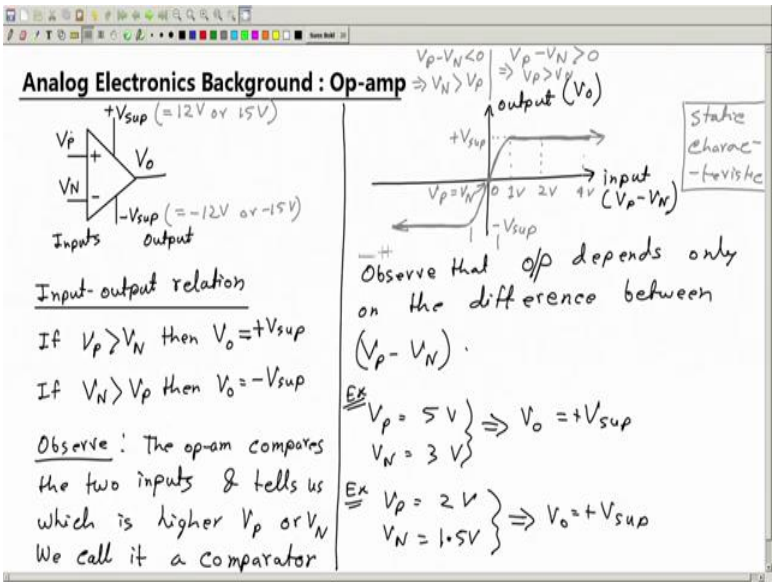
Electrical Measurement And Electronic Instruments
Prof. Avishek Chatterjee
Department of Electrical Engineering
Indian Institute of technology, Kharagpur

Lecture - 49
Background: Operational Amplifiers - I

Hello and very welcome to this next week and previous week we have studied digital electronics.

(Refer Slide Time: 00:35)



Today, this week we will study, analog electronics and op-amps ok. So, op-amp is often very frightening, very scaring to a many student, which was also true to some accident to me but I think if you study it carefully this is one of the easiest equipment, easiest element in electrical circuits ok.

What is an op-amp? Op-amp is nothing but an electrical equipment, which has 2 inputs and 1 output ok. So, we you know (Refer Time: 01:14) we draw it with a triangle ok. And, it has two inputs we denote them as plus and minus and it has one output ok. So, these are inputs and this is the output ok.

So, we a denote the two inputs with plus and minus symbol and we call them as a inverting and non-inverting inputs minus for inverting plus for non-inverting inputs ok, you can also call for simplicity plus input minus input ok.

So, this is what happened this? Now, what we need to know; we need to know how it works? Ok. So, what is the relationship between the input and output ok. So, input output relation and it is very simple. So, if I call this input let me call this V_P P for positive voltage positive and call this V_N N for negative. So, these are the 2 inputs, I am giving them in V_P and V_N and this equal V o O for output ok.

If $Vp > V_N$ Vo = + Vsupply

If $V_N > Vp$ Vo = - Vsupply

So it has 2 inputs, 1 output, 2 power supplies among other things. So, these are the main things it has two power supplies if these two voltages are plus V supply and minus V supply, then if V P is greater than V N output is positive, if V P is less than V N output is negative. So, you observe the op-amp compares the two inputs two inputs and tells us which are which one is had and tells us which is higher V P or V N this is so, simple ok.

So, that is why we call it we call an op-amp also as an comparator ok. Because, it compares the two inputs and tells us which is higher V N higher V P higher or V N higher as simple as that ok. So, now, when you know this, this simple thing let me show you a bit complicated representation of this simple fact, which is a pictorial graphical representation of the simple fact. So, what I want to do, I want to draw a graph a picture representing input versus output ok. So, I will draw input versus output.

Output is nothing but V o but I am in trouble because we have two inputs V P and V N, but I have one x axis, one input axis how do I put two; two inputs V P and V N, I do not have a 3D graph I do not want to make it that complicated but what I will do just see observe that, output depends only on the difference between V P and V N call it V P minus V N.

