Integrated Circuits and Applications
Prof. Shaik Rafi Ahamed
Department of Electronics and Electrical Engineering Indian Institute of Technology, Guwahati

Introduction to Operational Amplifiers
Lecture – 03
Instrumentation Amplifier

So, in the last lecture we have discussed about the summing amplifier, difference amplifier, we have derived the expressions for the output of the summing and difference amplifiers. So, for a difference amplifier, so the difference amplifier that we have discussed in the last lecture is this one. This is V naught, this is R' R R_1 R_2. We have derived the expression as $v_o = \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)v_1 - \frac{R'}{R}v_2$. So, the two special cases we have considered if all the resistors are having same value $R = R' = R_1 = R_2$. Then what happens this R_1 plus R_2 this R plus R' will get cancel R_2 will get cancel R' R will get cancel will get simply output $v_o = (v_1 - v_2)$.

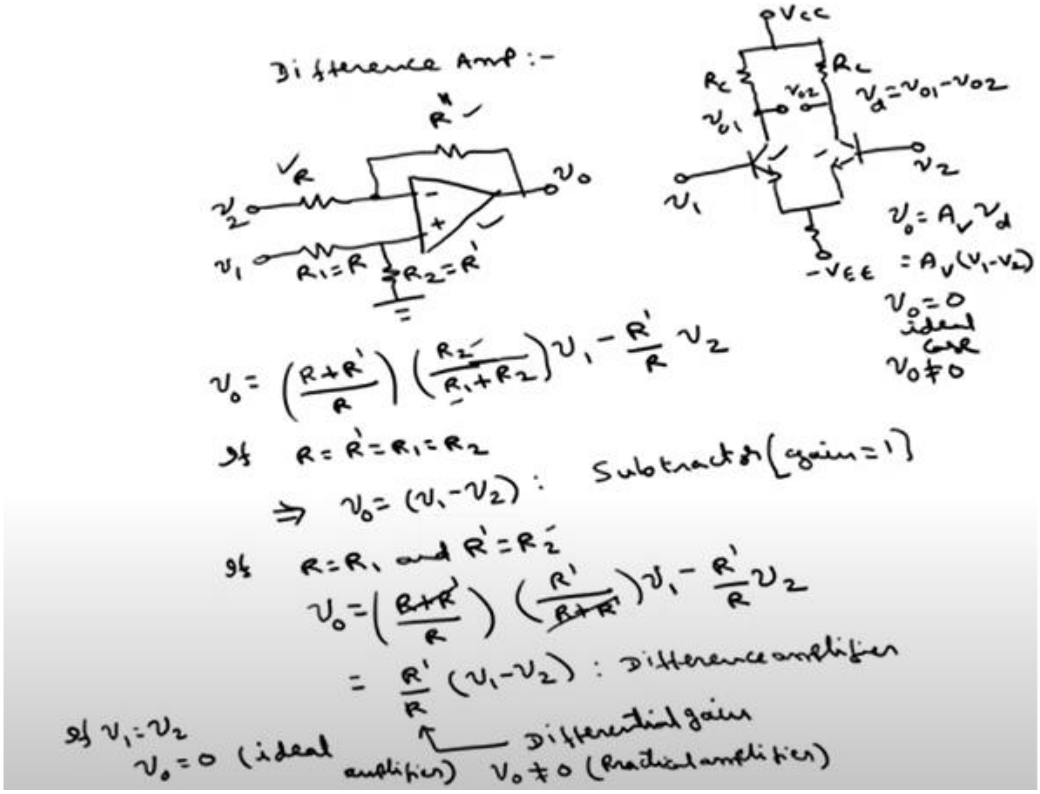
This will acts as subtractor, difference amplifier with unity gain, here the gain is unity. On the other hand if you want to have some gain for the different signal also, then the condition is $R = R_1$ and $R' = R_2$. If I make this R_1 is equal to this R, this R_2 is equal to this R'. Now, what happens to this expression output V naught? V naught is equal to I will keep all the values in terms of R and R' only. $v_o = \left(\frac{\cancel{R+R'}}{R}\right)\left(\frac{R'}{\cancel{R+R'}}\right)v_1 - \frac{R'}{R}v_2$.

$v_o = \frac{R'}{R}(v_1 - v_2)$.

So, this is called differential gain. So, this will acts as difference amplifier. The difference of the signal is amplified with the gain of R' by R.

There is one important parameter in case of this amplifiers is called common mode rejection ratio. So, I will discuss what is that common mode rejection ratio. Here if I see this output expression $v_o = \frac{R'}{R}(v_1 - v_2)$. If $v_1 = v_2, v_o = 0$. This is the case of ideal amplifier, but for practical amplifier $v_o \neq 0$.

(Refer to the slide at 06:25)



So, the reason for this one is if I take the internal circuitry of this op-amp inside this there is a difference amplifier made of either bipolar junction transistors or it can be MOSFET. This is some sort of this circuit. Here this v_1 and v_2 will be applied and they will be having equal resistances connected to V_{CC}. This is also R_C, this is also R_C. The output is going to take across this one the different signal.

This is say v_{01}, this is v_{02}, $v_d = v_{01} - v_{02}$. Now here if this $v_1 = v_2$, then V naught is equal to the gain into if I call the gain as A_v into v_d, $v_d = v_1 - v_2$. If $v_1 = v_2$, $v_0 = 0$. This is the ideal case, but practically this is not 0. The reason is there is a mismatch between these two transistors.

Even if you made by the same manufacturer with same specifications still there will be some mismatch because of that even if $v_1 = v_2$ you will not get the output as 0. So, in other words you can explain this concept as so, the output not only depends on the difference of the signals, but also on the common mode signal which is defined as the average of the signals. So, we can express the output of this difference amplifier as $v_0 = A_1 v_1 - A_2 v_2$. This is gain due to A_1 only, gain due to v_1 only. That means, you have to make $v_2 = 0$.

