Electronics for Analog Signal Processing - II

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Lecture - 9
Positive Feedback (Regenerative)

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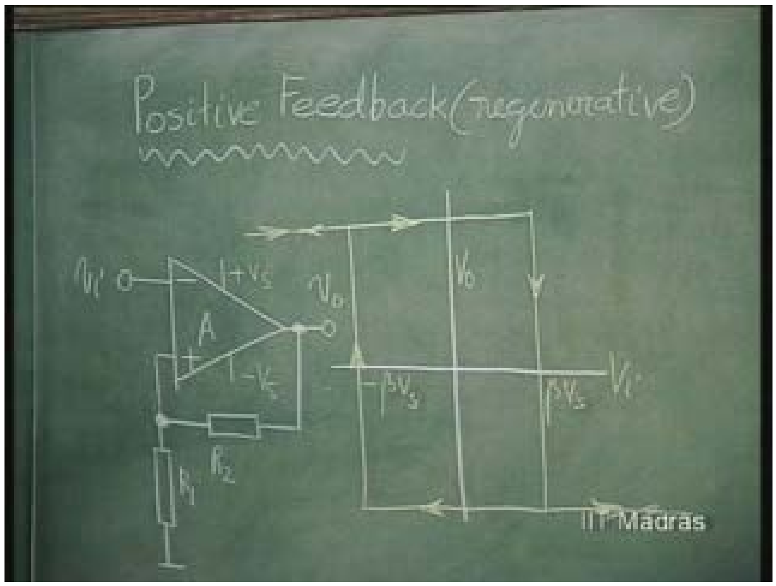

We had discussed about positive feedback which is regenerative. We said this is a very useful configuration with memory. That is hysteresis. The circuit understands how the input is varying; whether it is increasing or decreasing. If the input is increasing, it changes state at a particular point and if the input is decreasing, it changes state at another point. So, this is what is called as memory.

The same circuit with this end grounded and with input connected here... say this is R 1, R 2. R 2 is the resistance from the output coming to the non-inverting input and R 1 is the resistance which had gone to the ground. Instead of grounding it, we are connecting it to V i and what has happened is, this inverting terminal is now grounded. So, what happens to this? This also retains the same feedback. It is still positive feedback; but what happens here is that V naught for large negative voltage here, large negative voltage here, has to be negative because this is applied to non-inverting. If large negative voltage is applied, this has to be minus V s.

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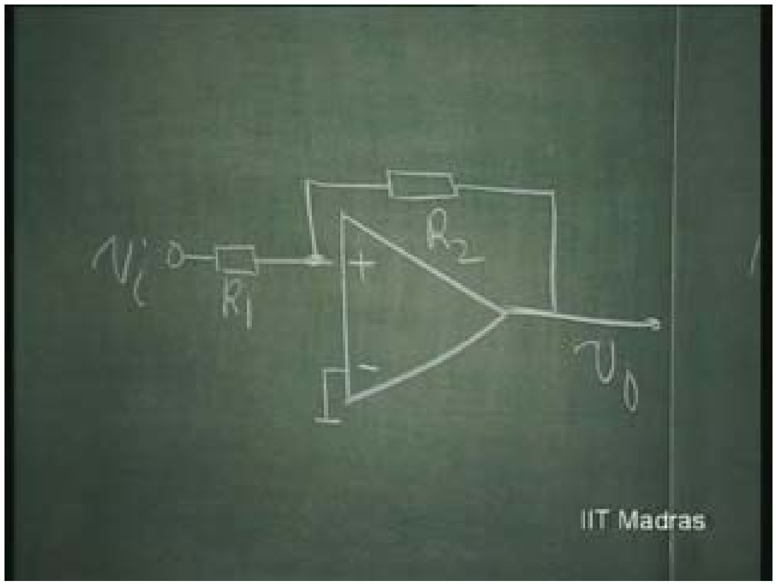

So, it would start from minus V s and this will start with minus V s. The voltage here therefore, when it becomes equal to zero here... this is grounded; so, when this becomes close to zero, change of state should occur. What is that voltage which will make this voltage zero at this point? V i. This voltage is V i into R 2 divided by R 1 plus R 2; V i into R 2 by R 1 plus R 2; plus V naught into R 1 by R 1 plus R 2.

If V i and V naught are the voltages here respectively, V i into R 2 by R 1 plus R 2 plus V naught into R 1 by R 1 plus R 2 is the voltage here. When this becomes equal to zero, change of state should occur.

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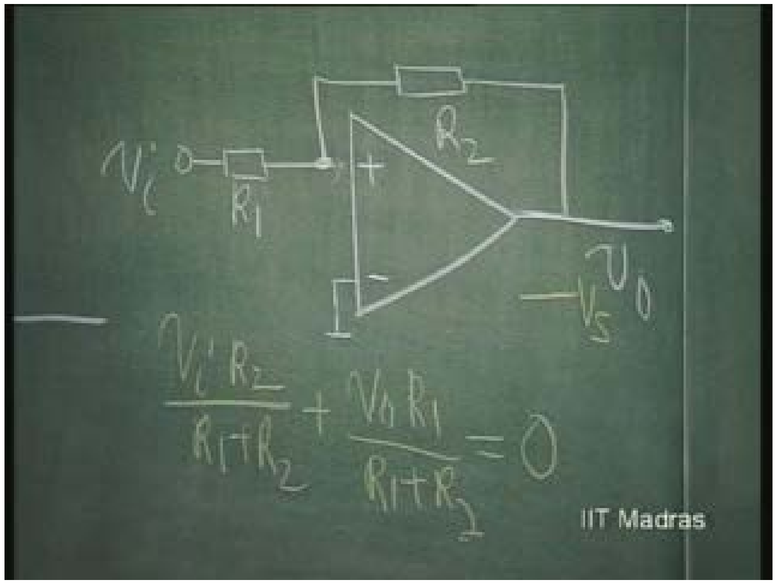

So, V naught at present is nothing but minus V s. So, when V i becomes equal to plus R 1 V s by R 2, change of state will occur.

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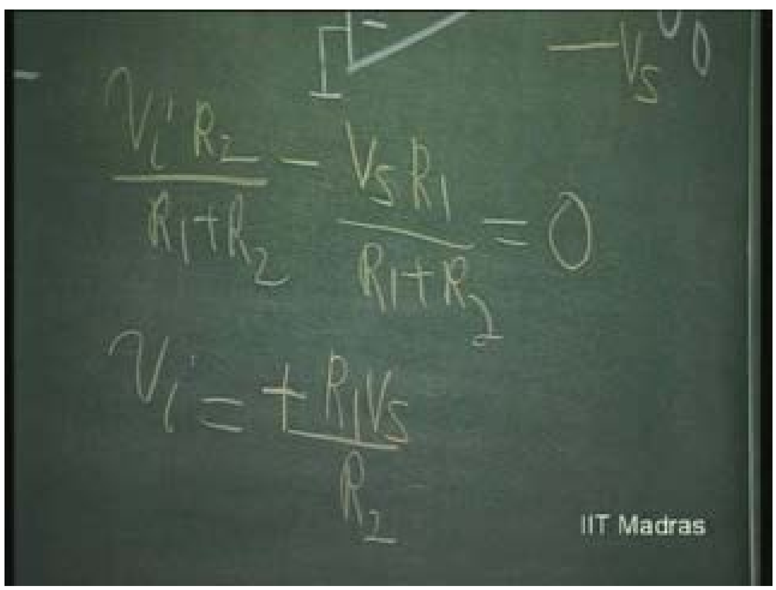

So, this will go on like this and then change of state will occur from minus to plus at a voltage which is R 1 by R 2 times V s. So, this is the change of state. It is going to now change state to plus V s from minus V s. Once this becomes plus V s here, the next change of state occurs only when V i decreases; and that will happen when this becomes minus. Same equation is valid.

So, so again, you get the same hysteresis; but it is of another type. The output is at minus originally, goes to plus; whereas the output was minus originally, plus originally and goes to minus. So this is one type of Schmitt trigger or regenerative comparator; that is the other type of Schmitt trigger or regenerative comparator. These two types are commonly used in a variety of applications like signal generation and wave shaping, etcetera.

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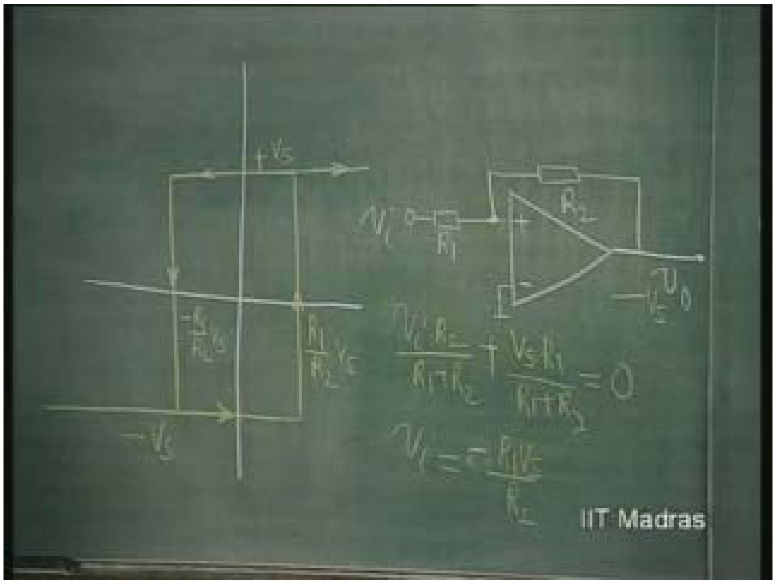

We will work out an example in order to illustrate one of the applications of positive feedback using this circuit. So, consider the Schmitt trigger that we have earlier discussed. Let V i be a sine wave, as shown here, being applied to the input of this Schmitt trigger.

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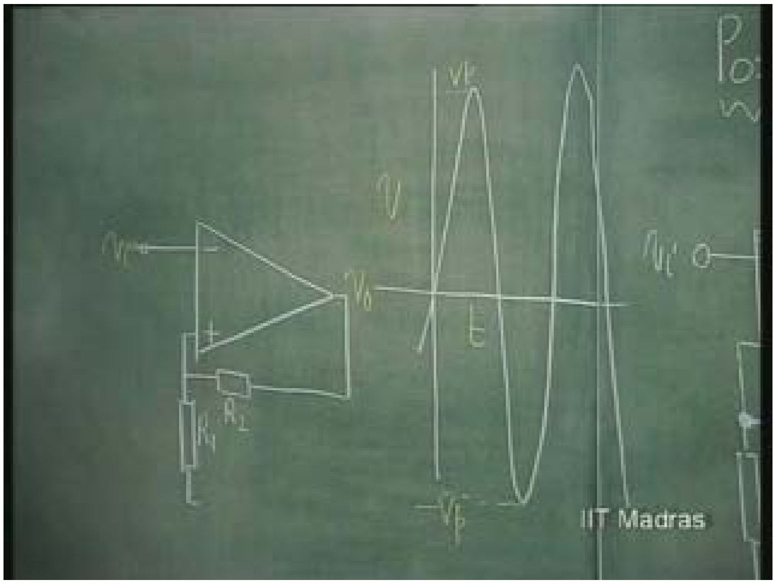

What is the output? We would like to see. So, this could be a sine wave or a triangular wave or an exponentially increasing and exponentially decreasing wave. I am typically discussing this for a sine wave.

