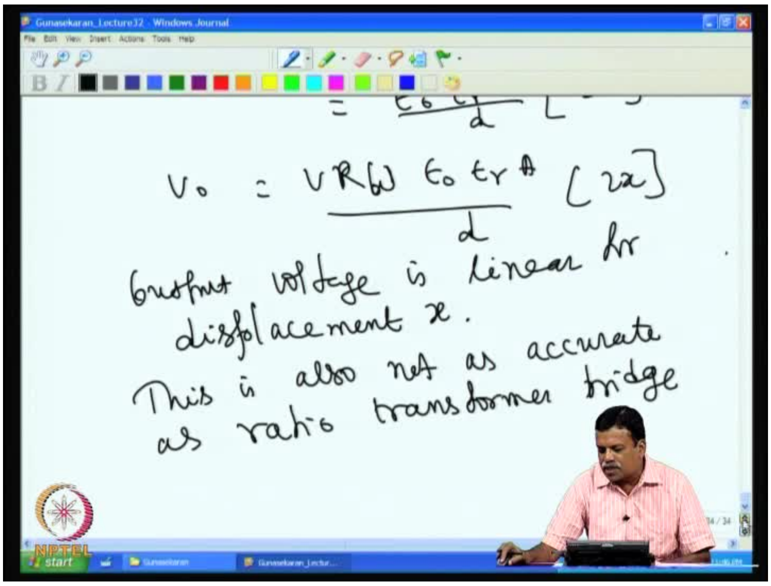

So this is also not as accurate as ratio transformer bridge, as accurate as ratio transformer bridge. Now of course, this has a this we got into linear but, linearity is there but, other variations are there. Now there is a one other way of looking this capacitor measurement that is, can we go for a null method, instead of looking at V naught, can we go for a null method, and then can it can the output voltage if it is a null will this problem would be solved or can we use instead of non-inverting amplifier, inverting amplifier and see how the circuit can work.

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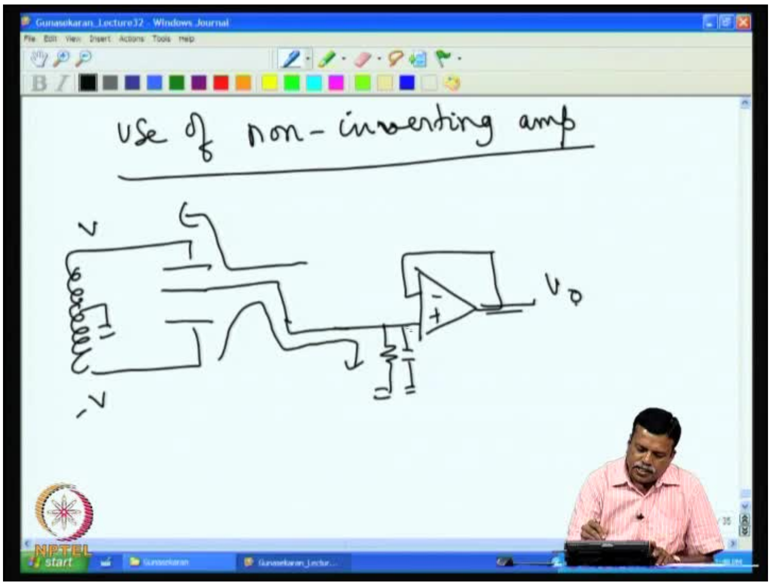

So use of inverting amplifier, use of non-inverting amplifier. (No audio from 46:04 to 46:15) In the case of non-inverting amplifier, we can do this for example, if I have a signal like this, I have this then we can have this voltage then for example, if I have a space variation here, for example, I have connect this of course, I put one resistance here then I will get V naught here. So, here this is the voltage V, if it is center tap then both voltages are V 1 comes as V 1, this is minus V. Then again the current actually flow like this, and then this current actually flows into the reverse direction. So, if both the currents are equal then you get a 0 voltage, and if I have to use this method then the capacitance that is present here.

If there is a, if the output voltage is present then, the capacitance that is present between this point and this point can create a problem because, the you will have this is loading the circuit and creating the issue with this. So, this technique is not accurate because, this is sensitive to stray capacitances.