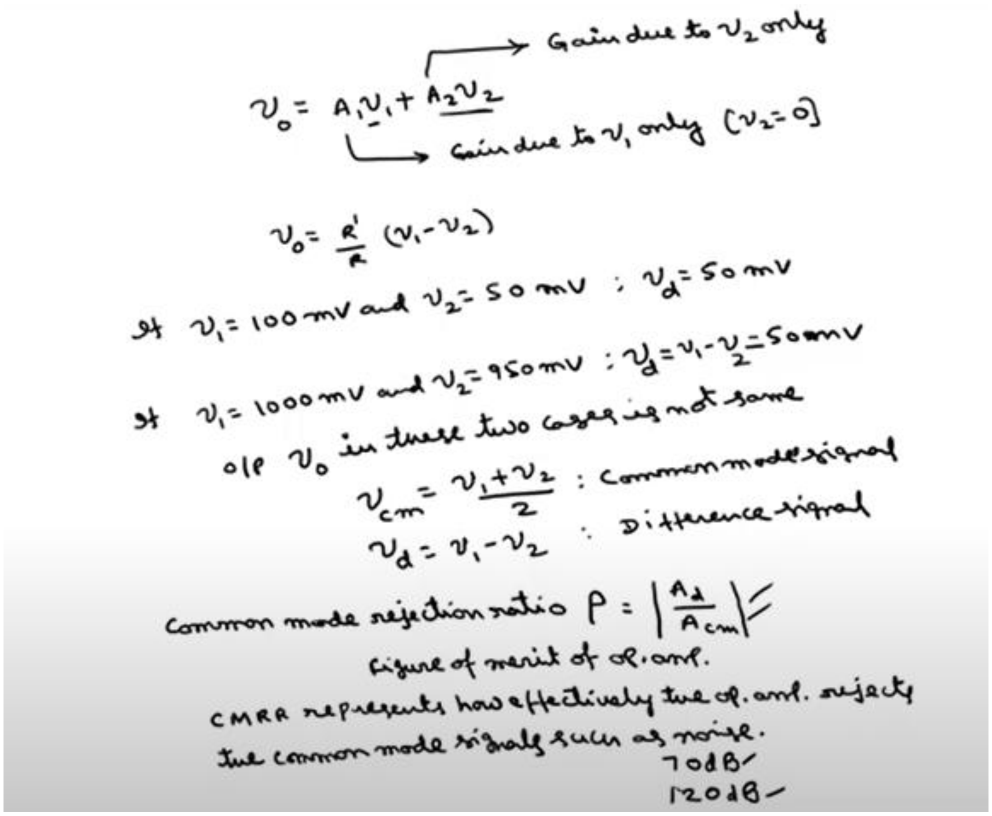
If $v_2 = 0$ this term becomes 0. So, this will be gain due to only v_1 and this is gain due to v_2 only. Now, we are going to see that the output voltage $v_o = \frac{R'}{R}(v_1 - v_2)$. So, if you take say we say $v_1 = 100mV$ and $v_2 = 50mV$. The difference $v_d = 50mV$ and if I take the second case $v_1 = 1000mV$ and $v_2 = 950mV$.

Still the difference is $v_d = v_1 - v_2 = 50m$. But the output in these two cases is not same, because of the mismatch of the transistors ok. So, we can conclude that the output of the difference amplifier not only depends upon the difference signal, but also on the average signal which is defined as common mode signal $v_{cm} = \frac{v_1+v_2}{2}$. The CM stands for common mode, $v_d = v_1 - v_2$. So, because of the mismatch the output of the difference amplifier not only depends upon the difference signal $v_1 - v_2$, but also on the common mode signal.

So, the ratio of the differential gain to common mode gain is called as common mode rejection ratio is denoted by symbol rho is equal to magnitude of the differential gain to common mode gain. This is called figure of merit of op-amp. This is one of the very important parameter of the op-amp. So, this is going to decide how effectively the op-amp rejects the undesired signals such as noise and all. The CMRR represents, how effectively the op-amp rejects the common mode signals such as noise.

Noise is undesired signal. So, we have to reject this noise. So, in order to effectively reject this noise we have to design the operational amplifier with high CMRR. Normally for 741 this is 70 dB. So, if you take the different manufacturers op-amp then it will be even 120 dB also.

(Refer to the slide at 12:15)



So, this is dB normally if you take the logarithm of this ratio then the value will be expressed in dBs. Now, we will derive the expression for the common mode rejection ratio of difference amplifier. So, the output of difference amplifier in general is given by $A_1v_1 + A_2v_2$ and here this v_d difference signal is defined as $v_1 - v_2$ and the common mode signal is defined as $\frac{v_1+v_2}{2}$. So, I will first find out the expressions for v_1 and v_2 in terms of v_d and v_{cm}. So, from this what is $v_1 + v_2 = v_{cm}$ whereas, from this $v_1 + v_2 = v_d$.

So, if we add one time if we subtract one time then you can obtain the expressions for v_{cm} and v_d this is $v_1 - v_2$. If you add these two values then v_2, v_2 will get cancelled $2v_1 = v_d + 2v_{cm}$ therefore, $v_d = v_1$, $v_1 = v_{cm} + \frac{v_d}{2}$. This 2 these 2 get cancelled and whereas, here v_d will become $\frac{v_d}{2}$. This is by adding this two expression 1 and 2. If you take subtraction $2 - 1$ so, this v_1 v_1 get cancelled v_2 minus of minus becomes $2v_2 = 2v_{cm} - v_d$ or $v_2 = v_{cm} + \frac{v_d}{2}$, this will call as 3 and 4.