So, as the input voltage here is increasing, this portion of the circuit, input voltage is increasing. So, this circuit says the change of state should occur when the input voltage is increasing at Beta V s. So, let us say this is Beta V s and this is minus Beta V s. Now, change of state should occur. Originally, when the input was negative, output was positive. So, it will start with positive voltage and at Beta V s, it will change state to negative. Let us say it is plus V s. Let us say V s is greater than V b. From there, plus V s, it will go to minus V s. So, this is the point at which the change of state will occur; that is Beta V s.

Thereafter, the input voltage is going on increasing. Nothing happens until now. It further starts decreasing. When it is decreasing, change of state will occur, not at this point; but at this point... because... at minus Beta V s. So, the next change of state is going to occur at this point to plus V s. Again, next change of state will occur at this point. So, you will see that for a sine wave input, you get a square wave output; but the change of state occurs at levels fixed by the Schmitt trigger; uniquely fixed by the Schmitt trigger. Not at any other point.

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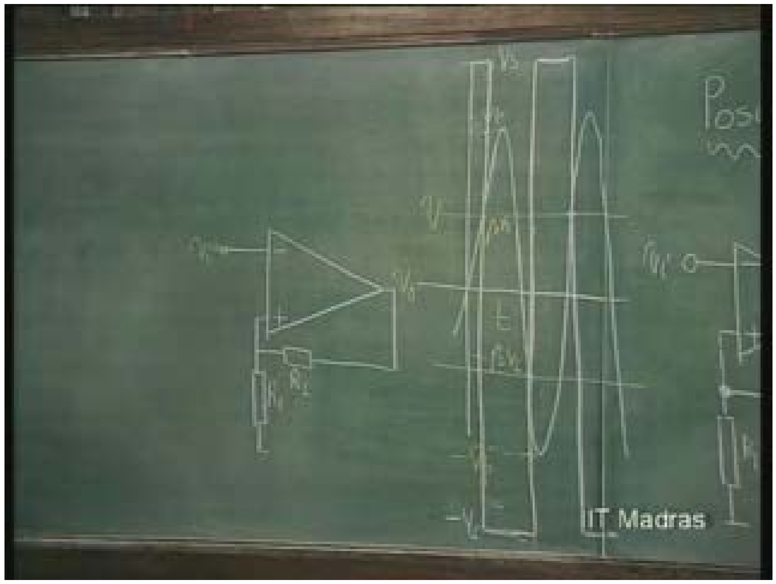

So, this is very useful in converting periodic wave form like sine wave or triangular wave to a very good square wave because the rate of increase of output voltage from this to this, now, totally depends not on input wave form but only on the maximum rate of rise possible or maximum rate of fall possible for the op amp or amplifier structure that is put here; comparator structure put here.

So, this is going to be very sharp transition here. So, in order to convert a stream of data which has got corrupted because of the line capacitors, etcetera, to exponential increase and exponential decrease, the so called square waves themselves may get distorted to exponential increase and exponential decrease because of line capacitors. Then, in order to convert them into sharp transition pulses, this Schmitt trigger is used. This is one application; one important application. Next application also, very simple.

Now what we do is... by itself it has two stable states or this is a bi-stable circuit. One is plus V s; another is minus V s. Now, I am going to make it what is called as Astable circuit. Consider this circuit.

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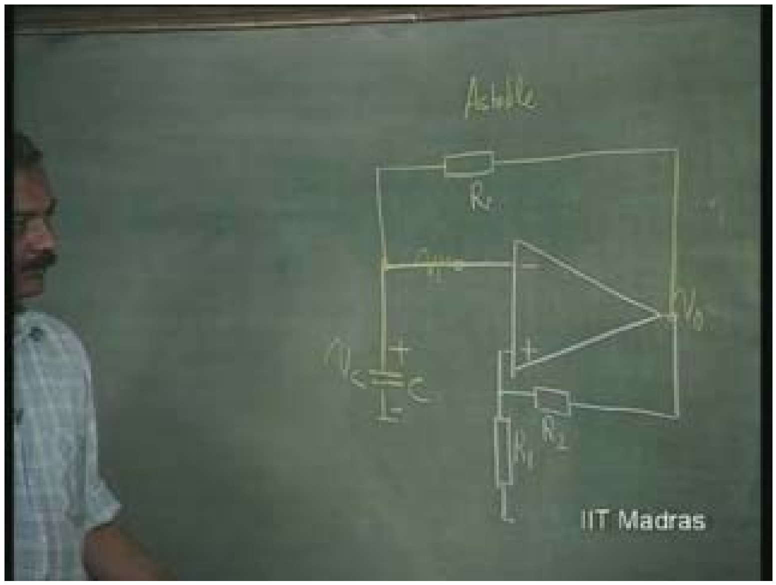

As far as this itself is concerned, this is a circuit with positive feedback here. So, it does not really know what is happening here, let us assume. But the capacitor is initially uncharged. We will consider capacitor is initially uncharged. I switch on the thing. Obviously, we say that this is a regenerative comparator and that output has to be either at plus V s or at minus V s. That is for sure.

So, output is at plus V s, let us consider. If output is at plus V s.... Let us put that down. What is happening here in this circuit? Let us independently consider. Capacitor is not charged. So, the capacitor will start getting charged through this resistance. So, that will be...that you know is an exponentially increasing wave form.

So, capacitor will start getting charged this way. What is this? This is going to be charged towards V s. It will try to go towards plus V s with a time constant equal to C into R. So, the tangent time constant is C into R. So, it is increasing. This capacitor voltage is increasing with respect to time. So, this Schmitt trigger says, if a voltage is increasing at its input, I will change state, when the voltage reaches Beta times V s, Beta being equal to R 1 by R 1 plus R 2.

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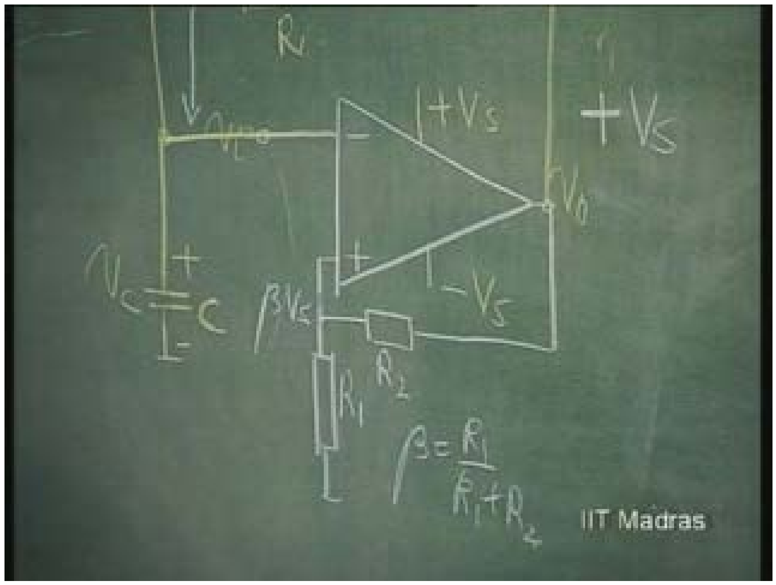

So, since this is plus V s, this is Beta V s. Change of state will occur when this voltage reaches a magnitude of Beta V s. How will the change of state occur? It will change state from plus V s to minus V s. Now, what will the capacitor see? This has changed over to minus V s. This becomes minus Beta V s.

So, the capacitor will now charge towards minus V s with the same time constant. So, the capacitor will keep charging towards minus V s with the same time constant; but as soon as it reaches minus Beta V s, because the voltage is decreasing now; this voltage is decreasing. So, this will say that I am going to change state the moment this voltage reaches minus Beta V s. So again, it will go to plus.

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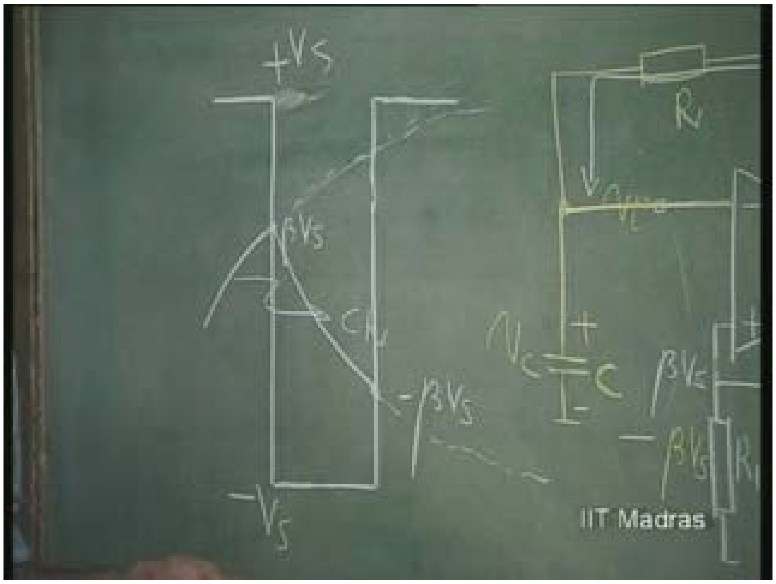

This story never ends because now the capacitor is going to sharp towards plus V s with the same time constant R C. As soon as it reaches Beta V s, this will change state. This is what is called as an Astable multivibrator.

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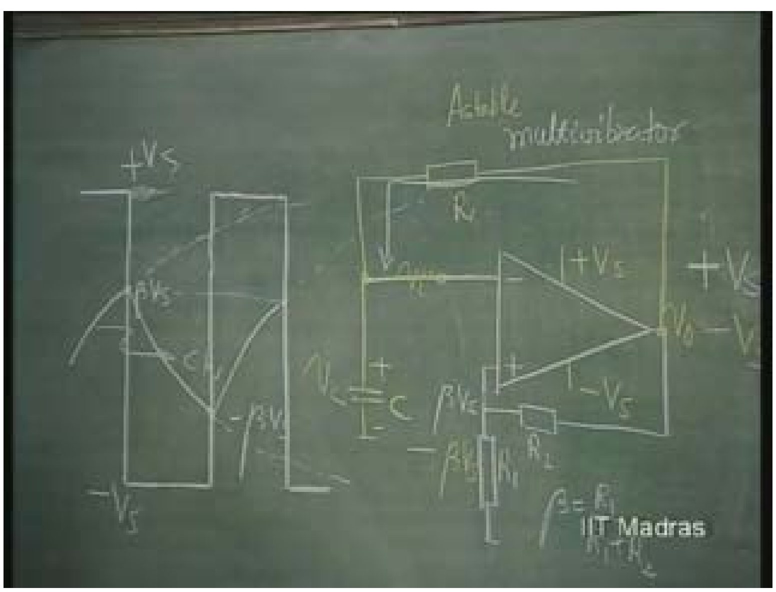

It keeps changing a state from plus V s to minus V s to plus V s, goes on on its own and therefore it produces a square wave at this point and an exponential increasing wave form and decreasing wave form at this point; this kind of wave.