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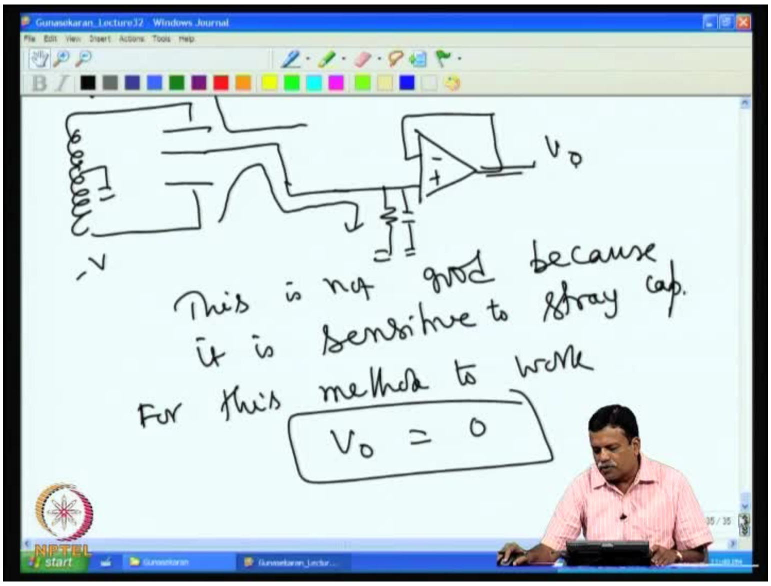

So, this is not good not good, because it is it is sensitive to stray capacitances stray caps. If this method has to be successful it should be a null method. So, this method, for this method to work, for this method to work method to work V naught should be equal to 0. This is very important actually otherwise, V naught is 0 then this capacitor because, V naught is 0 this voltage is 0 and this capacitor has no effect, then we have to modify the circuit just to make it V naught 0.

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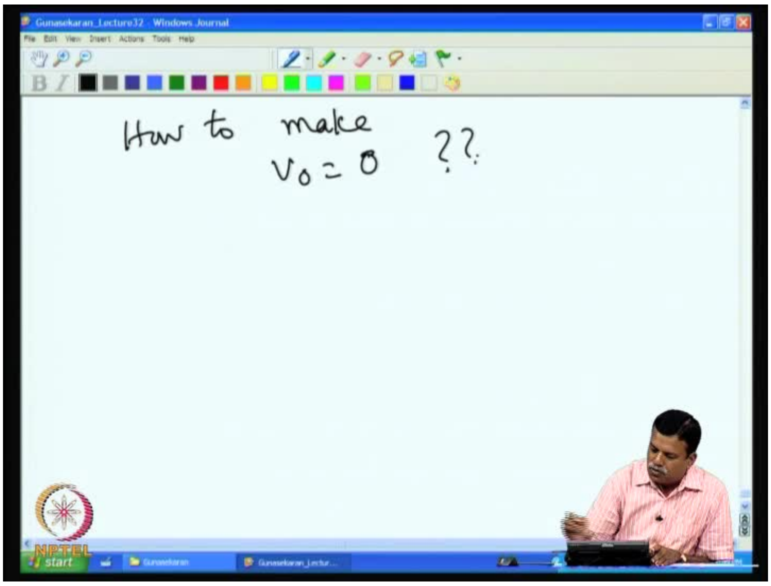

So, how to modify the circuit, how to make V naught 0, how to make V naught equal to 0? That is the question, now that, we can do by using in the feedback technique.

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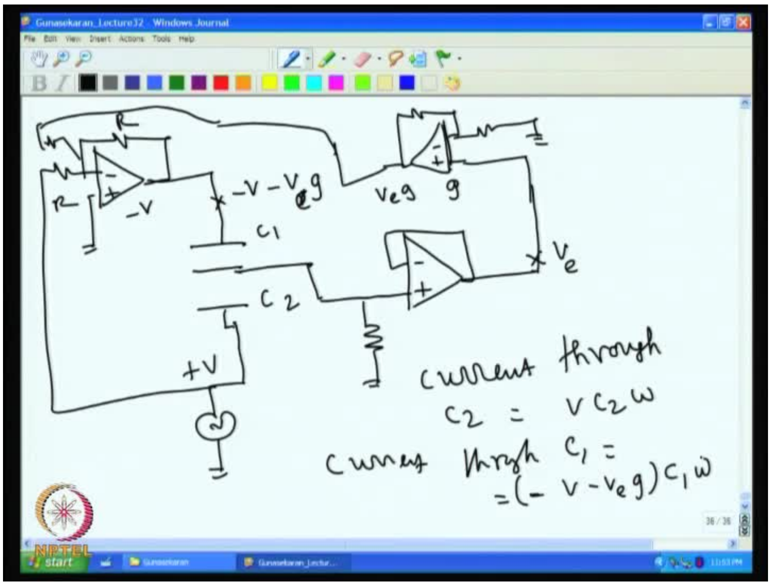

What can be done is, we can have the op amp circuit. Then for example, we can have this output then one of the plates for example, I can show like this, I have the source here, source I connect to this one plate and this I connect to this. Then, for bias current I put this resistance at the input then whatever voltage that output voltage I am getting that actually can be amplified. For example, I can have a amplifier here, I can amplify this then I can sum it up with a feeding the minus voltage for this I give this one. So, I will get minus V here, I will get minus V here because, this is plus V and that is if there equal resistance I put then this becomes minus V. Then, I can connect this minus V to this.

