Integrated Circuits and Applications

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

Introduction to Operational Amplifiers
Lecture - 01
Introduction to Integrated Circuits

So, welcome to this course on Integrated Circuits and Applications. So, in this lecture, first, I will give the brief introduction to integrated circuits, different types, uses of this integrated circuits, and then we will consider one of the popular integrated circuits, such as operational amplifier. So, what is this integrated circuit? In short form, this integrated circuit is called as IC. So, if you see the realization of the circuits, you can realize any circuit using discrete components. You can connect the discrete components on the bread board, and you can give the input and power supply, you can check the outputs. So, the other way to implement this circuits is integrated circuit in which we are going to fabricate all the components, all the components on a single chip of a silicon or any other semiconductor device.

So, there are several advantages of this type of a realization. So, if you consider, say for example, a CE amplifier, which you might have studied in your earlier years, common emitter amplifier. So, how do you implement this? You can use a discrete component based realization, or you can also use integrated circuit based realization. If you take a typical circuitry, this will be something like, this is the transistor, this is the bias, these are the bias resistances, this is the input and this is where we are going to take the output.

This is output, this is input, this point is grounded, this is ground terminal, and this is V_{CC} terminal, this is collector resistance, emitter resistance, this is in fact, a capacitance which is called as bypass capacitance, this is R_1, R_2. This is basic circuit diagram of a common emitter amplifier. So, here how many components are there? 1, 2, 3, 4, 5, 5 resistors and 3 capacitors. So, you can implement this using 5 resistors and 3 capacitors you can connect on a breadboard, and you can give the V_{CC} power supply of around 5 volts and this point, you can ground. So, on the other hand, in IC based realization, so all these components will be fabricated on a single chip, IC means, so all the components.

These components includes active as well as passive. So, in this circuit what are the active components is transistor, and passive components are R and C, are fabricated on a single chip of silicon or any other semiconductor devices, any other semiconductor material. So, here we will have a IC form, this is an integrated circuit. So, typically, here, what are the accessing points? The input, output, V_{CC} and ground, 4 pins are enough even you require some other pins. For the sake of simplicity, I am showing that this is a 4 pin IC, this is a 4 pin IC I will call this as CE amplifier. So, what are the 4 pins? One is input pin, another is V_{CC} output pin ground. This is not exactly any IC, but just I am giving as an example.

So, these are the two realizations; one is discrete component based realization, another is IC based realization. I have defined the IC what is meant by IC? IC nothing but a circuit in which all the components active as well as passive components are fabricated on a single chip of either silicon or any other semiconductor material. So, what are the advantages of these ICs? There are plenty of applications. So, one of the application is this is having large packing density in the sense. So, many of such components can be fabricated in a given small area.

If I take this area of the typical area of a small scale integration circuits that we are going to discuss later is of the order of 1 mm square. Within 1 mm square, we can fabricate nearly 10 components. Here, we have totally 7 components, these 7 components you can fabricate on area of 1 mm square. Whereas, if you want to fabricate this if you want to realize this using discrete component, it takes lot of area. So, this is one of the advantages.

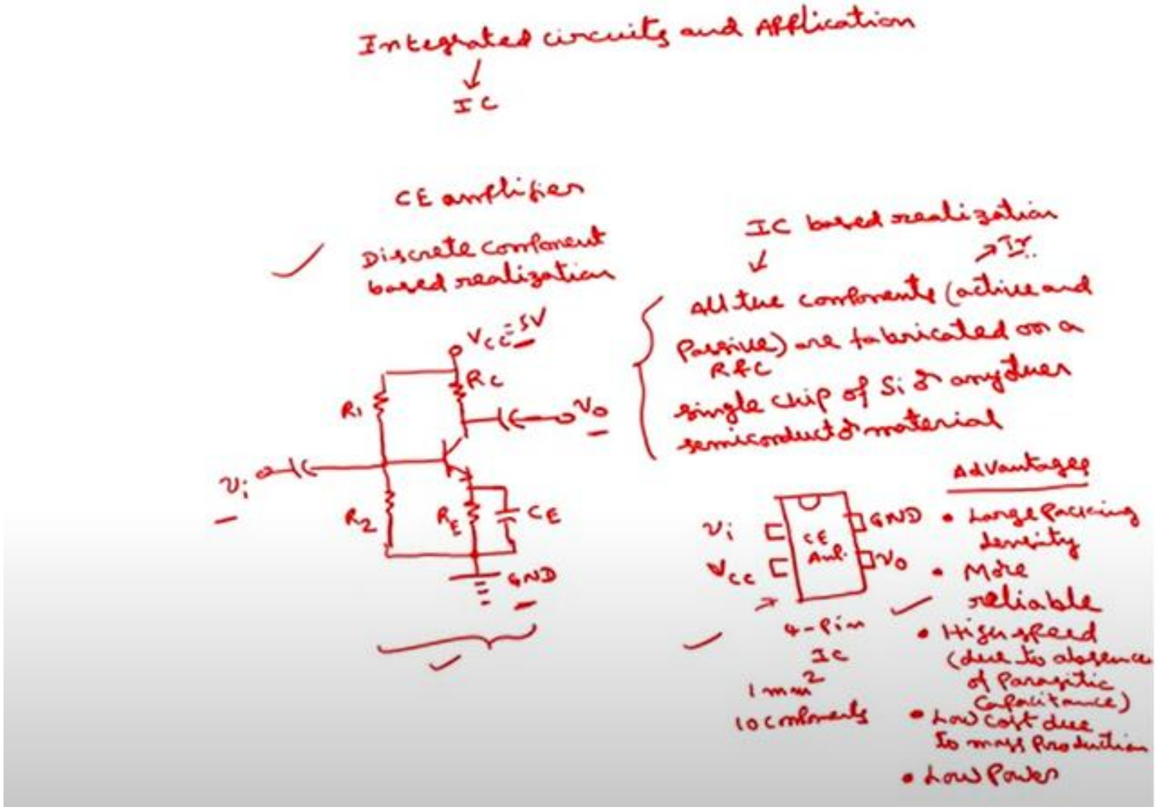
Large packing density in the sense more number of components can be fabricated in a small given area of the order of mm square. And the second advantage of this one is because we are going to eliminate the soldering connections. So, this type of IC based realization is more reliable more reliable in the sense the less number of errors. So, in case of discrete components, we are going to use soldering connections. So, because of that, it may sometime results some errors, whereas that type of errors is not possible in case of ICs because of elimination of soldering connections.