If you substitute 3 and 4 in this expression so, what is $v_0 = A_1(v_{cm} + \frac{v_d}{2}) + A_2(v_{cm} - \frac{v_d}{2})$. So, if we take the coefficient of v_{cm} and coefficient of v_d the coefficient of v_{cm} is common mode gain and the coefficient of v_d is differential gain ok. So, what is the coefficient of v_{cm}? So,

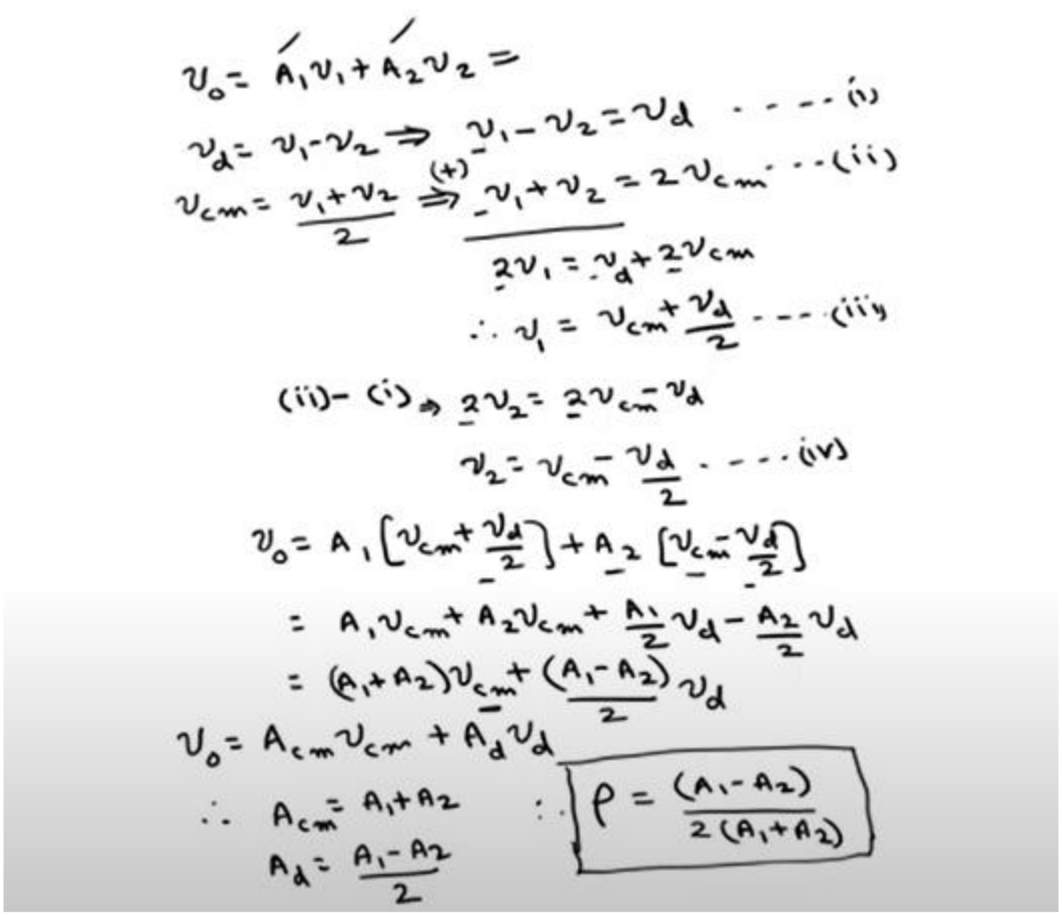
$$v_0 = A_1 v_{cm} + A_2 v_{cm} + \frac{A_1}{2} v_d - \frac{A_2}{2} v_d.$$

$$= (A_1 + A_2) v_{cm} + (\frac{A_1 - A_2}{2}) v_d,$$

but we know that the general expression for this output is this is common mode signal. So, the gain for common mode signal is A_{cm} is the gain due to common mode signal into the common mode signal plus A_d the gain due to the different signal into v_d ok.

So, therefore, here what is $A_{cm} = A_1 + A_2$, $A_d = \frac{A_1 - A_2}{2}$ therefore, what is CMRR? A_d by A_{cm}. So, $\rho = \frac{(A_1 - A_2)}{2(A_1 + A_2)}$. This is general expression for the common mode rejection ratio of any differential amplifier. Here A_1 is the gain due to v_1 only, A_2 is gain due to v_2 only ok.

(Refer to the slide at 16:55)



So, I will derive this common mode reaction ratio for the difference amplifier that we have discussed in the last slides.

This is the difference amplifier that we have considered. One of the important derivation is $v_o = \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)v_1 - \frac{R'}{R}v_2$. So, I have to derive the expression for the common mode rejection ratio of this circuit ok. So, what is the expression for this output that we have obtained? v_o is equal to the contribution due to v_1 we have obtained as $\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)$ this we have already derived into v_1 this is contribution due to this $-\frac{R'}{R}v_2$ this is expression for v_o ok. So, in order to find out the CMRR we should know what is the common mode gain and what is the differential gain ok.

So, for that we know already this expressions V1 is equal to so, in the previous slide we have obtained this $v_1 = v_{cm} + \frac{v_d}{2}$, $v_2 = v_{cm} - \frac{v_d}{2}$. If you substitute these values here what is

$$v_o = \left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right)\left(v_{cm} + \frac{v_d}{2}\right) - \frac{R'}{R}\left(v_{cm} - \frac{v_d}{2}\right)$$

$$= \left\{\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) - \frac{R'}{R}\right\}v_{cm} + \frac{1}{2}\left\{\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) + \frac{R'}{R}\right\}v_d.$$

Now, our intention is we have to find out the coefficient of v_{cm} coefficient of v_d coefficient of v_{cm} is A_{cm} coefficient of v_d is A_d if I take the ratio of A_d to A_{cm} then I will get the common mode rejection ratio ok. So, for that you divide this into the v_{cm} coefficient and v_d coefficient separately. So, what are the v_{cm} coefficient here? So, this v_{cm} coefficient is this here whereas, here the v_{cm} coefficient is this.