It does not depend on the value of V P or V N separately, it depends only on the difference. If the difference is say positive that is V P is higher than the output is positive and if this difference is negative; that means, output; that means, V P is lower than V N then output will be negative ok.

So, it is possible that V P = 5 volt V N is equal to 3 volt, then the this is implied V o equal to V P is higher. So, V o will be equal to V supply ok; example. Similarly another example

you take V P is equal to say here 2 volt and V N is equal to say 1.5 volt, then will so, V o will be equal to plus V supply.

It does not depend on the actual value of V P or V N. It depends only on the difference right; it does not depend on the actual value of V P or V N individually it depends on the difference. Therefore, why do you not put the difference as the input instead of putting V P or V N separately right?

So, I will use this now you observe that on this side right side on this side (V P - V N) > 0 ok. So, on this side right side we have (V P - V N) > 0 and on this side we have (V P - V N) < 0 this implies V P > V N and, this implies V N > V P.

Now, what does the rules, say if V P is higher output will be positive ok. And, if we so, here we will have a positive output whose value will be equal to plus V supply and on it does not depend on the difference actually, the difference can be V P so, say here V P minus V N is 1 volt, then also the output is plus V supply. So, here at this point the V P minus V N is 2 volt, then also the output is same plus V supply here say here this value is 4 volt so; that means, V P is 4 volt more than V N, then also the output is plus V supply.

So, therefore, we have this as straight horizontal line. It does not change ok; and, so, normally if say for example, normally we have this V supply is equal to 12 volt or may be 15 volt these are the normal values, then in this case we will have minus V supply equal to minus 12 volt or minus 15 volte, then this value is actually 12 vote or 15 volt.

Now, the difference can be 1 volt 2 volt 4 volt anything, but the output will be same as 12 volt constant, it is not going to change ok, but on this side left side V P is less than V N. So, output now should be negative ok. And, it will be negative and constant no matter how large or small this differences is, no matter how more the V N is compare to V P it can be more by 1 volt. It can be more by 2 volt what is output will always be negative.

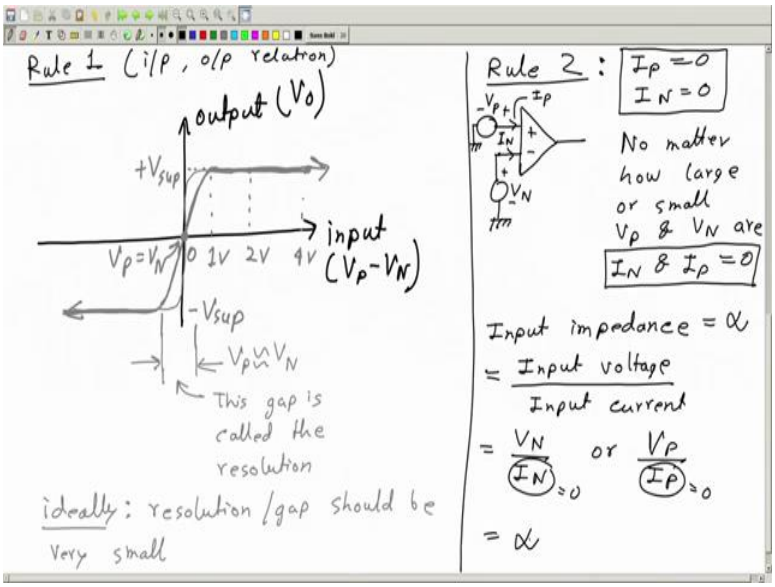
So, this is how it is constantly negative equal to minus V supply and here you can put an arrow to indicates that, it goes on like this flat horizontal also called you can call this saturation ok, it does not increase or decrease any further ideally. So, this is the graphical behavior. The (Refer Time: 11:30) fact just 2-line fact that if V P is higher output is positive; if V N is higher output is negative. The small fact can also be represented it

graphically pictorially with this diagram and this diagram we called we call it static characteristic.