This is the second advantage. The third advantage is high speed because of absence of the parasitic capacitance. This high speed is due to absence of parasitic capacitance. Parasitic capacitance is basically a wherever you have two wires, a capacitor is nothing, but two conductors separated by some dielectric. So, wherever some two wires are there.

For example, this wire and this wire there will be some capacitance. So, like that there will be some capacitances because of this wires that type of capacitance are called a parasitic capacitance which is going to limit the speed of the circuit. So, in case of IC because we are going to fabricate all the components on a single wafer. So, this type of parasitic capacitance effect will be less because of this speed will be more because the capacitance is going to limit the speed of the circuit. This is third advantage.

Fourth advantage is we can have low cost. If you take the cost of this realization, this realization this is low cost because we can have the mass production. Once if you fabricate this IC, we can produce in a mass. So, low cost due to mass production. And fifth, advantage is this requires low power IC based realization requires low power.

(Refer to the slide at 10:13)



So, because of these advantages nowadays, most of the circuits will be having IC based realizations instead of having discrete component based realization. So, most of the realizations will be using ICs only. So, this is about the difference between the discrete component based realization and IC based realization and the uses of IC based realization. So, next, I will discuss about the classifications of ICs. ICs will be classified based on the way in which the components are fabricated on the substrate.

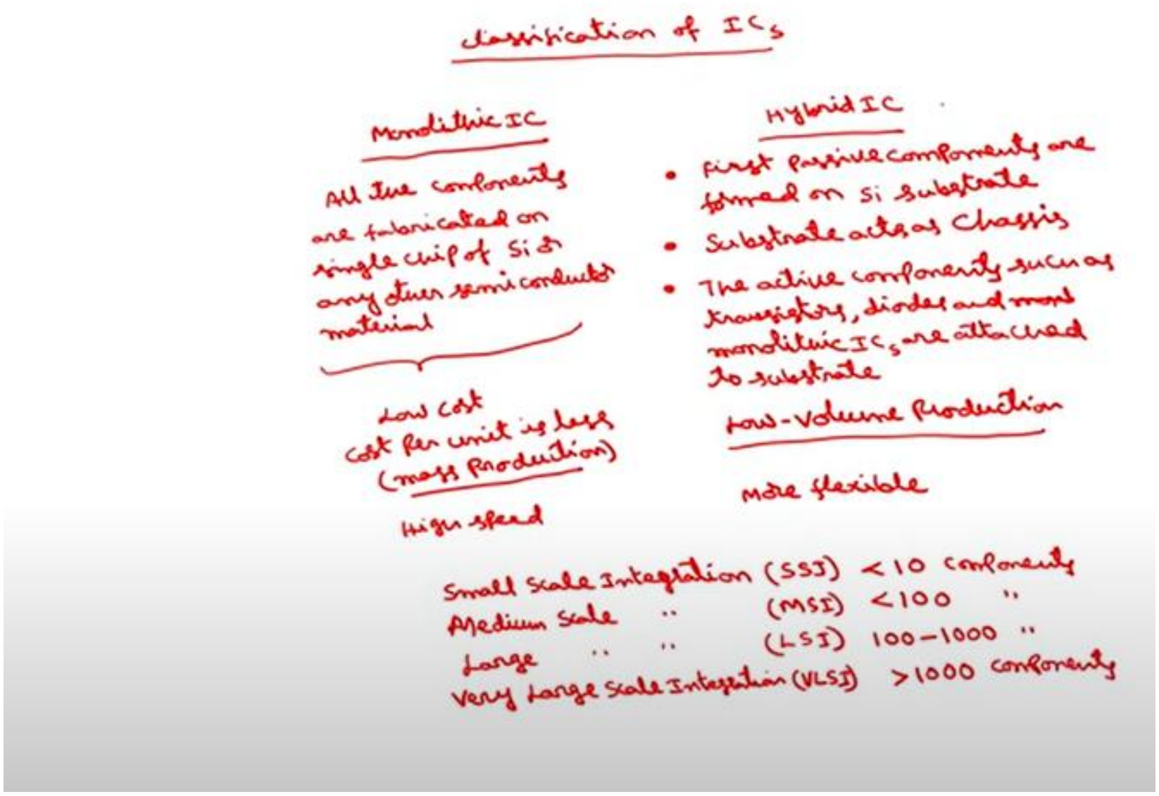
So, broadly these ICs can be classified into two categories. So, one is called as monolithic IC. The meaning of monolithic is single stone and the other one is hybrid IC. So, the basic difference is in case of monolithic IC, as I have defined the IC in the last slide. So, here, all the components which includes active as well as passive are fabricated on single chip of silicon or any other material.