So, if I take the v_{cm} as common this is $\left\{\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) - \frac{R'}{R}\right\}$ this is the overall coefficient of v_{cm} plus what is v_d coefficient is $\frac{1}{2}\left\{\left(\frac{R+R'}{R}\right)\left(\frac{R_2}{R_1+R_2}\right) + \frac{R'}{R}\right\}$. So, the v_d coefficient we can call as A_d and the v_{cm} coefficient we can call as this v_{cm} coefficient we can call as A_{cm}. So, the ratio of A_d to A_{cm} is common mode rejection ratio ok.

So, what is A_d here? Let us $A_d = \frac{1}{2}\{\frac{(R+R')R_2 + R'(R_1+R_2)}{R(R_1+R_2)}\}$. So, this R into R_1 plus R_2 is there here you will get this as it is $\{\frac{(R+R')R_2 - R'(R_1+R_2)}{R(R_1+R_2)}\}$ as what is A_{cm} after simplification this A_{cm} term. So, here the LCM is $R(R_1+R_2)$ half will not be there in the numerator we have.

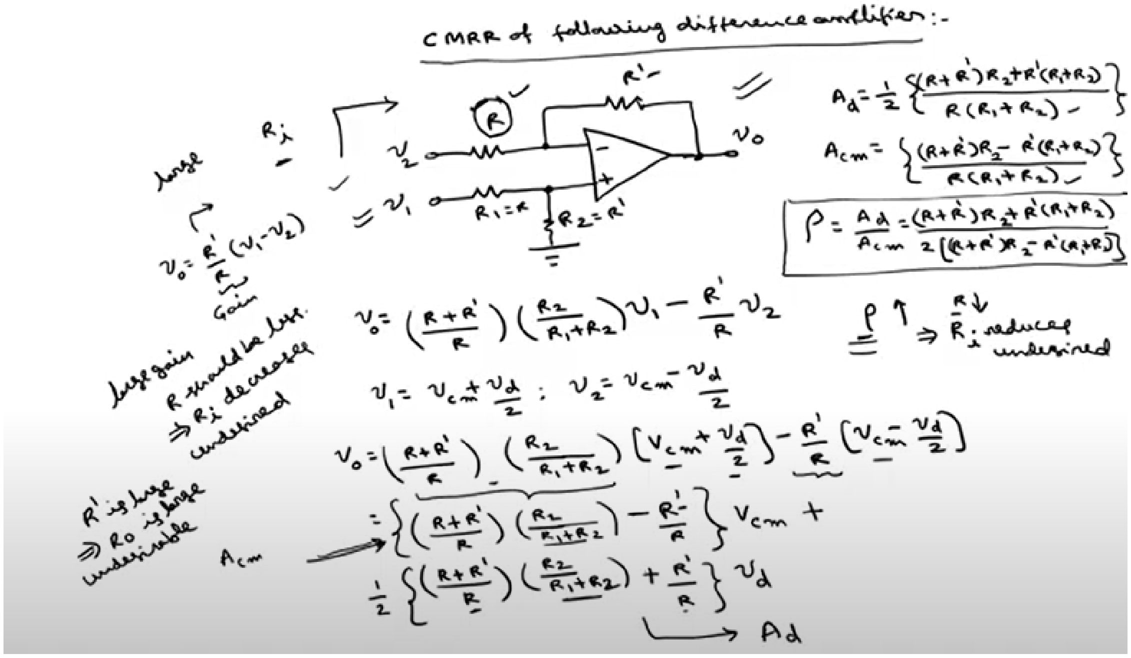
So, here this is directly $(R + R')R_2$ whereas, here this is plus $R'(R_1 + R_2)$ this is $R_2 - R'(R_1 + R_2)$. So, what is common mode rejection ratio row $CMMR = \frac{A_d}{A_{cm}}$. So, this denominator will get cancelled both are same. So, $\frac{A_d}{A_{cm}} = \frac{(R+R')R_2 - R'(R_1+R_2)}{2\{(R+R')R_2 + R'(R_1+R_2)\}}$. This is the expression for the common mode rejection ratio of this differential amplifier ok.

So, here normally this common mode rejection ratio is large, larger is the common mode ratio better is the operational amplifier ok. But here if you want to increase the common mode rejection ratio what you have to do? So, you have to reduce the denominator or you have to increase the numerator. If you want to reduce R or R' you have to reduce R not increase the common mode rejection ratio you have to reduce R right. So, if I reduce this R so, the input resistance Ri of the amplifier also reduces implies Ri reduces this is undesirable ok.

So, this Ri depends upon the R. So, I will discuss the derivations of this input resistance and all in the coming lectures. So, this R is going to decide the input resistance. So, you have to choose this R value large so, that Ri is large. So, high input impedance is desirable whereas, here if I reduce this R common mode rejection ratio increases, but at the same time Ri decreases this is undesired. So, without reducing the input impedance how to increase the common mode rejection ratio ok, this is one point and the second one is even if you take the gain also ok.

So, if I take the gain of this amplifier with the condition that if R_1 is equal to R, R_2 is equal to R', R_1 is equal to R, R_2 is equal to R'. So, what is the expression that you have got from this gain is equal to R' by R times v_1-v_2. Here also if you want to have large gain this is the gain of this amplifier not to have large gain R should be less. So, if R is less again the input resistance Ri decreases which is undesired. On the other hand R' can be large, if R' is large this is going to decide the output resistance ok.

(Refer to the slide at 27:20).