In fact, you can therefore find out this time interval. This time interval and this time interval will be the same because the capacitor during this time has discharged with the same time constant, as it is getting charged. So, the discharging time constant is same as charging time constant; and the voltages changed will be from Beta V s to minus Beta V s. That means 2 Beta V s is what is acquired by the capacitor. So, these two time intervals will be same. That means this is the period of the wave form T.

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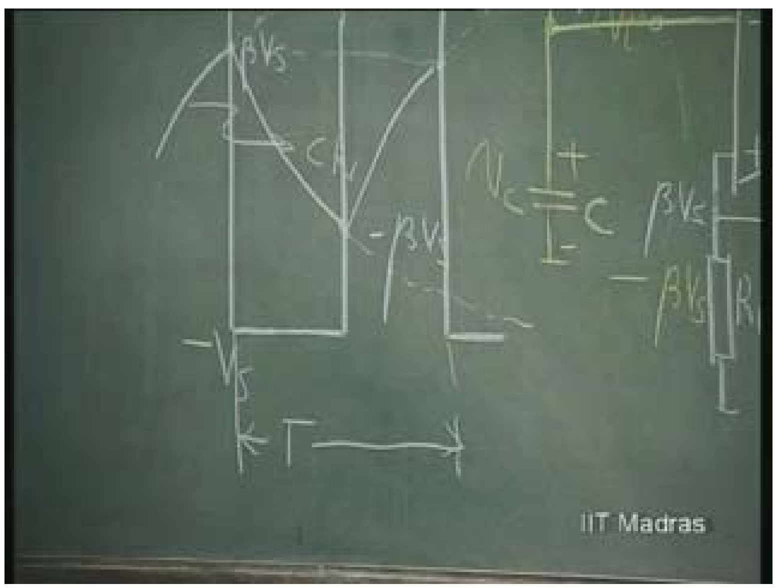

You can evaluate this by equating...let us say that this is exponentially changing; e to power minus t by R C. 1 minus e to power minus t over R C. This is the way voltage changes. The voltage applied here is...from minus Beta V s, it is trying to go towards plus Beta V s.

So, the total voltage applied is Beta plus 1 V s from here to this point, assuming that this is zero. So, from here to the top point, it is Beta plus 1 V s; and it is going to change at 1 minus e to power t over R C. That kind of rate. But voltage acquired within T by 2 is twice Beta V s. That means, during this time period T by 2, the voltage acquired is twice Beta V s. From this equation, T comes out as... If we write down, V s, V s, gets cancelled. You have... you can equate this. T comes out as R C log 1 plus Beta by 1 minus Beta.

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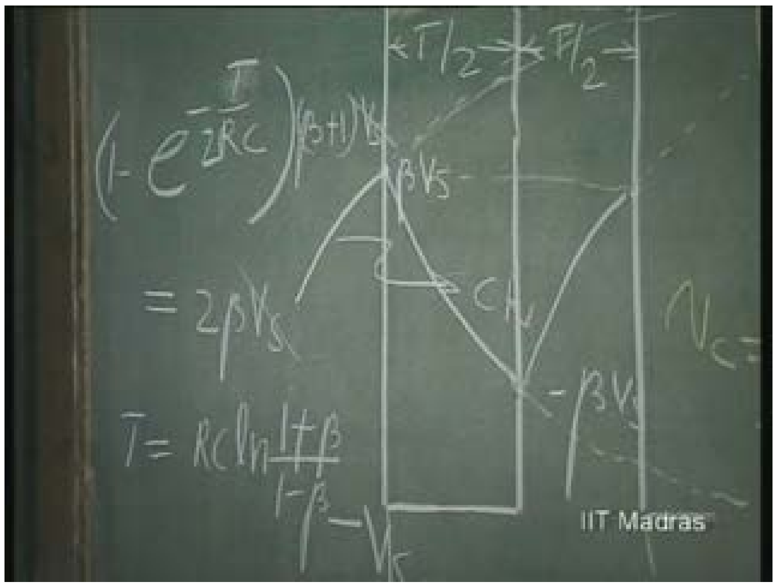

That is, this is T by 2. T by 2 comes out as R C log 1 plus Beta by 1 minus Beta; or, T is equal to twice R C log 1 plus Beta... So, you can therefore evaluate the frequency of oscillation of this Astable multivibrator, if you know the resistance capacitance and the Beta value.

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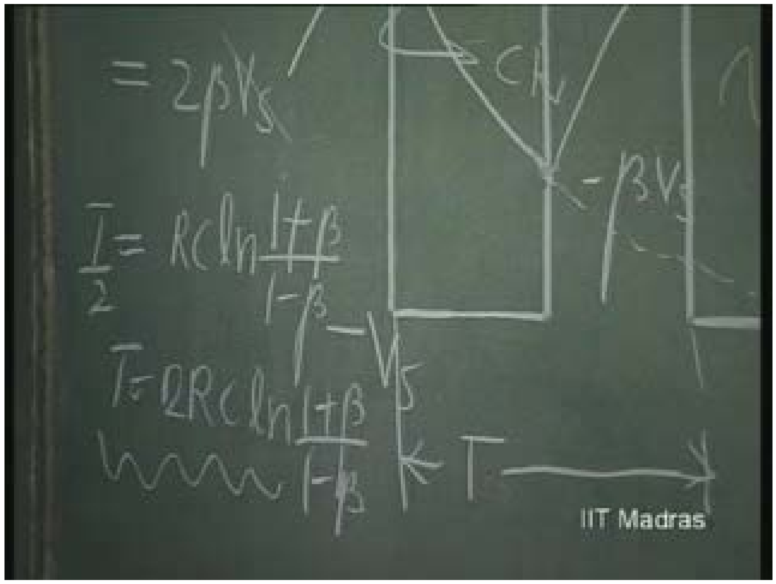

This circuit is useful as a signal generator. It is commonly used in signal generators; and you can see that the basic principle is very simple. It is using some kind of integrator here. This is a rough integrator; capacitor getting charged through a resistor is equivalent to an integrator. And this is the Schmitt trigger. This integrator, Schmitt trigger, combination is a common circuit for what is called as function generation or wave form generation.

We had digressed a little bit. We were discussing negative feedback configuration. In order to differentiate it from positive feedback, we went over to positive feedback configuration.

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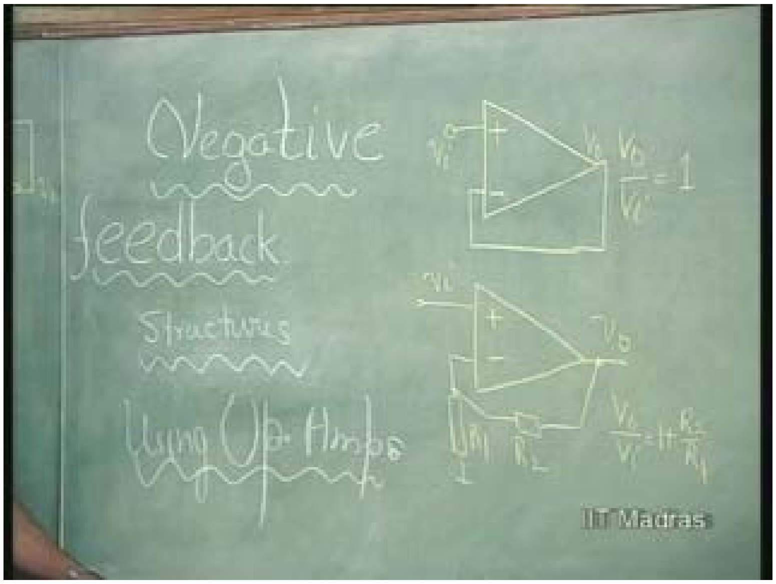

For example, this is negative feedback configuration. To show that structure looks similar with this minus, this plus; but that structure is entirely different. That is one with positive feedback, regenerative positive feedback and with hysteresis when this becomes plus and that becomes minus.

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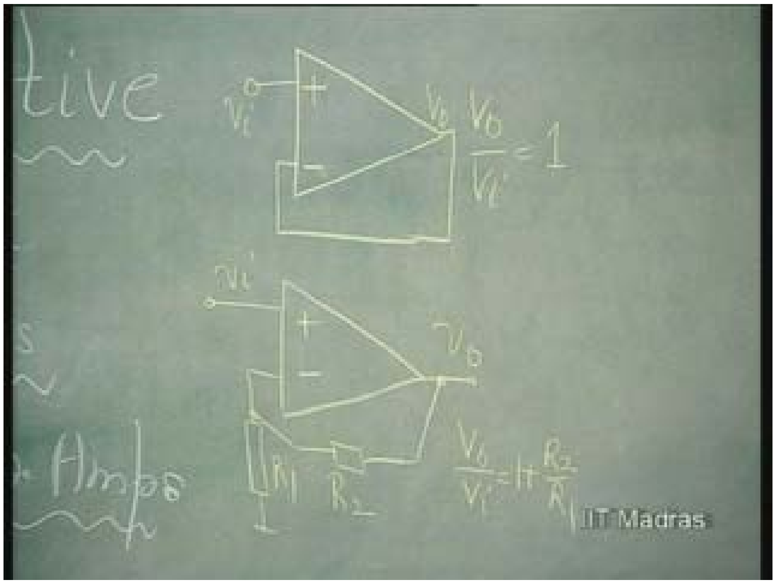

Similarly, when this becomes plus and that becomes minus, that is another regenerative feedback configuration. So, this should be kept in mind that, the feedback changes, the characteristics becomes different. That is a non-linear circuit; this is a linear circuit with a gain of 1 plus R 2 over R 1.

So, continuing with the basic negative feedback configurations, this is a buffer unity gain amplifier. This is a non-inverting amplifier of gain 1 plus R 2 over R 1, which we had discussed; and this is another important configuration called inverting amplifier. So, just compare this with the two configurations for positive feedback that we had just now discussed. These are regenerative positive feedback with different characteristics. So, one was non-inverting Schmitt trigger and another was inverting Schmitt trigger.

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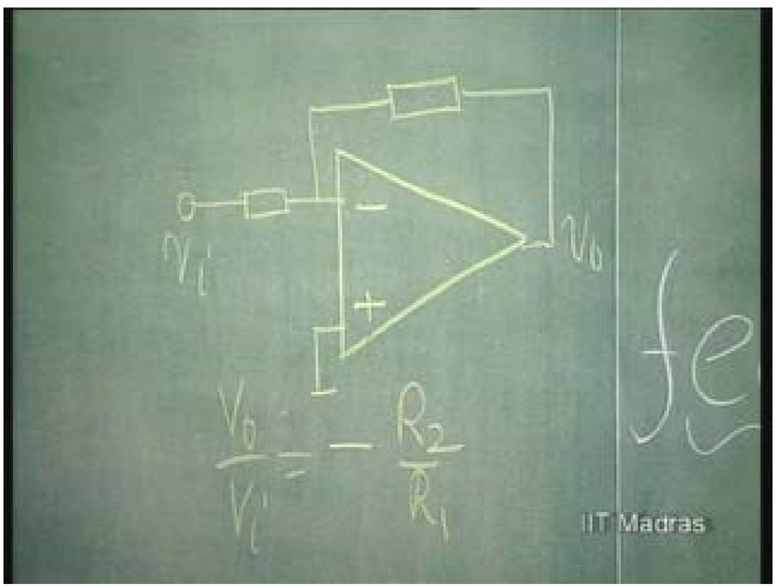

Now, coming back to the negative feedback, let us see how we can generalize this negative feedback configuration here.