Whereas, here we will divide the components as active and passive first the passive components such as resistance capacitance, and all are formed on silicon substrate, silicon or any other semiconductor material. So, these only passive components this substrate now will acts as a chassis. Then, the active components such as transistors, diodes, and even this monolithic IC also we can fabricate here monolithic IC are attached to substrate. Now, what are the relative merits and demerits of monolithic IC and hybrid IC? So, monolithic IC because all the components are fabricated on a single chip. So, this is low cost or the cost per unit is less.

In case of mass production, whereas, this it advantages in low volume production. So, this is advantages in mass production; this is advantages in low volume production. And the second advantage of this monolithic IC is high speed when compare with hybrid because in hybrid some of the components are inside some are outside because of that the speed is less. But the advantage of this hybrid type of IC is more flexible because there are some components outside you can change the design of the circuit easily. In that way it is called as more flexible. So, this is the one classification of IC and the second classification is based on the number of components you are going to fabricate on a IC.

We have three type of four types of technologies. One is called small scale integration called SSI. If the number of components in the IC is < 10, this technology is called SSI, and the second one is called medium scale integration, called MSI. If the number of components < 100, then this type of technology is called medium scale integration, and the third one is a large scale integration LSI. Here, the number of components are between 100 to 1000, and there is one more called very large scale integration very large scale integration. Nowadays, most of the circuits are VLSI circuits in this > 1000 components.

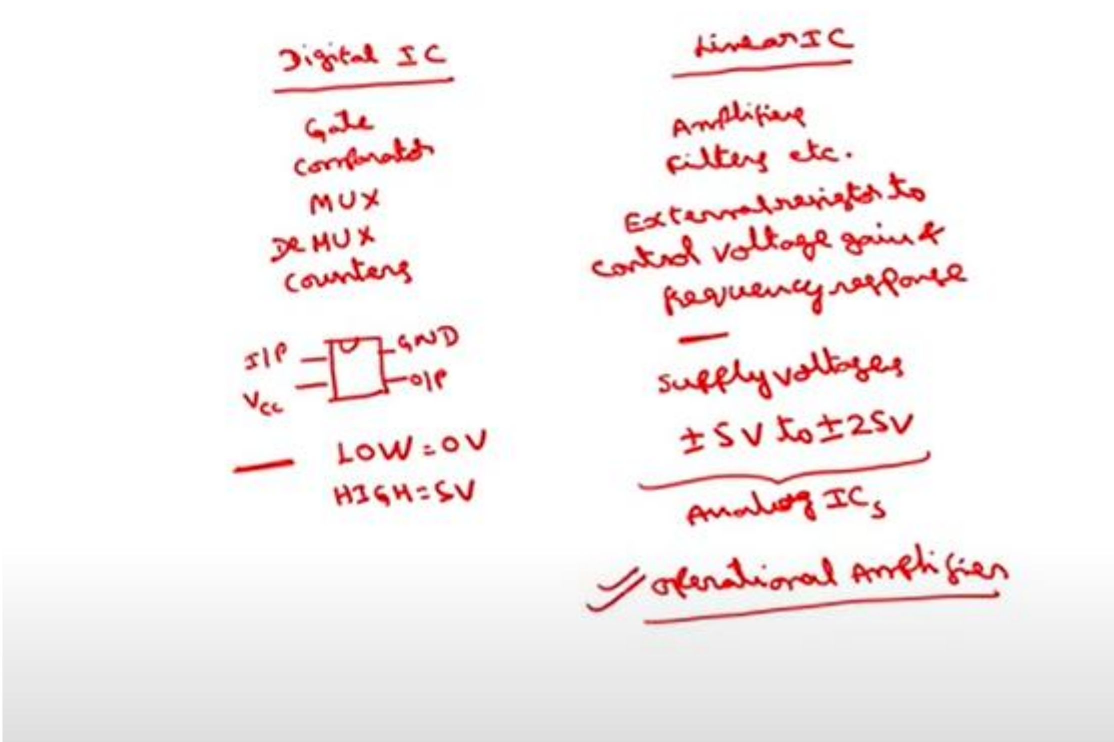
(Refer to the slide at 16:41)