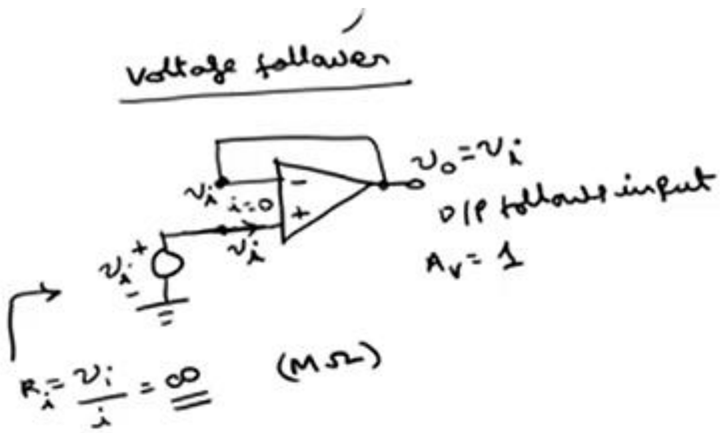


If R’ is large implies output resistance is also large this is also undesired ok. So, without changing the input and output resistance of the op-amp if you want to increase the gain, if you want to increase the common mode rejection ratio there is an alternative solution called instrumentation amplifier. If you use the instrumentation amplifier without affecting the input and output resistances you can increase the gain as well as common mode rejection ratio ok. Instrumentation amplifier is basically a difference amplifier with a voltage follower. So, before going to discuss about this instrumentation amplifier I will first discuss about the voltage follower.

So, here the voltage is v_i according to one of the assumptions of this ideal op-amp is the voltage at inverting and non-inverting terminal is same. So, because this point is connected to the output v_o is also v_i v_i this v_i. So, output voltage is equal to input voltage that is why this is called as voltage follower the output follows the input then what is the use of this? So, voltage gain is unity. So, what is the use of this is if I take this input resistance here input resistance is defined as the input voltage divided by the resistance in the input path ok. So, here the resistance is short circuit in the sense 0.

So, the input resistance here is because no current flows through this one i is 0 here. So, this because $i = 0$ this is equal to infinity this is the input resistance. So, this is one of the very important advantage of this voltage follower is this will have almost infinite input resistance ideally practically this is of the order of mega ohms. So, because of this wherever you want high input resistance we can use the voltage follower stages ok. So, now using this voltage follower and difference amplifier we can develop a instrumentation amplifier.

(Refer to the slide at 29:40)



This instrumentation amplifier plays a important role in many of the industrial applications. So, after discussing this instrumentation amplifier after deriving the expression for the output. So, I will discuss one of the applications of this instrumentation amplifier also ok. So, the basic circuit diagram of instrumentation amplifier is the first stage is two voltage follower. This is v_1, this is v_2, this is R_1, this is also R_1, this will choose as R gain then followed by differential these two are voltage followers followed by difference amplifier which is here I will choose this as R_2 R_2.

This is the basic difference amplifier that we have discussed in the last slide. This will choose as R_2 R_2 R_3 R_3. So, this stage is difference amplifier and at this stage is buffer or voltage follower. So, the other name for the voltage follower is buffer. Now, what is the expression for the output of this instrumentation amplifier? How it is better than the difference amplifier in terms of the gain, in terms of input impedance, in terms of the CMRR? So, in order to derive the expression for this let us assume that the voltage here is say v_A, the voltage here is v_B.

Then assume that all the op-amps are ideal. So, if op-amp is ideal here the current through this one is 0, current through this is 0, this is one of the assumption and the voltage at inverting terminal is equal to voltage at non-inverting terminal. This voltage, this voltage are same, this voltage and this voltage are same. Just clearly see here now can you tell me what is the voltage here? Because this is v_1, this is also v_1 and this v_1 is short circuited. So, this is also v_1. Similarly, this is v_2, this is also v_2 and because this v_2 is short circuited here this is also v_2.

This is one important thing and if I assume that this current is I. So, what is the current through this? If I take this junction this current I is coming here, there are two ways one is this current another current is this current, but this current is 0. So, the entire I will flows through this one this is also I. Similarly, here there is another junction this incoming current is I. So, what is this outgoing current? The current through this one is 0 because this is one of the input terminals of the op-amp.

So, the entire I will flows through this. So, now, in order to derive the expression for this v_o first I will derive the expression for v_A and v_B. So, if I know this v_A and $v_B$what is the expression for v_o? This we have already derived $v_o = \frac{R_2}{R_3}(v_A - v_B)$ this we have already derived $\frac{R_2}{R_3}(v_A - v_B)$. Now, I have to derive the expression for v_AVA and v_B in terms of v_A. I have to express as a function of v_1 and v_2 and v_B also you have to express as a function of v_1 and v_2. So, that the final expression will be in terms of v_1 and v_2 instead of v_A and v_B. v_A and v_B are the intermediate voltages not the input voltages I have to express the output in terms of the input voltages.