This is an inverting amplifier with R 2 over R 1. When you ground this, what we said was, always this is at virtual ground as long as output is connected to input. Please remember that. For this to be at a virtual ground, the condition is, output should be somehow connected to the input. Somehow. It does not really, necessarily, get connected like this. It can be connected in any manner that there is negative feedback. Then, this can be at virtual ground. Such a situation the... this becomes a current summing note because at this point the potential is always zero and currents can get summed up.

So, this property can be used in summing currents. So, this is actually I 1, I n. So, the entire current is going to flow through this R f, appear as this current is going to be sigma I i, i equal to 1 to n; that therefore, the voltage here is going to be... that summed up current gets converted into a voltage which is minus because this is plus and that is minus. Sigma I i, i is equal to 1. Or, we will call it i j in order to differentiate. j, j is equal to 1 to n. So, this is... into R; that is the scaling factor R f. So, this is therefore going to be called as generalize, I mean, as a sum up summing amplifier. Sigma i j into R f; j equal to 1 to n.

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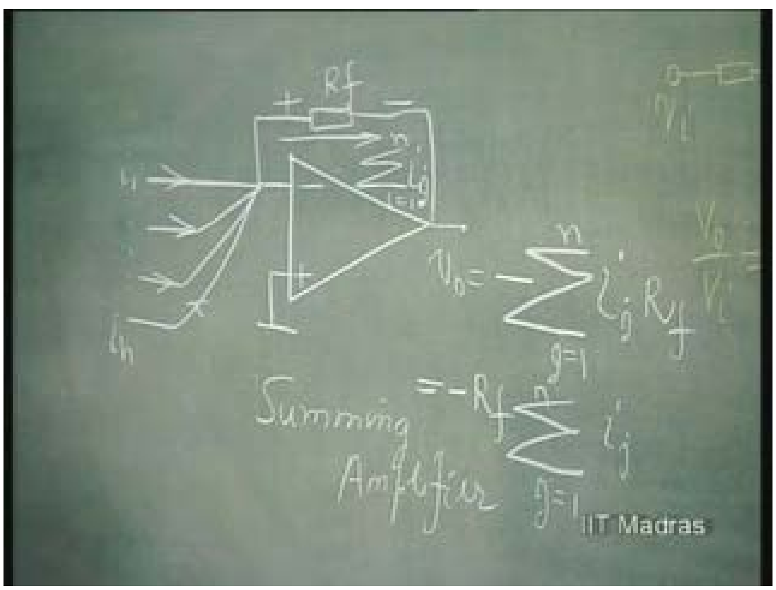

So, if I want, for example, resistors connected here, R 1 V 1, R 2 V 2, so on...R n V n, then all these currents, i js can be replaced by V js by R js because V j is equal to... i j is equal to V j by R j because this potential is zero.

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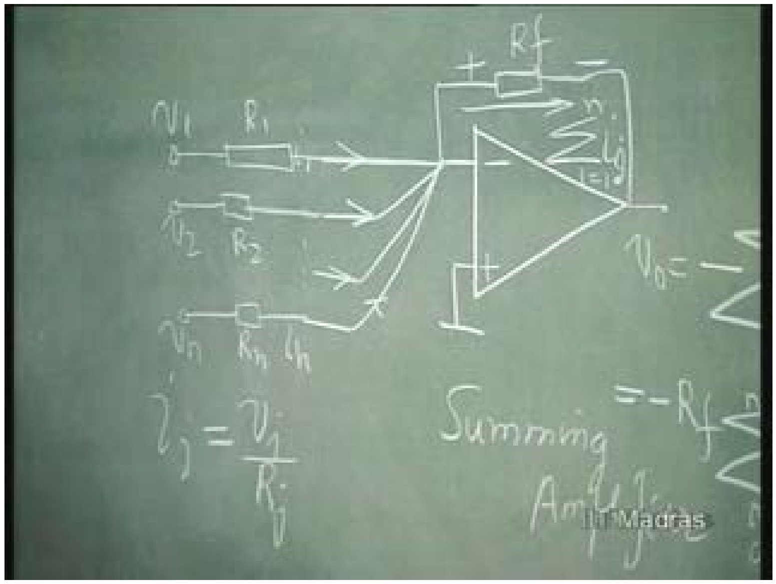

So, you can therefore get this output as minus R f. Let us say, we will call this as Alpha 1 times R 1, Alpha 2, Alpha 2 times R, this is Alpha n times R, scaling factor. Then, this will be sigma. This Alpha R will come. V j divided by Alpha j; j is equal to 1 to n.

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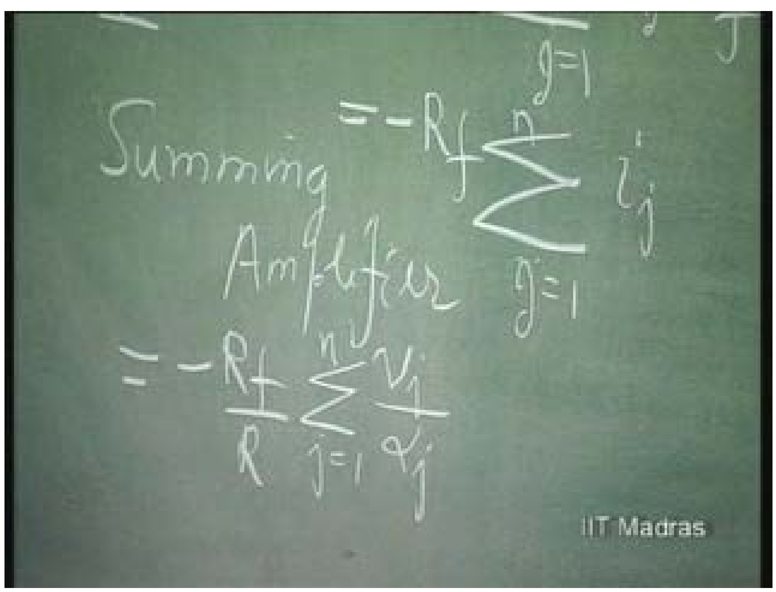

So, if you have R f by R equal to 1, then the co-efficients of V js can be conveniently chosen as 1 over Alpha Js. So, this becomes a very convenient summing amplifier.

Now, I am going to further generalize. I do not have any choice regarding the sign of the co-efficient here; but the value of the co-efficient can be greater than 1, less than 1, anything. So, it is a very simple design. Now, let us see whether we can have a means of controlling the sign as well as the magnitude so that it becomes a generalized summing amplifier.

Consider this circuit simply. At all times, we only give negative feedback. That you should remember. This is V a, this is V b. What is the output? V naught. If, let us say, this is R 1, this is R 2, this is R 3 and this is R 4, that is a general configuration. Let us see how to evaluate this.

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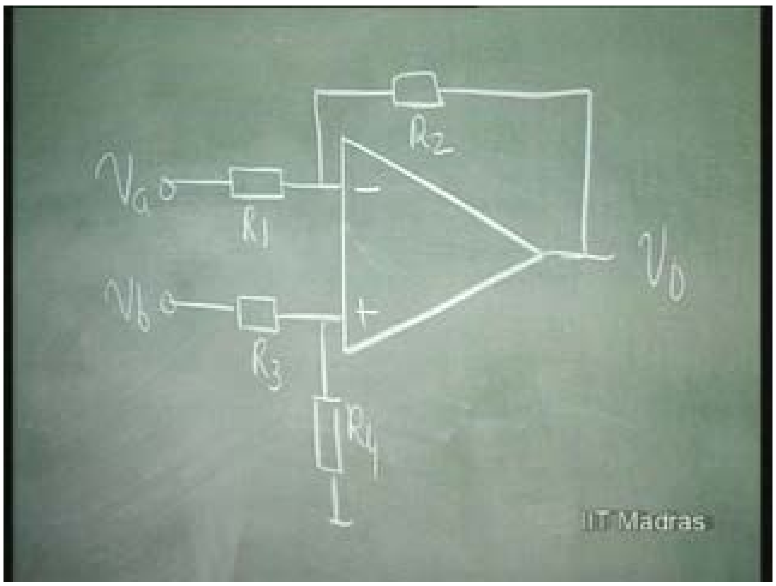

We can do this by super position theorem because there are two voltages. We can do this by super position theorem. First find out only for one voltage, other voltage being connected to ground; and then find out for the other voltage.

Now, considering that V b is connected to the ground, let us find out the output for V a. Now, this becomes nothing but the inverting amplifier shown here with R 2 and R 1. If you are grounding this, this potential is zero. So, it is almost equivalent to this circuit. So, this becomes an inverting amplifier. So, V naught is nothing but minus R 2 over R 1 times V a. With V b connected to ground, it is equivalent to just an inverting amplifier there.

Next, let us lift this above ground. This is V b. Connect this to ground. Now, what does it become? From here to here, it is an attenuation. So, the voltage here is V b into R 4 by R 4 plus R 3 attenuator.

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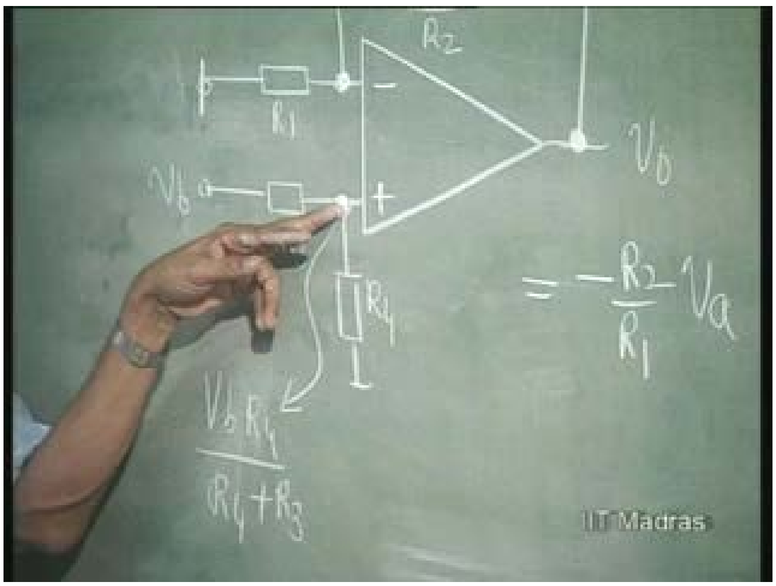

And from here onwards, it is nothing but the non-inverting amplifier there. So, it is the same configuration. So, gain is 1 plus R 2 over R 1. So, this is plus V b into R 4 by R 4 plus R 3 into 1 plus R 2 over R 1. So, this is the composite output of this amplifier. This is therefore equal to... This has a negative sign, you see; this has a positive co-efficient.