So, another classification is based on the type of operation it performs digital ICs and linear ICs. As the name implies digital IC so, this performs the various digital operations such as implementation of the gates, comparators, multiplexer, demultiplexer, counters and all. So, here, one of the advantage of this digital type of IC is the design of digital IC is easier because this digital IC, it requires only the input output and power supply, this requires only input output and power supply. It does not require any external control, unlike this digital IC in case, of linear ICs which basically implements the amplifiers, filters et cetera. Here, this requires external resistor in some cases to control the voltage gain, and frequency response, whereas, in digital there is no need of any external resistance because it operates on only two voltages, low and high.

Ideally, if I take low, this is 0 volts; ideally, this is 5V, but normally, the range of voltage will be taken as low the range of voltage will be taken as high. Whereas here, because this voltage varies from $\pm V_{cc}$, normally, this range of this supply voltages will be of the order of $\pm 5V$ to $\pm 25V$. So, this requires external resistors to control sometimes the voltage gain and frequency response. So, mostly this linear ICs are analog in nature. This is also called as analog ICs. So, in this course, we will discuss mostly the linear ICs, and at the end, we will discuss some of the digital ICs also.

(Refer to the slide at 19:54)



And there are some ICs which uses both analog circuitry as well as digital circuitry that is called mixed ICs, such as A to D, D to A converters, that also we will discuss at the end of this course. So, initially, I will start with one of the popular analog IC or linear IC is called operational amplifier. This is one of the very popular linear IC. So, nowadays you can find rare circuits where the operational amplifier is not employed. ok. So, what is operational amplifier? So, basically operational amplifier is a differential amplifier.

So, with some of the important characteristics such as high gain, high input impedance, low output resistance and then high bandwidth. On the other hand, this is not only amplifier this also performs some mathematical operations such as addition, subtraction, multiplication, exponential function, logarithmic function that is why, the name operational amplifier. This is amplifier in addition to this amplification, this also performs some mathematical operations such as addition, subtraction, multiplication, division, logarithmic operation which we are going to discuss in the coming lectures. ok. So, if I take the block diagram of this operational amplifier, basically, this is a differential amplifier, which you might have studied in your analog circuit course. So, basically there are four stages of this operational amplifier.

The first stage is called input stage. This is basically, dual input balanced output differential amplifier. As the name implies, it amplifies the difference of the signal instead of single signal. So, there will be two inputs, one is v_1, v_2 this is non-inverting terminal this is inverting terminal. So, difference signal v_d is v_1 minus v_2 this will be amplified with some gain.

Second stage is another differential amplifier stage this is called as intermediate stage. This is also simulated of this differential amplifier the difference is only here this is also dual input, but it is called as unbalanced output differential amplifier. I will discuss the use of each stage. So, this will be having single output. This is unbalanced in the sense we have only single output, this is balanced output means two outputs. This is having single input then there will be a level shifter stage. This is basically an emitter follower, which you might have studied in your analog circuit course follower with constant current source.