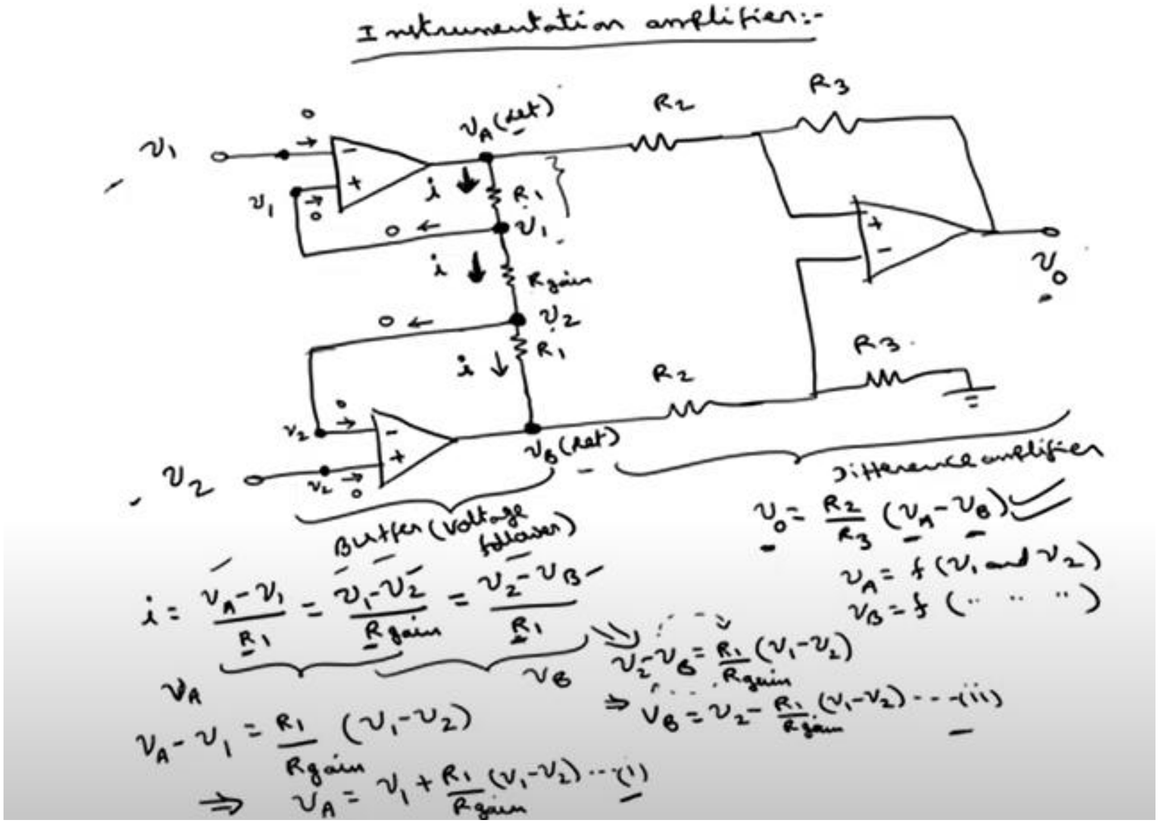
So, this is a simple solution for this finding simple solution for finding the v_{OH}. So, only thing is now we have to express v_A and v_B in terms of v_1 and v_2 then you substitute that v_A and v_B here. So, in order to do that so, I have this current this is the current direction this is v_A this is v_1. So, what is one expression from here to here? What is expression for i? $i = \frac{v_A - v_1}{R_1} = \frac{v_1 - v_2}{R_{gain}} = \frac{v_1 - v_B}{R_1}$. So, what are the voltages? This is V1, this is V2, this is R_{gain}.

So, $\frac{v_1 - v_2}{R_{gain}}$, this is also equal to if I take from this point v_2 to v_B current is again same i, but the resistance is again R_1. So, what is the expression $\frac{v_2 - v_B}{R_1}$. If I solve these two, will get v_A expression, if I solve these two we will get v_B expression. If I take the first two expressions $v_A - v_o$ this one this expression. So, what is $v_A - v_1$? This R_1 if you take to other side this is $\frac{R_1(v_1 - v_2)}{R_{gain}}$ or what is v_A? v_1 you take to other side.

So, $v_1 + \frac{R_1(v_1 - v_2)}{R_{gain}}$. Now, you consider these two expressions you have to derive for v_B. So, from these two you take this R_{gain} to the other side this R_1 to the other side. So, that v_1-v_B, v_2-v_B is equal to this one R_1 you are taking to other side. So, this is equal to R_1

by R_{gain} times this expression is v_1-v_2 or implies what is v_B? You take v_B to this side and this term to this side.

(Refer to the slide at 38:13)



So, $v_B = v_2 - \frac{R_1}{R_{gain}}(v_1 - v_2)$. Now, you substitute this 1 and 2 in this expression you will get the final v_o expression. So, what is v_o?

$$v_o = \frac{R_2}{R_3}\{v_1 + \frac{R_1}{R_{gain}}(v_1 - v_2) - v_2 + \frac{R_1}{R_{gain}}(v_1 - v_2)\}$$

$$= \frac{R_2}{R_3}\{(v_1 - v_2) + \frac{2R_1}{R_{gain}}(v_1 - v_2)\}$$

$$= \frac{R_2}{R_3}\{1 + \frac{2R_1}{R_{gain}}\}(v_1 - v_2),$$

this is the expression for the output of the instrumentation amplifier. Now, we can see that by just changing this R gain V0 can be varied, V0 is varied means gain also can be varied. So, the advantage of increasing the gain using only R_{gain} is it does not affect the input and output resistances. Here this R gain will we are going to vary to vary the overall gain of the circuit. So, this does not affect the input and output resistance of the circuit.

(Refer to the slide at 40:53)

$$v_0 = \frac{R_2}{R_3}(v_A - v_B)$$

$$= \frac{R_2}{R_3}\left\{ v_1 + \frac{R_1}{R_{gain}}(v_1 - v_2) - v_2 + \frac{R_1}{R_{gain}}(v_1 - v_2) \right\}$$

$$= \frac{R_2}{R_3}\left\{ (v_1 - v_2) + \frac{2R_1}{R_{gain}}(v_1 - v_2) \right\}$$

$$\Rightarrow \boxed{v_0 = \frac{R_2}{R_3}\left\{ 1 + \frac{2R_1}{R_{gain}} \right\}(v_1 - v_2)}$$

v_0 can be varing by changing R_{gain}

$\Rightarrow$ Gain varing with R_{gain}

So, input resistance will be looking at here or here this is input resistance, but R_{gain} is here it will not affect Ri. Similarly, output resistance is here it will not affect this R_{gain}. So, unlike in case of difference amplifier where if I want to increase the gain I have to decrease the input resistance or I have to increase the output resistance that will not happened here. Similarly, CMRR you can increase the CMRR we can show that the CMRR of this instrumentation amplifier is larger than that of difference amplifier. So, because of these advantages this instrumentation amplifier is having lot of applications.

So, if I take one application of temperature measurement. So, what we will do is we can measure the temperature using RTD, thermistor, thermocouple. So, if I take the RTD resistance temperature detector. So, the principle of this one is the resistance varies with the temperature or is proportional to the T. So, what I will do is I will take a bridge.