So, let us say, I would like to make this a difference amplifier. There are two voltages. I want to take difference of V b and V a. Therefore, I would like to take this as a common factor, let us say. R 2 over R 1 minus V a plus this should have been plus V b; minus V a plus V b would have been the differential thing. So, I have taken out R 2 over R 1. So, this becomes 1 plus R 1 over R 2 divided by 1 plus R 3 over R 4.

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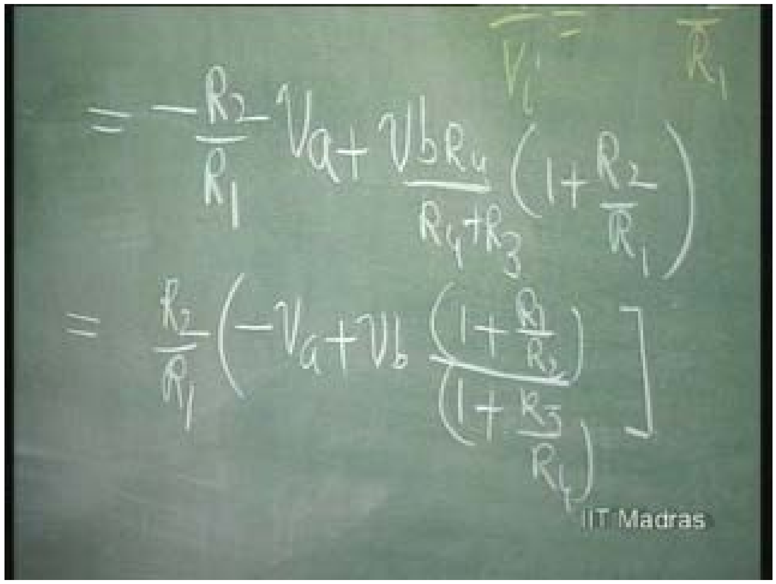

I am dividing by R 4. So, 1 plus R 3 over R 4. This R 2 over R 1, I have taken out. So, this becomes 1 plus R 1 over R 2. So that means, if, this is important, if 1 plus R 1 over R 2 equals 1 plus R 3 over R 4, that co-efficient becomes 1. So, this becomes R 2 over R 1 into V b minus V a. A difference amplifier. This is called a difference amplifier.

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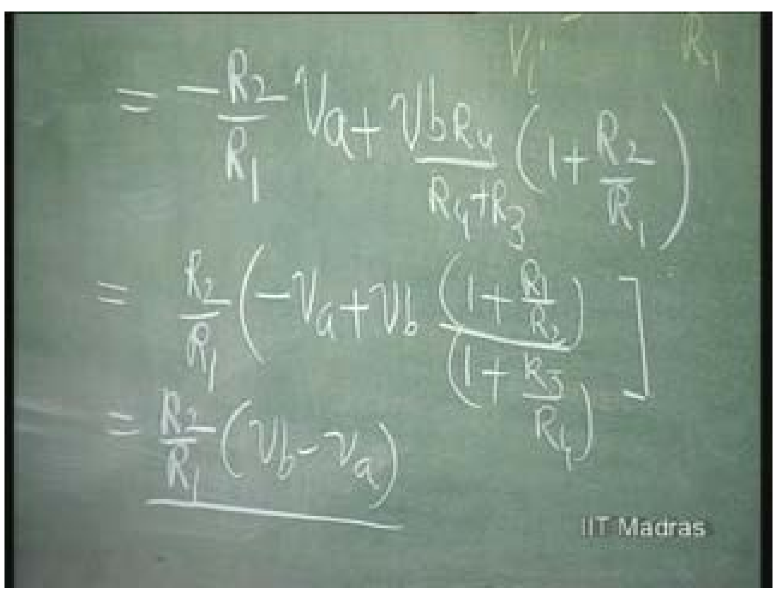

What is the condition? This 1 gets cancelled. So, R 1 by R 2 should be equal to R 3 by R 4.

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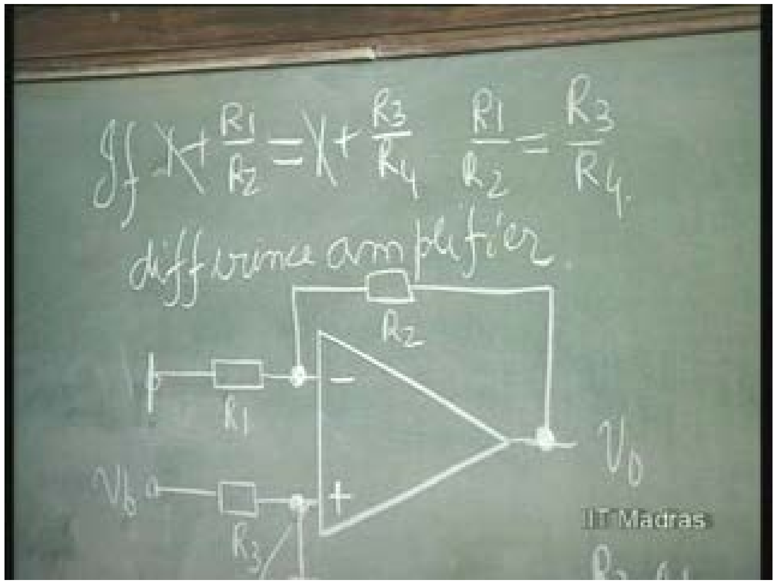

If you make R 1 by R 2 equal to R 3 by R 4 equals 1, then this gain also becomes equal to 1. It is ordinary difference amplifier. Output is V b minus V a. Such an amplifier is necessary in all bridge measurements. You want, for example, the bridge voltage comes as a difference voltage V a minus V b or V b minus V a; and I want to amplify this by a factor R 2 over R 1. So, this is a common amplifier configuration which is used along with bridge.

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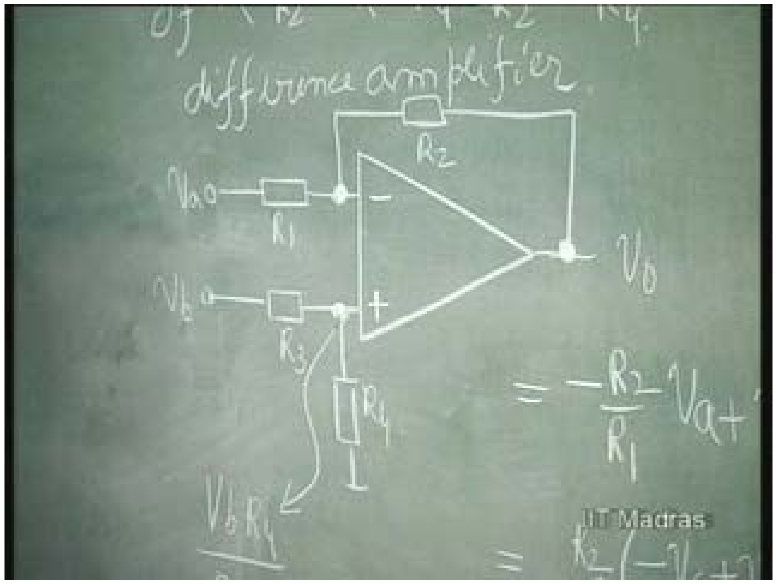

So, where do you use a bridge? May be in resistance measurement, capacitance measurement; in all these measurements, you use bridges. And where do these bridges become necessary? Whenever we have transducers whose resistance varies or capacitance varies or inductance varies, and we want this variation to be measured, we form them into bridges so that the common voltage gets cancelled and only the difference voltage which is the unbalanced voltage comes at the input of the amplifier.

So, this forms a basis of an important amplifier called instrumentation amplifier. Almost all the transducers which are coming as bridge, as bridges, this instrumentation amplifier is the first amplifier which amplifies the different signal component. An instrumentation amplifier is therefore basically a difference amplifier. Now obviously, this instrumentation amplifier might disturb the bridge balance because it is loading the bridge.

So, if you want a good instrumentation amplifier, you have to buffer it from the bridge. Apart from taking a difference, it should also be acting as a buffer, so that it does not load the bridge.

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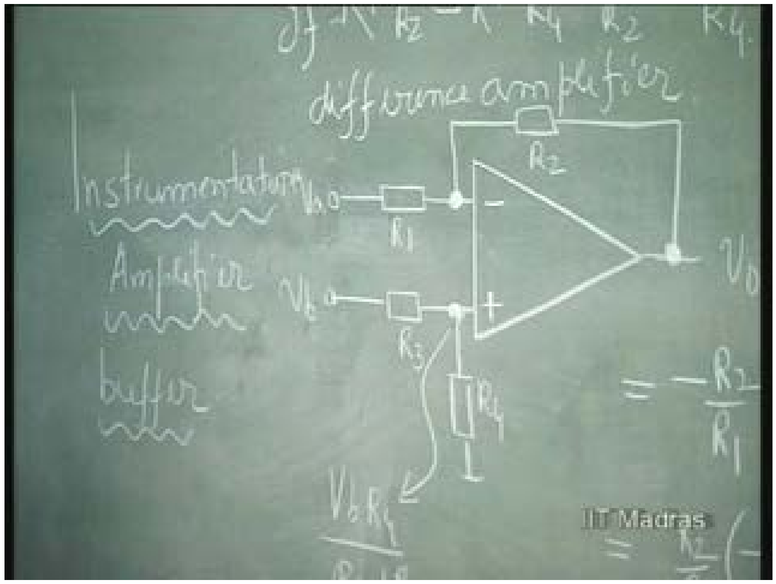

Therefore, we will now introduce two buffers here so that this loading actually... Those buffers are already known to us. They are therefore going to be unity gain amplifiers or non-inverting amplifiers. Any of this could be used as buffer stages. V b which is not inverted and V a which is inverted there. So, we have the buffer stages just introduced here so that this becomes a good instrumentation amplifier.

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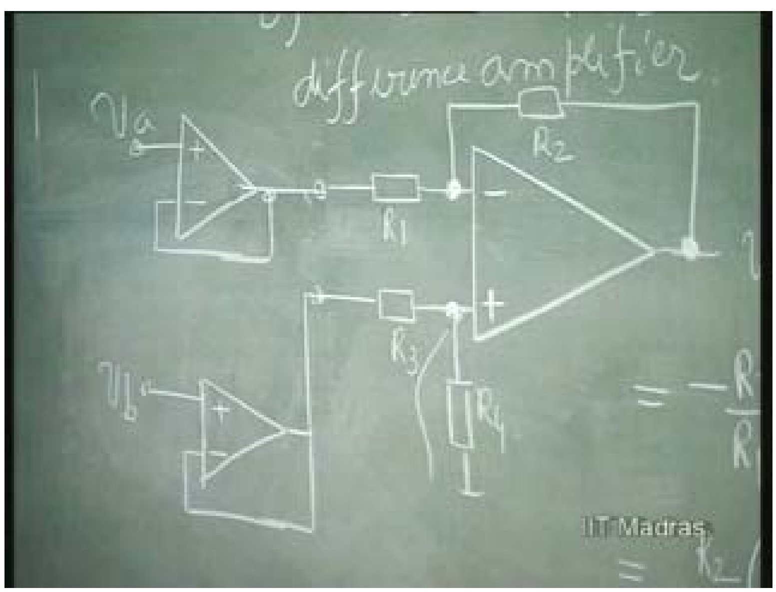

So now, these three op amp configuration can act as a fairly good instrumentation amplifier with a gain of R 2 over R 1. But you know; this condition has to be satisfied. R 1 by R 2 should be equal to R 3 by R 4. Now we say that I have the op amp; almost near ideal op amp; but the resistors I have chosen are just nominal resistances with some amount of tolerance.