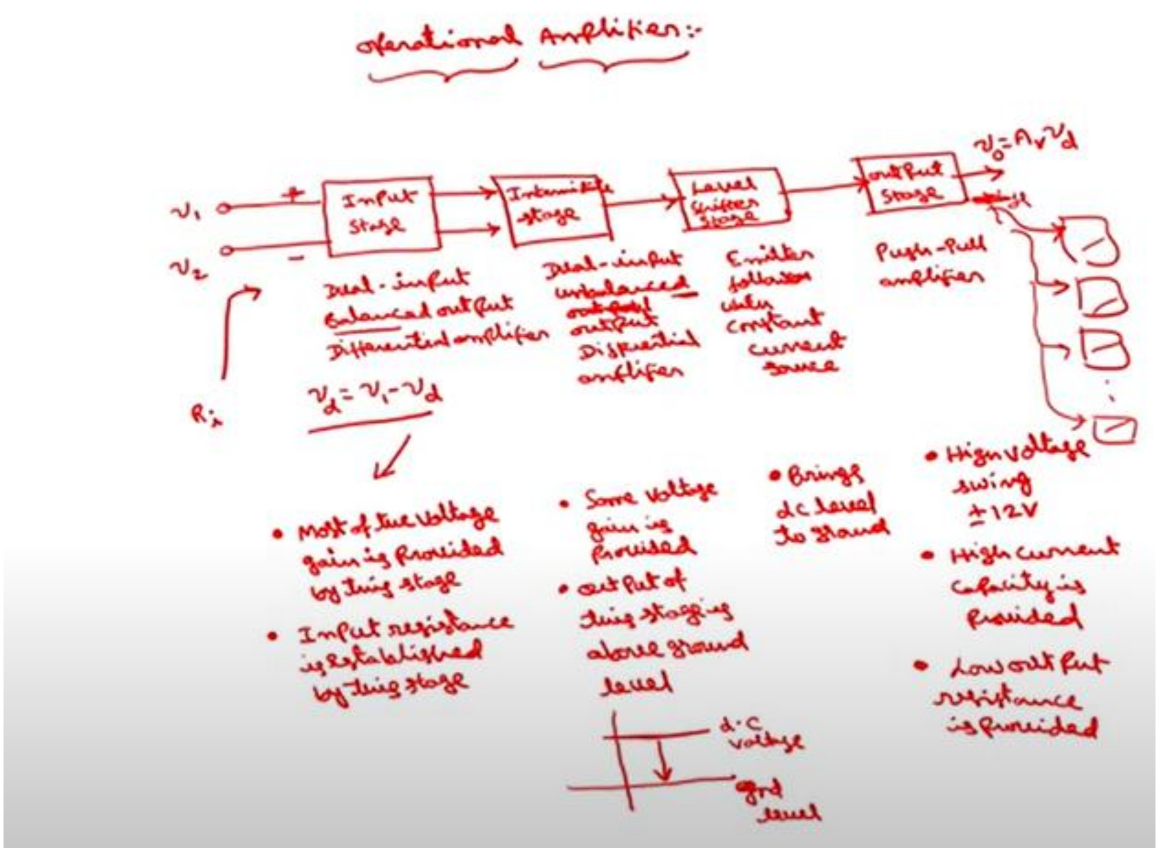
And finally, there is a output stage. Then finally, you will get output v_0, which is some gain times input v_d, v_d is the difference signal, difference signal will be amplified with some gain. So, this output stage, is basically a push pull type amplifier. Now, what are the uses of each and every block? So, first, if I take the input stage dual input balanced output, differential amplifier most of the voltage gain, will be provided by this stage. And the second use of this block is, it established the input resistance. Here, if you take this is input resistance. So, this input resistance will be established by this stage.

Where are the second stage, which is a intermediate stage, this is also again a differential amplifier also provides some voltage gain. But, because this is a direct coupled stage, so, this produces the output, whose DC line will be shifted above ground level, that is, if this is the ground level 0 volts level. So, the output voltage will be something like this; this is DC voltage above ground level. So, in order to bring this DC level to the ground, we are going to use a level shifter. So, level shifter is going to bring the DC level to ground.

And the last stage provides, high voltage swing, in the sense in the sense the range of the output voltages. If I want the output voltage in the range of $\pm 12V$ or $\pm 10V$, this total swing is called $-12V$ to $+12V$ is called voltage swing. So, this stage is responsible for producing the high voltage swing. And another advantage of this block is so, this establishes high current carrying capacity.

So, this is provided by this stage. So, that this is having high current. So, if I connect this to the other circuitry, it can drive many of these devices, if I connect to the number of devices. So, in fact, ideally, it can drive, the infinite number of devices practically. So, many of such devices can be driven by this current because this current is large this current provided this is large. So, this is enough to drive this many such output devices, that is the advantage.

(Refer to the slide at 28:44)



In the other use of this last stage is, which is called as output stages, if you properly design, this provides the low output resistance. So, these are the different blocks of the operational amplifier. So, the details of these blocks you might have studied in your analog circuits course. Now, here, we will not go into the details of this circuitry. So, we will use this operational amplifier using a symbol this.

This is the symbol used for operational amplifier. So, there, will be two inputs, one is non inverting input another is inverting input; you can name in any way, v_2 minus v_1 or v_1 minus v_2; you call this one as v_1 v_2, then v_1 v_2 minus v_1 will be amplified, this is output v_0. This is equal to A_{OL} times v_d, where v_d is this. If you take the equivalent circuit of the operational amplifier. This is called operational amplifier equivalent circuit. In short form, this is called as op-amp, CKT is short form of circuit.

