Integrated Circuits, MOSFETs, OP-Amps and their Applications
Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture - 44
Experiment: Op-Amp as Inverting Amplifier

Alright, welcome to this module. here we will be understanding what are the application of operation amplifier. In last modules if you have seen it, right if you have gone through it, we have understood what are the characteristics of an operational amplifier, such as input bias current, right what exactly input bias current, means, and how it is going to affect the operational amplifier?

What are input offset voltages? We have understood what are slew rate, right? How we can measure the slew rate, hence, and we have also seen that how we can measure using the equipment that we have, that is we had DC power supply, we had function generator, and we have the oscilloscope. So, this is your function generator this is your oscilloscope and this is your DC power supply, right.

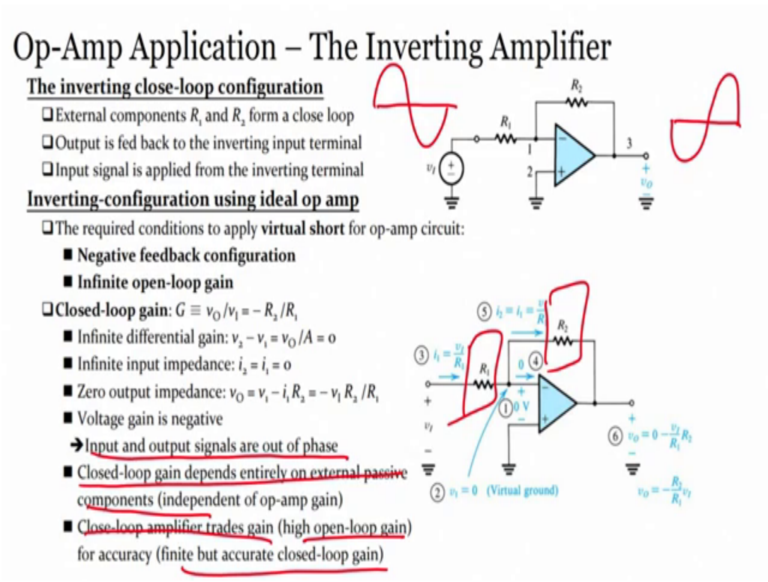
We have took the help of breadboard, on which we have mounted the circuit, and we have seen what are the change in the signals, when we apply some input signal what is change in output signal how you can measure the change in voltages, right. And how can calculate the I B, there were some formulas given in a table. So, those who have not attended that module, please go and see that module, and then you come to this particular lecture.

Now, here today we will be understanding what exactly is an inverting amplifier, then we will look at what is a non-inverting amplifier, followed by voltage follower circuit is also called buffer. And finally, we will have summing amplifier. So, these are the set of things in today's series, we will we will again divide into 2 or 3 different modules so that it does not become too boring. the point is whenever we look at something we read at something, it is very hard to concentrate.

And there it is always good that you look at something for 15 to 20 minutes take a break, and then start another module. That will keep your mind a fresh, right. Also, whenever you work in a laboratory or when you study for half an hour study for one hour take 5 minutes break. That is how you should study, it will help to keep our concentration and keep our mind focus. So, we will start with the first experiment, that is the inverting amplifier. How can we use operation amplifier as an inverting amplifier? Now we already have discussed in the theory class that, why operation amplifier comes or has been given in operational right; that means, can do several operation, right. That we have already seen.

So, let us quickly see what exactly the inverting amplifier was, since it was already covered in the theory class, then we will see how to perform the experiments, and we will move from there ok. So, if you look at the screen, today we are understanding the basic op amp circuits. These all are basic op amps ok, there are very complex op amp circuits, we start with the basic things. So, first is your inverting, then it is your non-inverting amplifier, then we have voltage follower and summing amplifier.

(Refer Slide Time: 05:29)



So, let us see first thing which is the inverting amplifier, right. Now this if you if you recall, we have already seen in the theory class, what exactly the inverting amplifier is right. So, I am just quickly moving on the to the next slide after discussing this slide so that we understand what was the theory class and we can correlate with the experimental class.

So, if you see the inverting amplifier, we can see here, that the input is given to the inverting terminal the input is given to the inverting terminal, right. And non-inverting terminal is grounded, non-inverting is grounded right. So, if you assume there is R, R 1 there is a feedback resistor R 2. And if you want to calculate, or if you want to understand what was the equation of the output voltage, right. Output voltage, then we can see here, right that if you apply voltage at the inverting terminal, you can see that I the current at this particular point i 1 would be v 1 by R 1, right. Here it would be i 2 equals to i 1 v 1 by R 1. Since, the difference is 0, the vo if you if you really go on understanding how the equation comes into picture, if you find out that once you solve this you can find vo equals to 0 minus v 1 by R 1 into R 2.

So, if you if you see this finally, you get vo equals to 0 has no meaning. So, minus v 1 or minus R 2 by R 1 into v 1. This is this was the formula for inverting amplifier right. So, we have seen in the theory class. So, I am not going into detail how you have derived this particular formula.