So, this bridge will be having 4 arms. So, two of these arms will be connected to power supply. The other two arms you are going to apply this to the instrumentation amplifier. So, what about the circuit that we have discussed. This is the overall output. So, this output voltage we are going to use to drive an indicator, which indicate the temperature here normally 5V.

So, the basic principle is we are going to connect in one of the arms this RTD. At room temperature normally this will be having some resistance say the resistance of this one is R at room temperature. Then I will set the remaining 3 arms to R, R, R only. So, at room temperature what happens is because all the 4 arms are same this voltage and this voltage these two voltages will be same as a result of that output will be 0 output voltage is 0 volts. So, at room temperature or even you can set at 0 degrees temperature it is up to you instead of this room temperature you have to take as 0 degrees.

Say at 0 degrees I am going to set the resistance value as the resistance of RTD is, R ohms. Then I will fix the remaining 3 arms also with R, R, R. So, at 0 degrees because all the 4 arms will be having R, R, R the bridge is balanced. In the sense the voltage here and voltage here is same that is v_1 if I call as v_1 and v_2 implies $v_o = 0$. So, just now I have derived the expression in that output $v_o = \frac{R_2}{R_3}\{1 + \frac{2R_1}{R_{gain}}\}(v_1 - v_2)$.

If $v_1 = v_2$ output is 0. So, this indicator I will set to this 0 temperature here I will be having some 0 degrees centigrade. Now at any temperature T. So, what happens to this resistance of this particular arm? This will be $R \pm \Delta R$. If this temperature increases then the resistance becomes $R + \Delta R$ decreases $R - \Delta R$, whereas, the remaining 3 arms are R, R, R only. So, because of this one arm resistance changes the bridge will be unbalanced, implies $v_1 - v_2 = v_d$ is directly proportional to temperature.

So, we can directly give this v_d to this indicator, but v_d is very small that is why it will not drive the indicator. So, we are going to use the amplification. So, we will amplify this v_d signal which is very weak signal. So, we are going to amplify and then we are going to place this indicator. So, now, this indicator will show the value of T, this T can be you can take a range from 0 to 100 degrees and so.

So, whatever this temperature change is going to change the resistance in the one of the arms thereby the difference $v_1 - v_2$ is going to change thereby the output voltage v_o also is going to change. So, this v_o you can calibrate to show the temperature in the indicator. This is one of the application called temperature measurement even you can measure the pressure measure also. In the pressure measurement also basically, the same principle whether you can connect a one strain gauge or four strain gauges. A strain gauge is one where if I fix a strain gauge on a cantilever beam, if I fix here one strain gauge and if you apply the force here the dimensions of this strain gauge will changes $R = \frac{\rho L}{A}$.

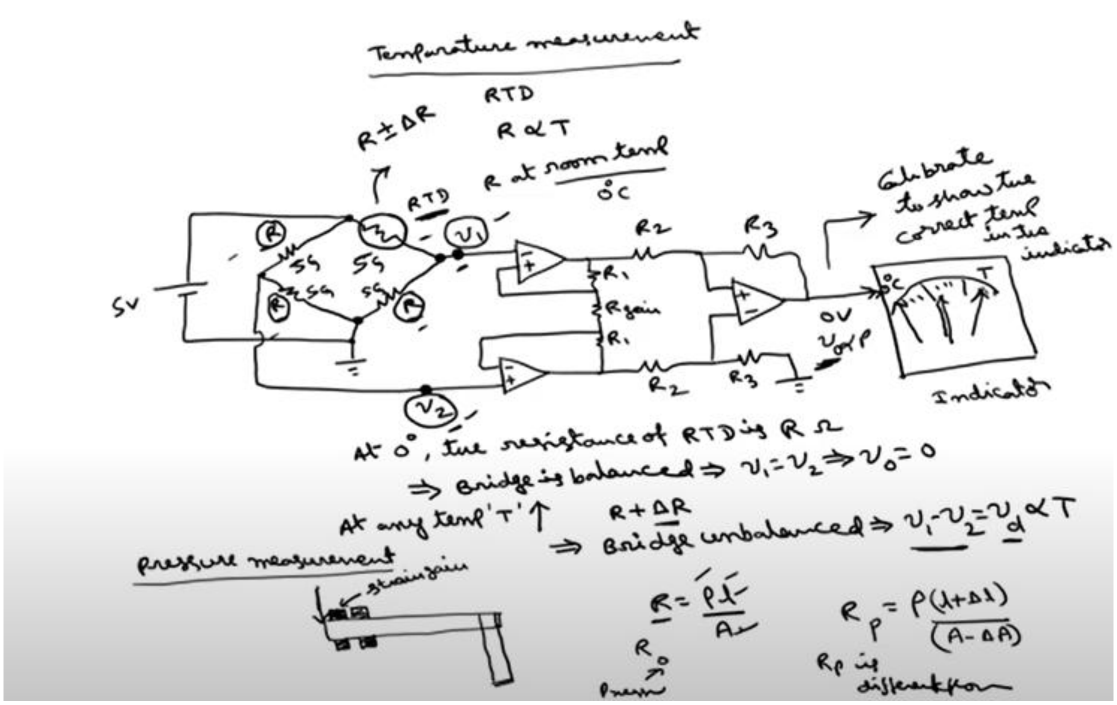
ρ is conductivity L is the length of the wire that we are going to connect here and A is the area of the wire that we are going to connect strain gauge we can call this one as strain gauge. So, if I connect in one of these arms instead of RTD if I connect the strain gauge, then at a given 0 say 0 pressure this will be having some R resistance that depends upon rho L and A this is at pressure of 0, 0 pressure this is rho L by A. At any other pressure B this rho remains same L becomes $L + \Delta L$ area becomes $A - \nabla L$. There will be change in L and A because of that this Rp is different from R. So, bridge will be unbalances, output voltage will be produced which is proportional to the pressure ok.