So, let us consider that the resistances that we use have a tolerance of Delta. The resistances that we have have a tolerance of Delta. That means R value is going to be R into 1 plus or minus Delta. That is what it means. Tolerance of Delta means. So, R can be changing from its nominal value by plus minus Delta.

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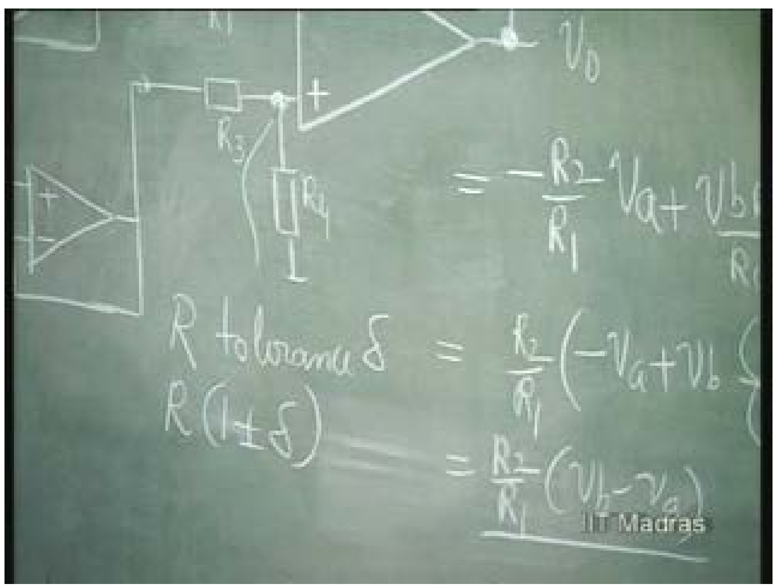

So, if such resistances are used for fabricating this instrumentation amplifier, this R 1 will be... R 1, whatever value it requires, and plus minus Delta. So, I want this to merely act as a difference amplifier with unity gain, let us say. R 2 by R 1 is made equal to unity. This is equal to R 4 by R 3. So, all resistances are made equal to R and all of them have a tolerance of Delta.

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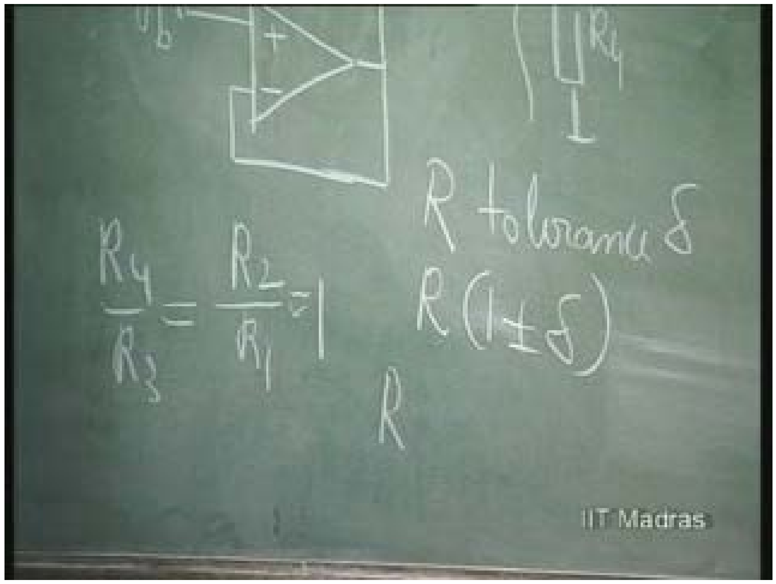

That means this is merely being used as a difference amplifier with unity gain. So, what is the difficulty?

Now please recollect what I discussed about, in terms of differential amplifiers. Any differential amplifier with a differential mode gain also has a common mode gain; and it has a specific common mode rejection ratio. This, I have discussed. What is it? When we want to amplify V, V minus V a or we want to just collect V b minus V a, there will be a common signal between V b and V a which is V b plus V a by 2.

So, it should be capable of rejecting that common signal. What does it mean? When V b equals V a equal to the common mode signal, which is V b plus V a by 2, there should not be any output because V b has been made equal to V a equal to V c. There should have been zero output. But, because of the problem with this tolerance, what happens? These resistances are not exactly equal. If this is 1, R into plus or minus Delta, this also is... The trouble arises not if the error is in the same direction in all. If this is R into 1 plus Delta, this also is R into 1 plus Delta. The ratio is still 1.

Here also, this is R into 1 plus Delta. This also is R plus 1...R into 1 plus Delta. The ratio is still equal to 1; and therefore, there is no problem. The gain is going to be... it is going to have no output, as far as common mode signal is concerned. But the problem arises when this is R into 1 plus Delta, this is R into 1 minus Delta; or when this is R into 1 plus Delta, this is R into 1 minus Delta.

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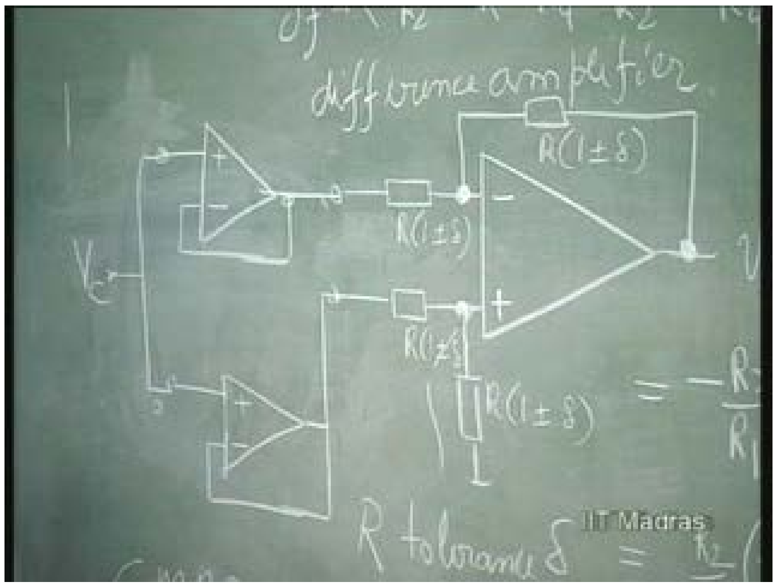

So, what happens is that this ratio, if instead of being 1, will be deviating from 1. If this is 1, this also should be 1. Then only, this cancellation occurs. Unless this cancellation occurs here and this becomes V b, just V b, this cannot be considered as difference amplifier. So, when V b is equal to V a, it is going to still give us an output, if these do not get cancelled.

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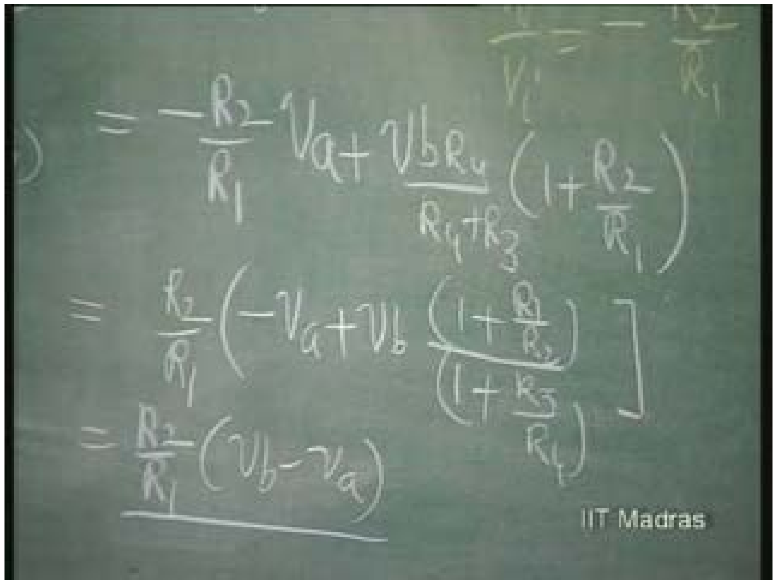

So, what is the common mode gain under this situation? Worst case common mode gain? So, we will want to find out common mode gain. That is A c. CMRR is nothing but A d by A c, the differential mode gain divided by common mode gain.

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Differential mode gain has been made equal to 1. So, R 2 equal to R 1. So, R 2 equal to R 1. A d is equal to 1.But, we have to also make R 2 equal to R 1 equal to R 4 by R 3. That means R 4 also has been made equal to R 3 equal to, nominally, same value of resistance R.

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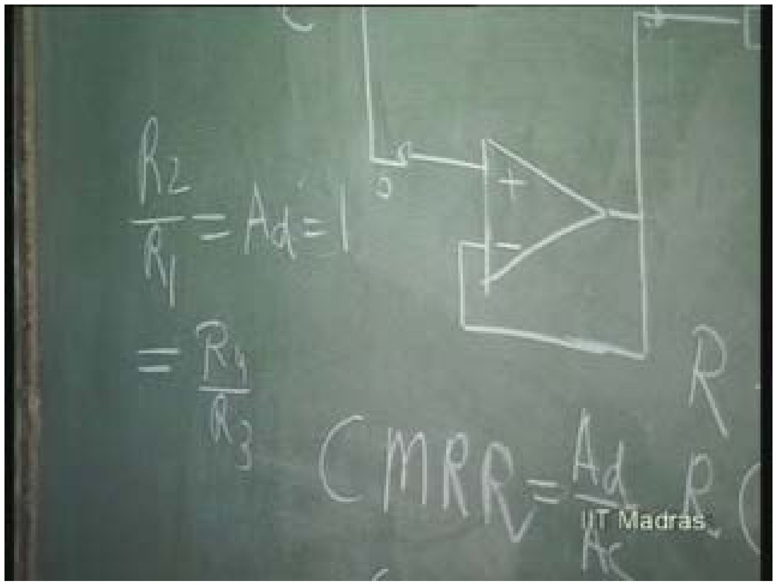

So, what is the common mode gain? Then V a equal to V b. This is V c, this is V c, now. V a has been made equal to V b equal to V c. So, whatever output I get now... What is the output? We will take R 2 equal to R 1. So, this is made equal to 1, nominally. So, this is having minus V c; let us say, R 2 by R 1. That is a common factor; R 2 by R 1 is very nearly equal to 1. This into minus 1 plus 1 plus R 1 by R 2 divided by 1 plus R 3 by R 4.