So, we got plus V here and minus V here, it is same as what we had done earlier but, then whatever voltage that we are getting with gain that can be added at this point. That is a feedback is provided to one of the capacitor input. So, voltage at this point consist of two parts one is that minus V, then minus V then, minus V error, V error into gain. For example, if this is a error voltage V error, V error and this has a gain g. Then, whatever voltage is there it is multiplied and it becomes V e into g here, and that is the minus and put here. So, if there is too much for example, if this two this plate close by then, plus voltage will be more and you will get plus voltage more that will increase this voltage.

Such that this is my, the voltage is more so, that the more current comes here and the output voltages start coming down. So, by arranging this feedback network, one can make the circuit balance automatically that is if the gain is more because, if you write the equation now for C 1 and C 2. For example, if this is C 2 and this is C 1 then you will find that, the current actually C 2 current would be current through C 2, through C 2 is given by V into C 2 omega. Then, current through C 1, current through C 1 is equal to you will have minus of V, minus V e into g is what it is coming as a voltage and then C 1 omega. Now obviously, for null we have to have these two equal.

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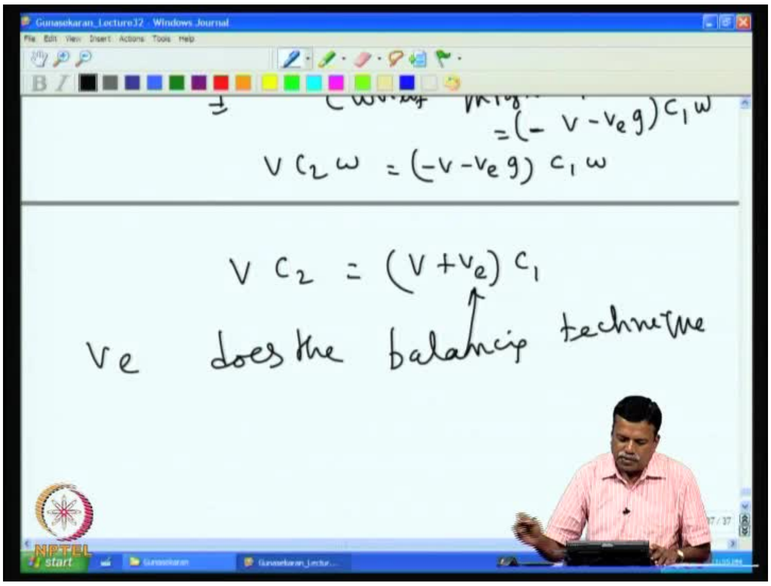

So we will have v C 2 omega is equal to minus V minus V e into g into C 1 omega. So if, so all that needed to be done is if I since, they equated this we can remove the minus sign, so we have omega can be removed. So, we have V into C 2 that actually equal to V plus V e into C 1 omega, or it can be even minus that depending upon the polarity this omega is gone, both sides its gone. So, the V it has done the balancing technique of the ratio transform because, this term that if you see that we are adding now V e if C 2 is large automatically V e is plus. If C 2 is small, then V e is if C 2 V e getting with polarity it is getting adjusted automatically because, the output voltage is inverted here. So, the bridge automatically balances out. So, by V e does the function of, V e does the does the balancing technique.

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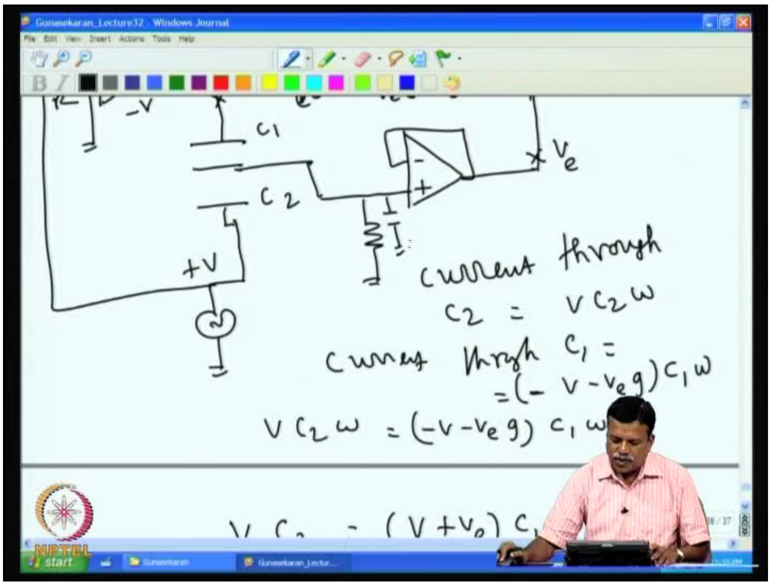

So, by this now if I write, then the bridge is getting balanced since, the bridge is getting balanced this capacitor is not a serious problem, the stray capacitor is not a serious problem, because the V e will be small if the gain is large.