So, there will be some input resistance, which is denoted by R_i. There will be some voltage output voltage, and then output resistance R_0; this output voltage is A_{OL} times, the

OLL is open loop v_d this will be grounded. In addition to this, it requires two power supplies. One is called plus V_{CC} and minus V_{CC}. This V_{CC} ranges from $R-5V$ to $R-25V$. This is the basic operational amplifier equivalent circuit. There are some important characteristics of this operational amplifier, which are called as voltage gain.

If I take the ideal operational amplifier, you have practical operational amplifier. In ideal, the voltage gain is infinity, voltage gain of the amplifier should be infinite so that it can amplify even a weak signal also. In many application, the signal to be amplified is very weak of the order of millivolts or micro volts. So, if the voltage gain is large it is advantageous to amplify even the weak signals also. Practically, this is high of the order of if I take a practical 741 IC; this is one of the popular operational amplifier is 741.

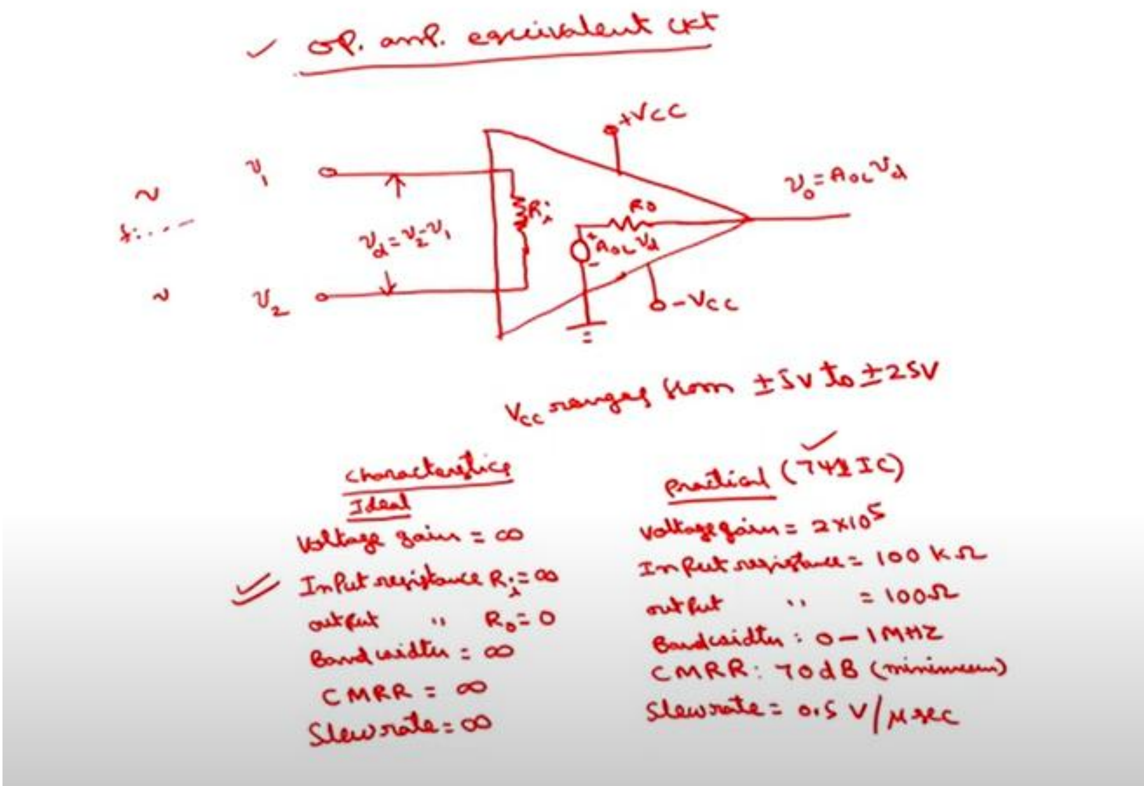
This voltage gain is the order of 2×10^5 very high. And the second parameter is called input resistance R_i. This is ideally, this should be infinity, but practically, this is for this particular IC 741 is the of the order of 100 kilo ohms. So, I will discuss why this input resistance should be large.

Large value of input resistance is advantageous ok. Amplifier with larger input resistance is preferable, when compared with the amplifier with less input impedance. And a small value of output resistance is preferable. Ro ideal is 0, practical for 741, this is 100 ohms. And another is the bandwidth. You can use this operational amplifier to amplify both DC signals as well as AC signals.

If AC signal is applied here, what is the frequency range of the signal that can be amplified faithfully means without any distortion. So, the bandwidth of ideal operational amplifier is infinite, means 0 to infinite, frequency all the frequencies to amplify. But practically, for 741, bandwidth will be of the order of 0, that is, DC to 1MHz. And there is another parameter called a common mode rejection ratio.

I will define later this parameter. So, this should be infinite whereas, for practical, 741 IC, minimum value of CMRR is 70 dB. This is measured in dBs, this is a minimum value. And another is called slew rate. This also, I will define later in the coming lectures, this should be infinite in case of ideal whereas, for 741 practical operational amplifier this slew rate is of the order of $0.5V/\mu sec$ this is measured in volts per microsecond.