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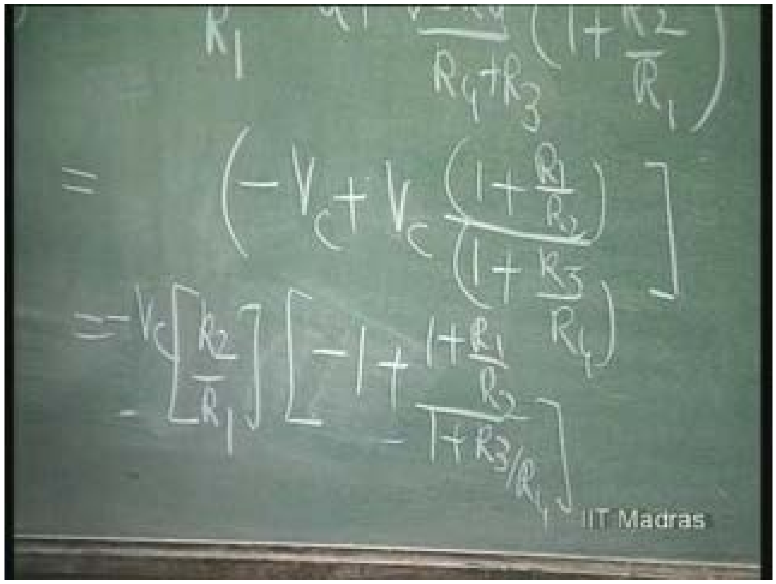

What is this? This is equal to this. R 3 by R 4 will go up. 1 will get cancelled. So, you have minus V c into R 2 by R 1 into minus R 3 by R 4 plus R 1 by R 2; from this, this is what you get; divided by 1 plus R 3 by R 4.

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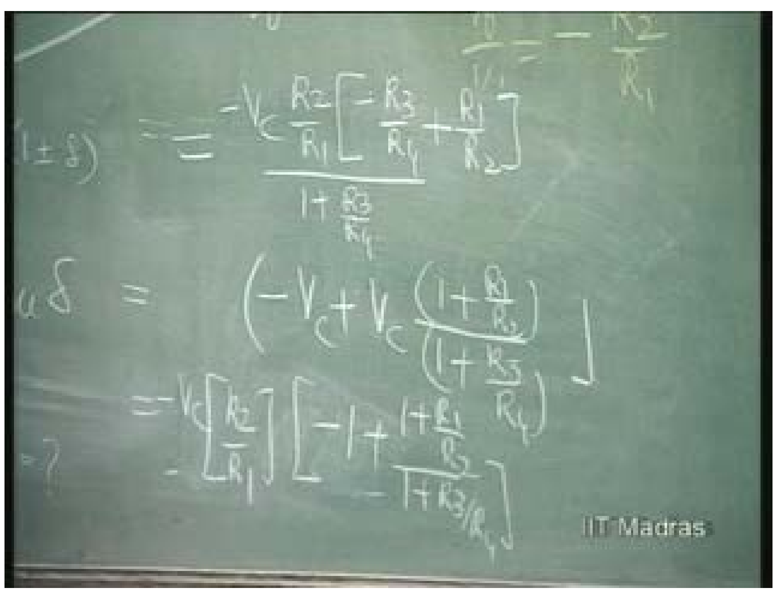

So, I can take this inside. This becomes equal to 1. This is R 2 by R 1. As before, you see, this is 1 minus R 3, R 4, R 3 R 2 by R 4 R 1; R 3 R 2 by R 4 R 1, which should have been equal to one, nominally. If this is 1, this 1 minus 1, this is zero. Common mode gain is zero; common mode rejection ratio is infinity.

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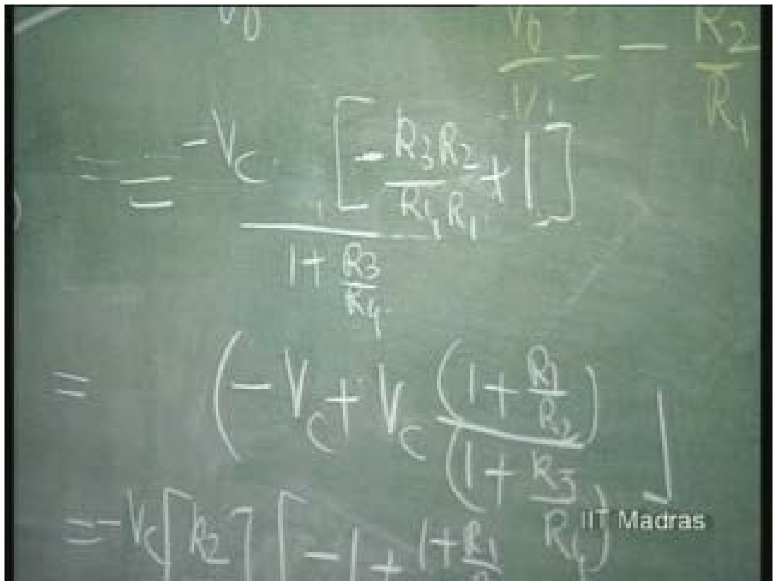

In this particular case, what is the worst case value for this? When all the nominal values are R, this will be R square, this will be R square; that gets cancelled. Nominal value is 1. Inside the bracket, you will have R square into 1 plus Delta into 1 plus Delta. So, 1 plus 2 Delta plus Delta square. Here, you have to consider the worst case situation; 1 minus Delta into 1 minus Delta. So, R square into 1 minus 2 Delta plus Delta square.

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If you neglect Delta square because Delta itself is very small, this is the value of... So, the so called 1 or how much is it? Different 1 plus Delta by 1 minus Delta is approximately equal to 1 plus 4 Delta.

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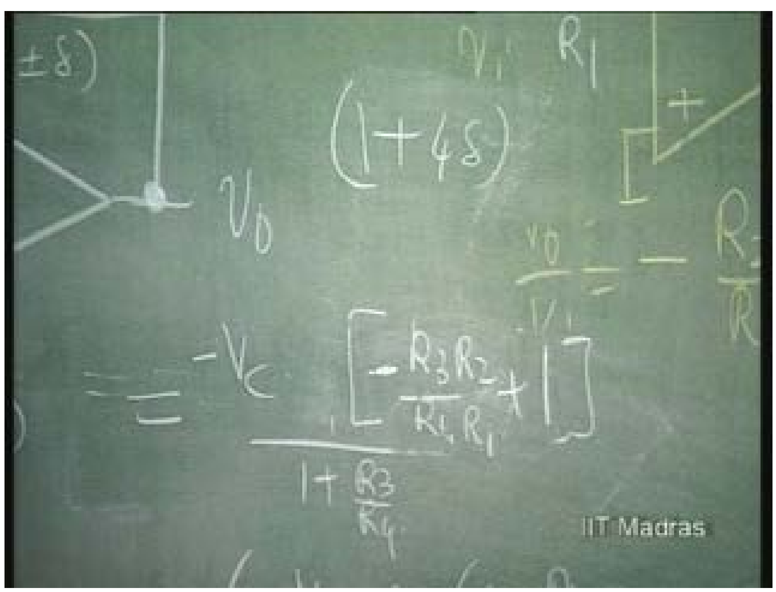

So, this becomes 1 plus 4 Delta. So 1, 1 gets cancelled. The whole thing will give you a contribution of only 4 Delta and the denominator R 3 is equal to R 4. This is going to be 2, nominally. So, this is going to be minus V c into 2 Delta; plus or minus, of course.

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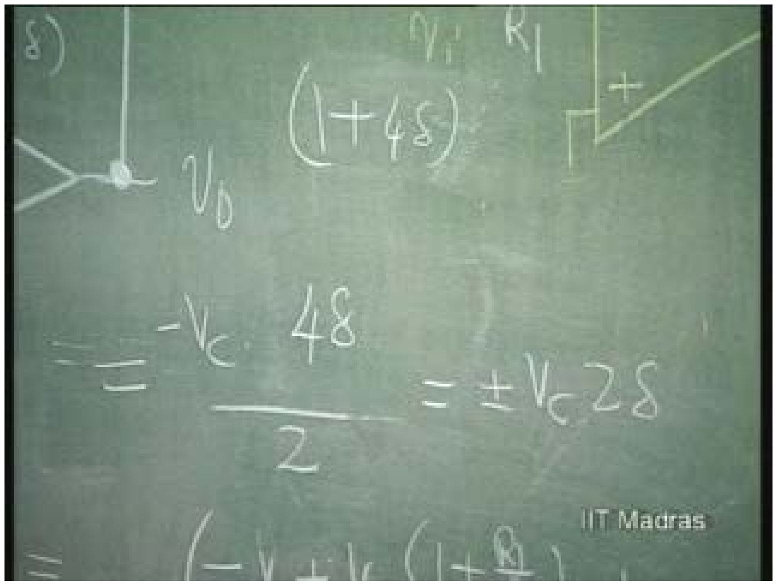

So, the gain A C... V naught is equal to plus or minus V c into 2 Delta. So, A C is equal to 2 Delta.

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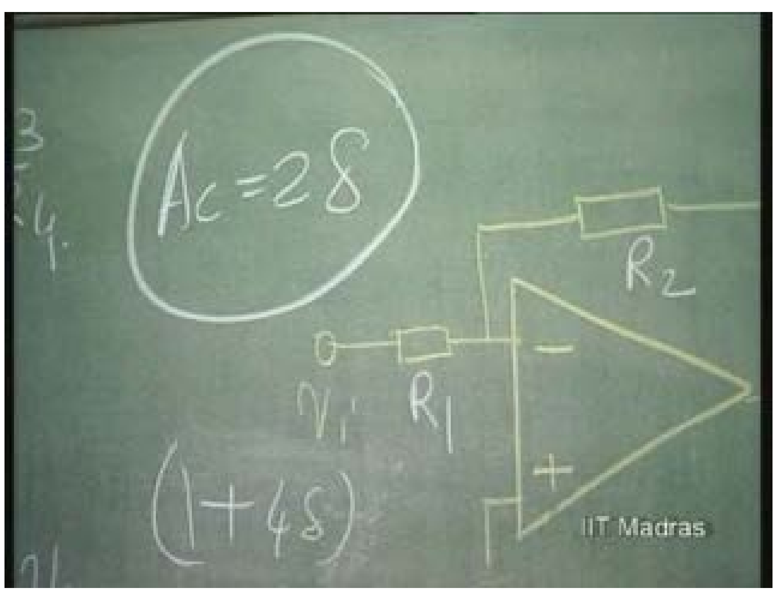

This is important in case of information which is needed by any designer of an instrumentation amplifier. If the instrumentation amplifier is designed using resistance of tolerance Delta, the common mode gain is 2 Delta. Worst case, that is. The best case value is zero. So, the worst case value is 2 Delta. That means common mode rejection ratio for this simple difference amplifier with gain equal to 1 is 1 by 2 Delta.