Why static? Ok. Just, I have to say in one line because the output in the input output relationship is true strictly true, if the input or output is not changing with time, then only this this relationship is strictly true but if input and output is changing with time, particularly you were changing very fast, then the input output relationship does not follow this pattern or this rule ok. So, that is why we call it static characteristic ok, roughly speaking ok.

Now, you may ask the question what happens if V P = V N; that means, add this point ok. So, what happens here? If, add of V P minus V N is equal to 0. That means V P is equal to V N at this point. The answer is at this point or close to the region of this point or V P is very close to V N, the output changes slowly from the negative to the positive value like this and at this moment I do not bother much whether this is a straight line or a curved line at this moment I do not care. The important fact that I say is that, near this region where I mean this region ok, where V P is close to V N output changes gradually from negative to positive let me just copy this diagram.

(Refer Slide Time: 14:09)



So let me just zoom into this part, this part only ok. Here, were V P is approximately equal to V N, then the output changes gradually from minus to plus value. This and this gap where the output goes from negative to positive is called the resolution of an op-amp; this

gap is called the resolution. Ideally this gap the resolution or the gap should be very small and ideally 0 for an ideal op-amp we will say that this is equal to 0 so that means, the pattern the input output characteristics should be like this.

Almost, vertical line like this this is the ideal characteristic and for a particular op-amp of course, it will not 0, this and this the larger the gap is we the we will say the op-amp is bad (Refer Time: 15:08) smaller the gap is we will say the op-amp is better why, because this is the region were the op-amp is confused.

What is the task of an op-amp? The task of an op-amp is compare to 2 inputs until which input is higher, how does it tell by making the output either positive or negative. If, V P is positive then it tells that, sorry if V P is higher, then it tells that then by making output positive but if V N is higher, then it tells that by making output negative, but in this region where V P is close to V N op-amp is confused, which is higher they are very closed.

So, that is why it does not make the output to positive completely positive or completely negative, it makes the output somewhat in between ok, it is confused it is not very sure.

So, the output is not completely positive not completely negative. So, output is somewhere in between depending on how large V P is compared to V N, how large V N is compare to V P. So, this is the region where op-amp is confused. So, this smaller the region is we say the op-amp is better ok. That is it; that is the main thing one should know about the op-amp this is the first rule that one should know about the op-amp.

Now, the second important rule that one should know about the op-amp is that call it rule 2 ok. So, this is Rule 1, then this is nothing, but input, output relation and Rule 2 says that, this is my op-amp plus minus these are the 2 inputs. Now, I can connect this to input to any voltage source, this is also 20 voltage source like this, this way rule 2 says, this current call it I N I and this current call it I P ok. The current that goes through the input terminal positive input terminal P for positive and this current I N, through the negative input order. The Rule 2 says, I P is equal to 0 for an ideal op-amp and I N is also equal to 0 for an ideal op-amp.

No matter, how large or small this voltages are this voltage is V N, this voltage is V P. No matter, how large V N and V P is I N and I P is going to be 0, which means no current can go in into the op-amp through it is input terminal, either of this input terminals. Similarly,

no current can come out from these input terminals ok. So, no matter how large or small V P and V N are I N and I P are equal to 0, practically it is no 0 this is for theoretical op amps ideal op-amps, practically it is not 0 but it is very small maybe microamperes; you can neglect it is so, small that for most of the calculations you can neglect it ok.

Input impedance = $\frac{input\ voltage}{input\ current} = \frac{VN}{IN}$ or $\frac{Vp}{Ip}$

The denominator this is equal to 0, this is equal to 0 or very small and this is a finite number numerator is a finite number therefore, this is equal to infinite. So, this is the second rule about an op-amp ok.

So, these are the 2 rules about an op-amp than that one should remember and with only this rules one can solve almost any problem involving op-amp. One can analyze any op-amp base circuits using only this 2 rules, what are this those these 2 rules number 1, the input output characteristics shown here, which if I say normally output is positive if V P is higher, output is negative if V P is lower rule number 1 and rule number 2; no current can go into the op-amp through the input terminal; no current can come out from the input terminal that is all.

So, let us continue from this point onwards ok.

Thank you.