(Refer to the slide at 34:44)



Here, I am going to define this. So, before going for this, the ideal and practical circuits. I will first explain, why the input resistance should be very large for a good amplifier, outputs resistance should be less. For example, I will take a amplifier, and after amplification, this will produce some output signal. Suppose, if I feed the input signal to this amplifier, the amplifier will have some input resistance. Let, this is the input resistance of the amplifier R_i.

So, how to feed this signal? I require a signal source. So, signal source this will produce some voltage, this can be either AC or DC, and there will be some source resistance. Normally, very very less source resistance R_S, is of the order of ohms, in many cases this will be neglected. So, this is v_s is the source voltage, and the actual voltage that is applied for the amplifier is this V_i. So, ideally speaking, what V_i should be v_s? V_i should be V_i, means this is ideal case. So, what about the voltage, that is produced by the source, we are going to input feed to the amplifier.

But, practically, what happens is what, will be the relation between the V_i and v_s. This will acts as a voltage divider. So, there, is a voltage source v_s there is R_S resistance, and R_i resistance. The voltage across R_i is equal to which we are calling as V_i is equal to v_s into R_i by R_i plus R_S. So, normally, as I have told R_S will be of the order of ohms say some 10 ohms it is very very less in many of the applications, the source resistance will be neglected.

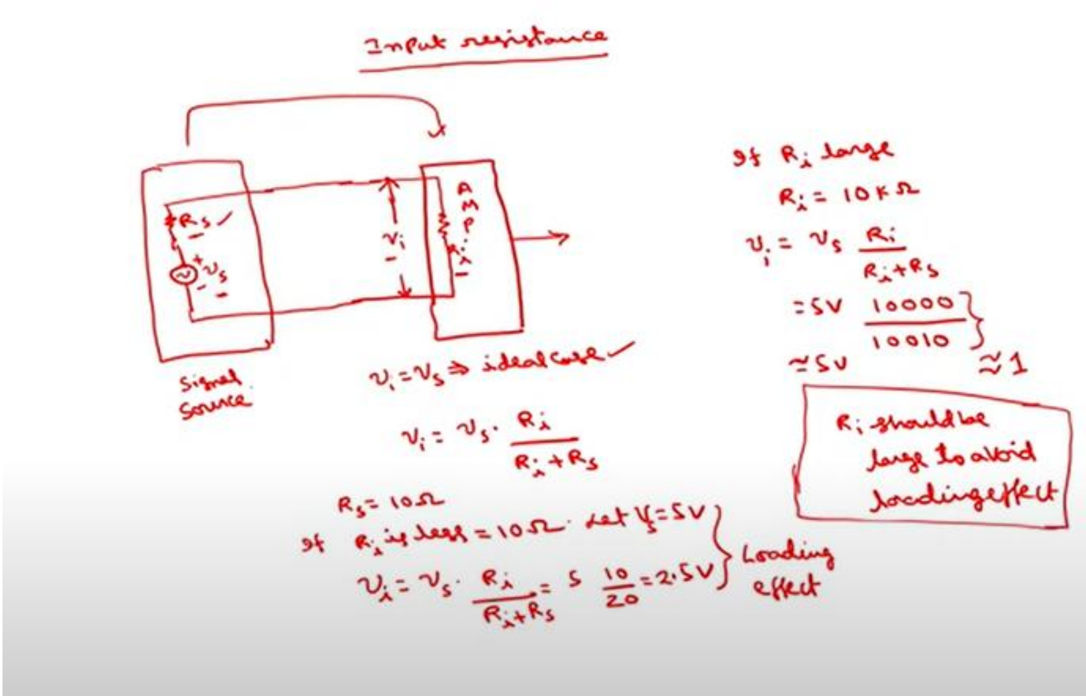
If I take R_i also less say, this is also 10 ohms. So, what is v_i, and let v_s is equal to 5 volts. What is v_i is equal to v_s into R_i by R_i plus R_S. This will be 5 volts into 10 by 20. This is equal to 0.5 volts that. Is half of the voltage will be drop across this resistance, and only half of the voltage will be transferred. This is undesirable. In practical, ideal case, the input that we are going to feed through the amplifier should be equal to the input produced by the source.

So, that is why less input resistance, will cause effect called loading effect; this is what is called loading effect. So, in order to avoid this loading effect, R_i should be large. On the other hand, if R_i is large, say, of the order of, say, R_i is some $10k\Omega$. Then what is v_i?

$$v_i = v_s \frac{R_i}{R_i + R_s} = 5V \frac{1000}{1010} \approx 5V$$

will be transferred to the amplifier; this is the desired situation. This type of situation is desired, where the entire the voltage, that will be generated by source has to be delivered to the amplifier, that is why, R_i should be large to avoid the loading effect.