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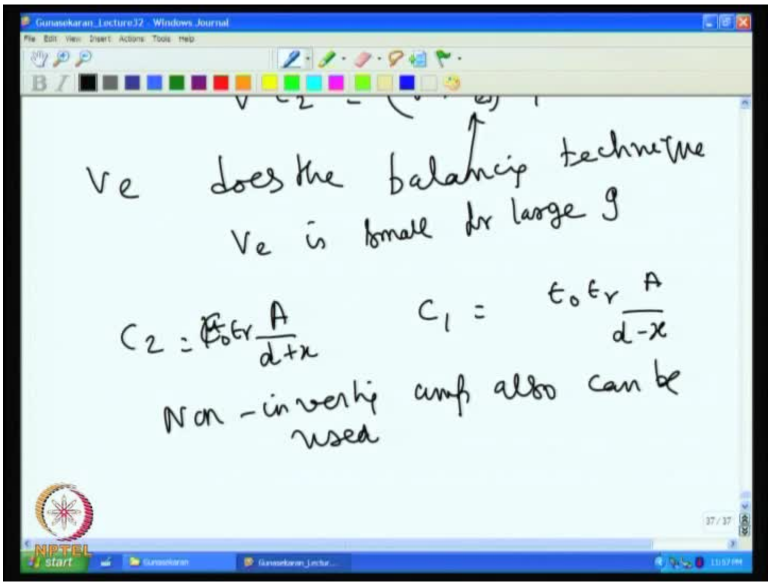

V e is small if the gain is large. V e is small with the V e into g sorry, V e into V e into g has to come here. V e if the gain is large V e is very small. If V e is small for large g. So, this is actually if you write the equation for C 1 and C 2 that C 2 is actually is coming for replacement, A by d plus x. For example, C 2 can be written in terms of A and d. Similarly, C 1 can be written in terms A and d, A and d plus for C 2, can be written as mu naught, its epsilon sorry, epsilon naught epsilon r A by d. And C 1 can be written as epsilon naught, epsilon r A by d minus x. Now we will find that, similar problem with what we had with our amplifier with a non-inverting terminal because, inverting terminal also we had the same issue.

But, then by feedback technique we can avoid the balancing and bring the output close to 0 and then, we can get rid of the effective to this capacitor. So one can use even the non-inverting amplifier also for balancing. So, non-inverting amplifier also can be used, amplifier also can be used. Nevertheless it will it will also we will show whether it is linear or non-linear in the next lecture.

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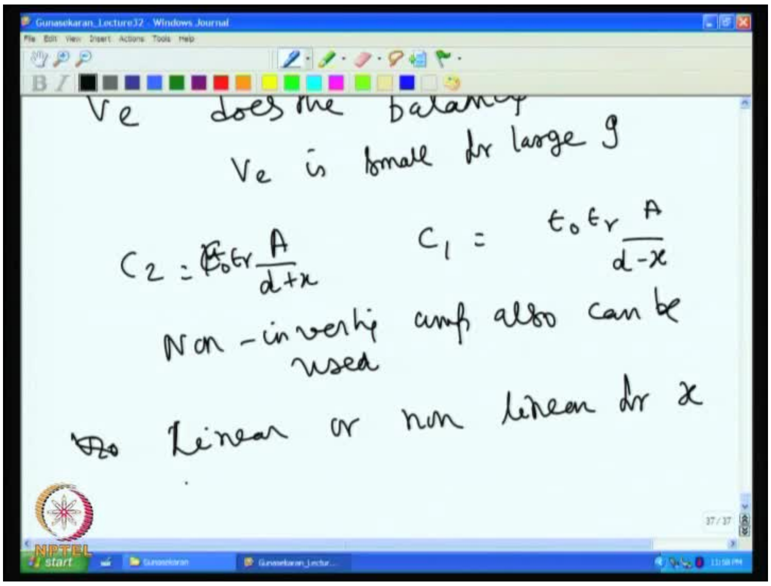

So, we will show in the next lecture whether it is linear or non-linear, whether it is linear or non-linear for a displacement x, that is V 0 because, it is balanced out. So, the measurement also depends upon V 1 and V 2 measuring. So, we will see how this is measured whether it is goes linear or non-linear in the next lecture.