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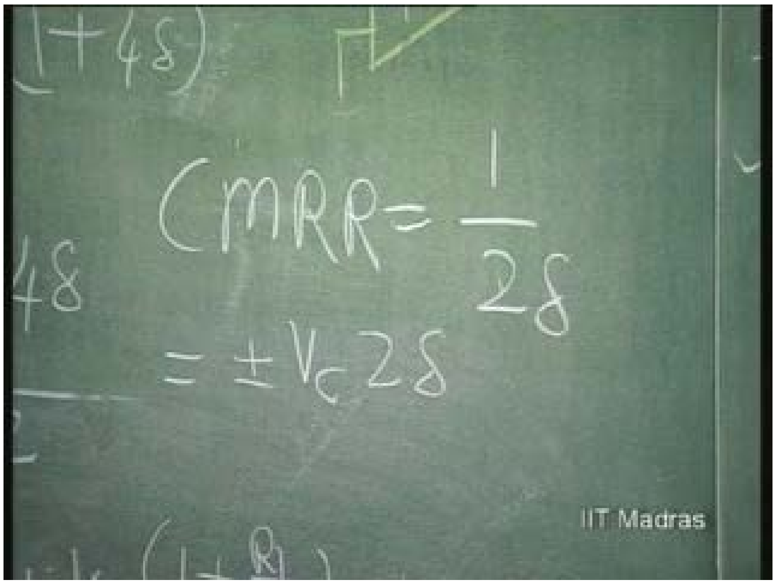

Consider ordinary resistances of 5 percent or so. Delta is 5 by 100. So, common mode rejection ratio is going to be 5, 2...1 by 2 into 5 by 100. That is only 10. Its ability to distinguish between common mode voltage and differential voltage is only a factor of 10, which is a very poor value and therefore you have to use precision resistors here in order to get good common mode rejection ratio.

So, we are now confronted with a very serious problem in instrumentation amplifier design. That, if I have to use actual resistors here and come out with huge number of instrumentation amplifiers... Now, please be careful. If I adjust these resistances in such a manner that this ratio becomes satisfied, then I can always make A C equal to zero.

That means you can always make an instrumentation amplifier with infinite common mode rejection ratio; but practically, what happens is, we cannot keep on adjusting these resistors for each instrumentation amplifier because for the test alone you will have to spend lot of money. So, the price for the instrumentation amplifier will go up. When the mass manufacture of a unit is being made, you would like to simply connect this and expect it to work satisfactorily.

In such a situation, tolerance of resistance becomes important. The resistances used must have good tolerance so that all of these units that are made will have good C M R R. And the units can be sourced straightaway without being tested. Then, they can be sold cheaply.

So, in order to make the instrumentation amplifier be sold at low rates, we must use off the shelf components without further testing the instrumentation amplifier. In such a situation, we must accept certain tolerance for this resistance. So, how to improve the common mode rejection ratio? This is important. How to use co-tolerance resistors here and still get better common mode rejection ratio is one thing; and how to buffer - that we have already discussed - is going to be the topic for the next class.

Therefore, we will now convert this into, let us say, instead of buffer, we will have non-inverting amplifier with the same gain. If you do this, V a is going to be amplified; V b also is going to be amplified by the same factor hopefully, because same factor is important. Otherwise, again, this will contribute to common mode.

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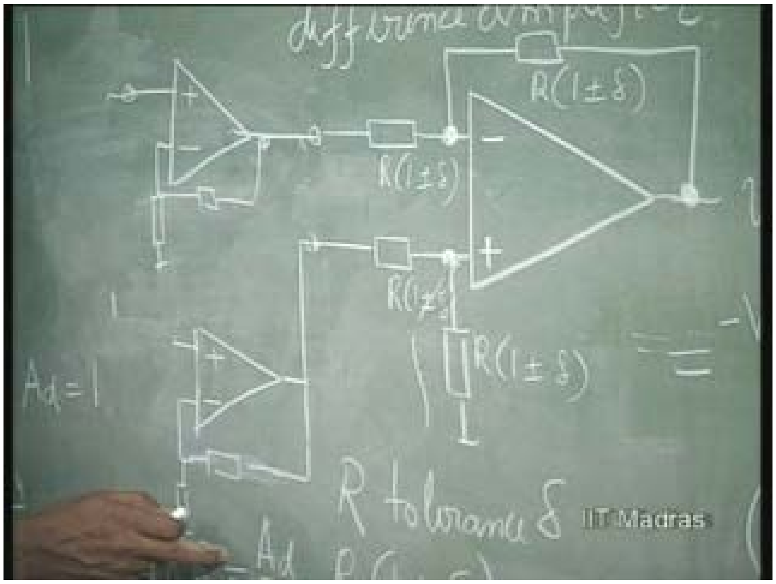

So, if these are amplifying by the same factor, V a and V b, by the same factor, then overall gain can be attributed by these gain factors. This can be R R R R; but this is not going to solve our C M R R. C M R R remains as bad as ever. In fact, it gets worsened because these tolerances also come into picture.

I have redrawn the circuit; same circuit, with these resistances put on this side as same as this side; but both of these amplifiers are now giving a gain of 1 plus R b by R a, if these resistances are identical.

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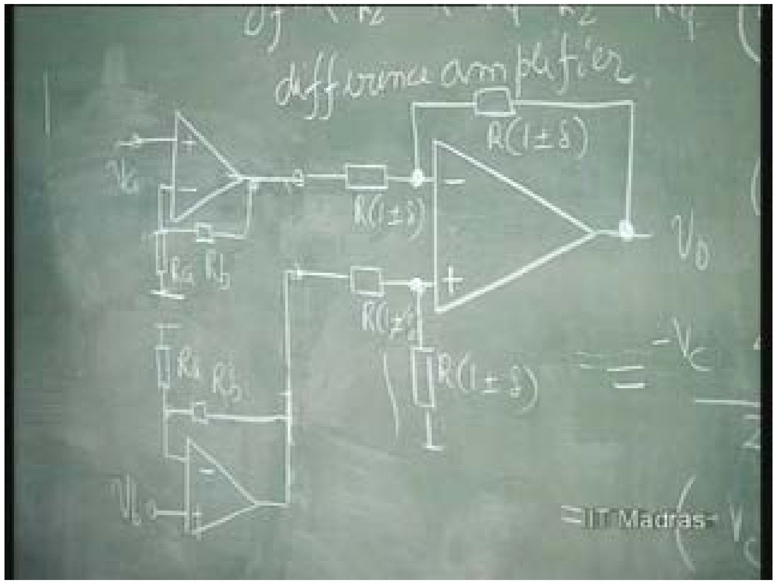

Now, there is only one simple trick in order to get over the problem of tolerance, but still give gain. So, this grounding is responsible for the current in this to be made V a by R a, current in this to be made V b by R a. The current should be same V b by...that is determined by the same resistance; but these resistance values, if they differ, the currents will be determined by different value resistors.

That can be made same by simply lifting this above ground. Look at this. Both these resistances are lifted above ground and connected together. Now, it simply loses the common mode problem.

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Only the difference mode voltage will have any say in fixing the current in R a. Let us see how it is. If this is V a, this is V a. If this is V b, this is V b. That we know. Nullor. So, the current in this is now uniquely determined by V a minus V b divided by twice R a.

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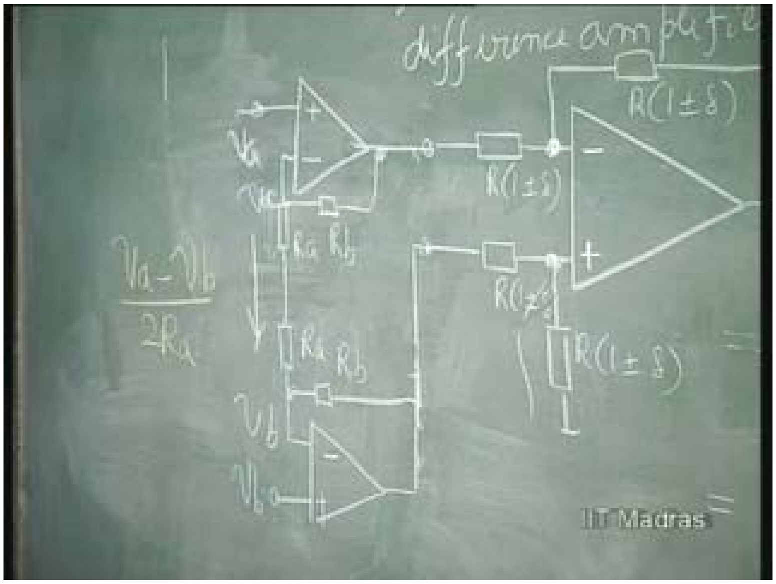

So, the difference is simply taken because of the fact that I have removed the ground connection here. If I had had the ground connection, this current would have been V a by R a. This current would have been V b by R a and those Ras' would have been different. Here, this resistance determines V a minus V b by twice R a.

So, the difference is automatically taken here without the influence of any resistor coming into picture. So, I can make this R a as small as I please and make this difference current as high as I please; and therefore make... I can make the differential mode gain alone very high. Have you understood this point? V a minus V b is automatically the difference voltage coming across a common resistance of 2 R a.

So, V a minus V b by 2 R a can be made as high as you please; but, when V a is equal to V b, current is still equal to zero. So, it does not amplify the common mode voltage. It amplifies only the differential mode voltage. This is the trick in the so called three op amp instrumentation amplifier. So, if this current is this, this current will flow through this and develop a voltage here which is V a. This is V a. This will be plus; this will be plus; so, plus V a minus V b by 2 R a into R b; that is the potential here.

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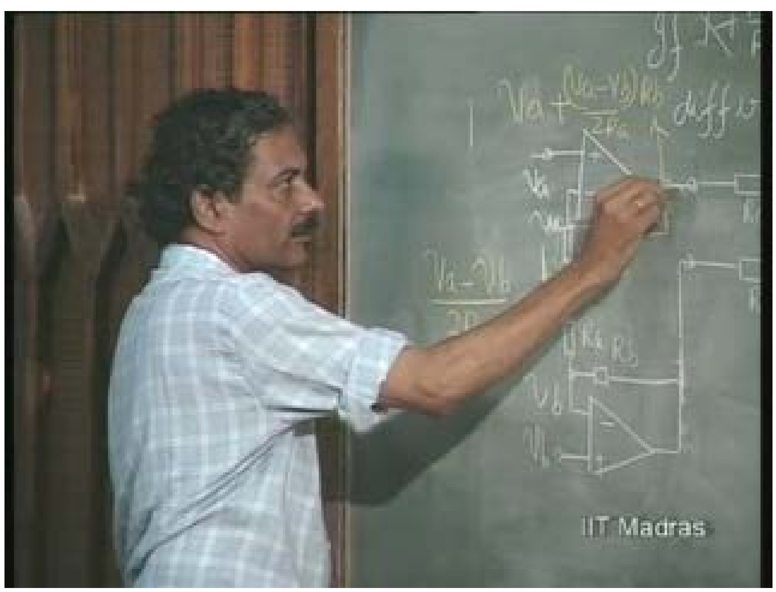

And this potential here, this current is also going to flow through this like this, develop a drop here. So, V b which is this, minus... plus, minus; so, minus V a minus V b [Noise] divided by twice R a into R b.

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