(Refer to the slide at 39:34)



So, in any case, a large value of R_i means it is a good circuit. So, then output resistance why output resistance should be low. Now, amplifier is the source. So, this will produce some output voltage, this will be having some output resistance, some voltage or output resistance, output resistance will be in series. So, this produce some voltage v_o is the output voltage, produced by the amplifier, say, this is R_o is the output resistance. So, where we are going to feed this output resistance to some load with some load resistance R_L.

So, the voltage that is generated by this operational amplifier or any amplifier, we are going to supply to the load through some output resistance or not. Then, actually, the voltage across this load, let us call as v_L, in ideal case. So, the maximum voltage will be transferred in ideal case the entire v_o has to be transferred to the v_L, if v_L is equal to v_o means ideal case, but practically, this, depends upon the R_o and R_L. So, what is expression for v_L,

$$v_L = v_o \frac{R_L}{R_L + R_o}$$

If R_0 is large, say, this is $10k\Omega$; if R_L is also $10k\Omega$, then

$$v_L = 5V\frac{10}{20} = 2.5V$$

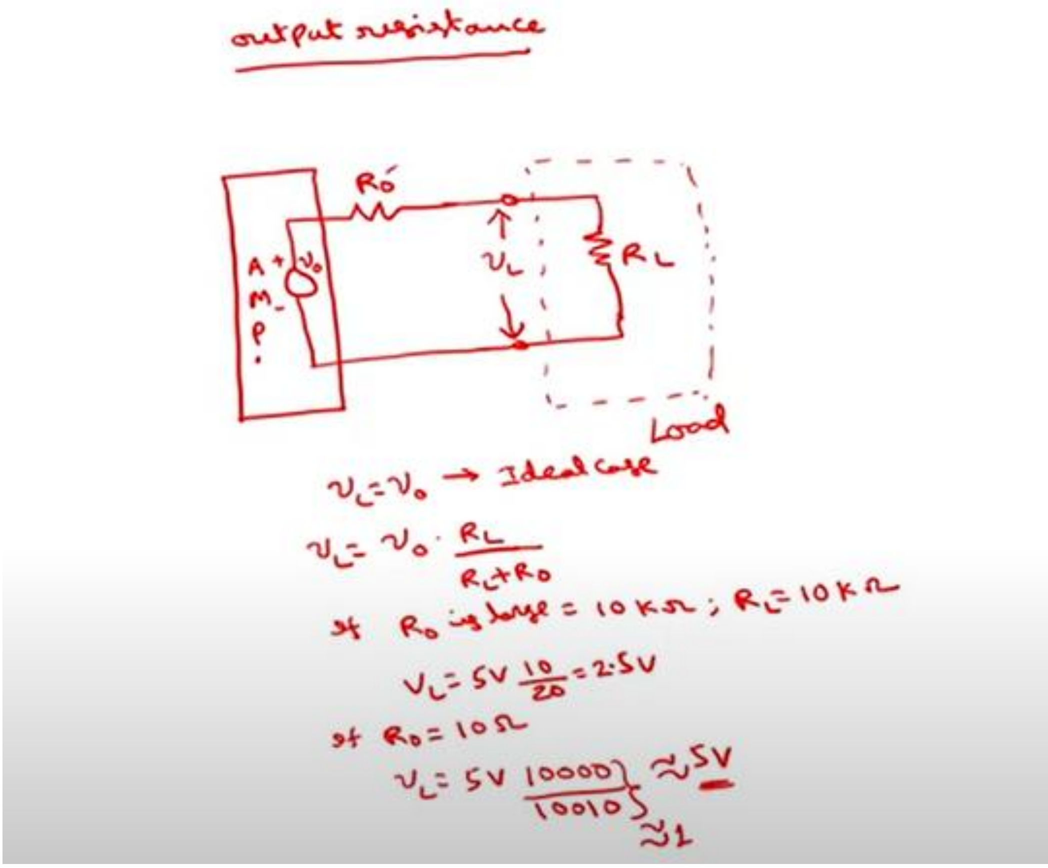
This is again 2.5 volts, this is not desirable.

So, in order to transfer the maximum output voltage to the load. So, we will consider R_0 is very small, say $R_o = 10\Omega$, then what will be the output voltage v_0,

$$v_L = 5V\frac{10000}{10010} \approx 5V$$

This is the maximum output voltage is transferred to the load, that is why a low output resistance is desirable. So, for an ideal amplifier, the input resistance should be very large, and output resistance should be very low. So, like an ideal operational amplifier, input resistance is infinite, output resistance is 0.

(Refer to the slide at 42:34)



So, these are the some basics of the operational amplifier the actual operational amplifier circuits, such as the inverting amplifier non-inverting amplifier we will discuss in the next lecture. Thank you.