This is the case of single strain gauge, but so, it is shown that if you connect 4 strain gauges then the sensitivity or accuracy of this system is more. So, normally 2 will be connected at the top of this beam, 2 will be connected at bottom of the beam initially at 0 pressure all the foams are 4 arms. Now, all the 4 will be connected to the strain gauges this is also strain gauge this is strain gauge Sg, Sg, Sg, Sg. At a 0 pressure all the 4 strain gauges will be having same resistance rho L by A.

So, bridge will be balanced ok. So, if you apply pressure force this is pressure or force here. So, what happens is in 2 of the strain gauges the length increases and area decrease in other 2 it is reverse length decreases and area increases. Because of that we will be having these 2 resistance will be having a particular value other 2 will be having another value because of that bridge will be unbalances thereby it produce the output voltage which is proportional to the pressure. So, like that we have a lot of industrial applications

of this instrumentation amplifier ok, because the signals that are going to be generated here from the bridge are very weak signals.

(Refer to the slide at 52:03)



So, you have to amplify this with the larger gains. So, that we can provide by using instrumentation amplifier. And another thing is while measuring this you have to avoid the common mode signals such as noise ok. So, that is why so, you have to design your instrumentation amplifier with high CMRR, ok. So, that here whatever the industrial noises that presented the measurement will be nullified. There is another application of this instrumentation amplifier is we can use in the ECG measurement also.

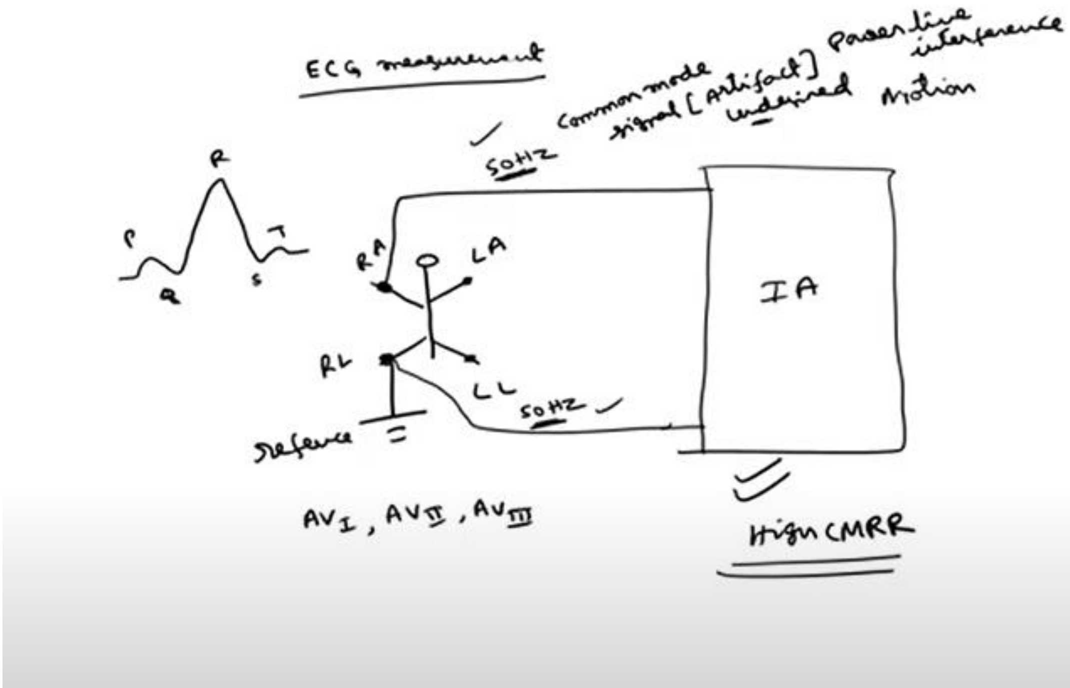
ECG electrocardiogram so, this is the signal that is generated from the body due to the hot activity ok. So, this is normally of the form of PQRST this is PQRST the amplitude and duration of this depends upon the health condition of that particular patient. So, normally this ECG will be measured using limb and leads this is say right arm, right leg, left arm, left leg. This right leg will be normally used as ground difference signal. Now, other with respect to this we will measure the voltage across RA voltage across LA and LL.

So, there are three measurements which is called AV1, AV2, AV3. If you observe this ECG waveform on that that will be very indication of AV1, AV2, AV3. So, suppose if it is AV1 so, this will be applied to the instrumentation amplifier. Here the desired signal is the voltage that is generated at this right arm and right leg due to the electrical activity of the body, but there will be some undesired signal such as 50Hz signal. So, if you want to record this in the hospital nearby there will be some power lines. Wherever power lines are there wherever the conductors are there will be some coupling of that power lines 50Hz signal.

So, this 50Hz signal is undesired signal this is available at the both the leads this we have to remove this is called as common mode signal. And also, there is another this is undesired signal this is what is called the noise or artifact in biomedical. Artifact is nothing, but noise undesired signal this we have to remove so, that if I design this instrumentation amplifier with high CMRR this will reject the common mode signal that is 50 hertz signal and it will amplify only the desired signal. Similarly, there is another type of the artifact, this is called power line interference, there is another is called motion artifacts, while recording the ECG there will be a motion of the body because of respiration ok.

(Refer to the slide at 55:29)

So, that



even motion also will acts as artifacts that will be available at both the arm and leg. So, that also you can remove by using a high CMRR amplifier. So, there are plenty of applications of the instrumentation amplifier ok. So, this is about some 4 amplifier that we have discussed that is inverting amplifier non-inverting amplifier then difference amplifier and instrumentation amplifier all these are DC circuits you have not used any capacitance or inductances ok. So, in addition to this DC op-amp also can be used to amplify the AC signals also. So, we will discuss some of the AC applications in the next lecture. Thank you.