But just to quickly recall, external components R 1 and R 2 form a close loop, right. R 2 and R 1 this forms a close loop. We have seen operational amplifier can be used as an op open loop amplifier, it can be used as an closed loop amplifier. So, this R 1 R 2 resistors help to get a feedback, and that is why it is a close loop output is fed back to the inverting input terminal you can see output is fed back to the inverting input terminal, input signal is applied from inverting input terminal we have already seen the input signal is applied to the inverting input terminal, right?

So, always remember when you talk about inverting amplifier, apply the input to inverting talk about the non-inverting amplifier apply input to non-inverting terminal. Now input signal is applied for inverting terminal, let us see configuration using ideal op amp, alright. So, the required condition to apply virtual short we have also seen what exactly virtual ground is or virtual short is in the theory class, the negative feedback configuration. One is negative feedback configuration, and infinite loop gain these are the required condition to apply virtual short, we already know.

Closed loop gain closed loop gain of this particular amplifier is nothing but minus R 2 by R 1, right. Differential gain will be v 2 minus v 1, what is v 2? v 2 minus v 1 v o by a vo by a, right. Infinite input impedance i 1 equals to i 2 equals to 0, why input impedance is infinite? Thus i 1 will be equal to i 2 equals to nothing but 0, 0 infinite input impedance means current cannot flow, that is why it is 0. This we are talking about inverting configuration using ideal operational amplifier, mind it, here ideal op amp um.

So, practical op amp again input impedance would be not extremely high or not in finite, it would be extremely high, right not infinite. So, we are talking about input inverting configuration using ideal op amp 0 output impedance, right. This also 0, but in reality, if it is practical op amp, it would be nothing but low, alright? Not 0, voltage gain voltage gain is negative, right.

You can see here so, negative of your R 2 by R 1 in to v 1 input output signals are out of phase, this is very important. this we have already seen again in the theory class, what we have seen, that when we apply the input signal to the inverting amplifier, the output would be opposite phase. So, we apply a single, right. We will see output which is opposite phase, this is 180-degree phase shift, alright. So, this is what is written input and output signals are out of phase, right?

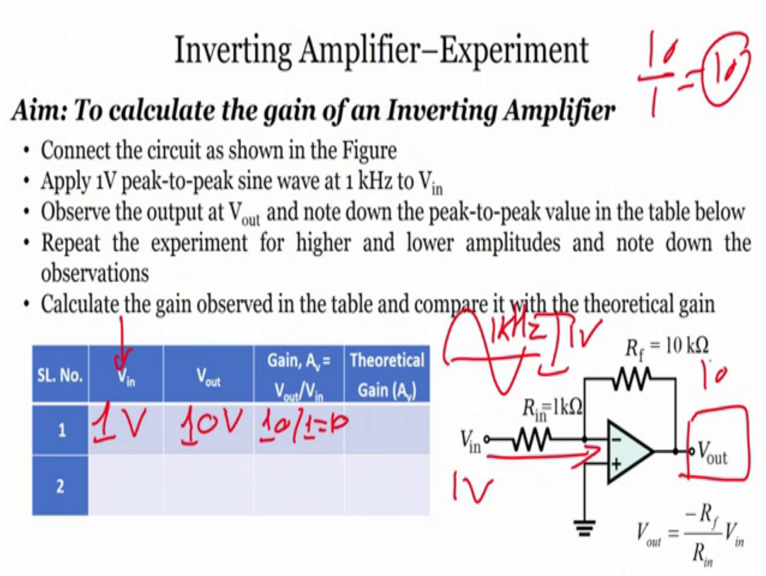
Next, close loop gain depends entirely on passive components, right. Independent of op amp, why entirely to passive components? You see it depends on R 2 it depends on R 1 is does not depend on the operational amplifier. So, it completely relies on the passive components, alright? Next is close loop amplifier trades gain that is high open loop gain, for accuracy, but finite gain for accurate close loop gain. What does it mean? That when you talk about amplifier there are 2 types of feedback we have seen, right. One is your negative feedback, another one is your positive feedback.

Now, if I keep on going applying positive feedback, what was the what was the thing that we have seen? If you keep on applying positive feedback, right the amplifier will not really work as an amplifier, but it will be an oscillator, right. It will be an oscillator to, to make the amplifier stable to understand or adjust the signal, right, we need to apply a negative feedback to the circuit. Then only we can change the gain we can we can adjust the gain we can play with the gain, and becomes a inverting amplifier non-inverting amplifier; means that, negative feedback field give us amplifier implication, positive feedback give us oscillation right. So, we have seen both the things in the class so, just recall it.

Now, if you see that we will have close loop amplifier. So, that is why we can have accurate for accuracy, we will have finite, but accurate close loop gain, alright. So, these are the things we already know so, just quickly look at your notes, or look at the lecture notes, and you will see anyway.

Now, once we know this which is our theory part which we have kind of repeated, right. How can we actually take a operational amplifier take this resistors passive components, and how exactly we can we can place the circuit on the breadboard, and how we can check the circuit. That is the real thing that we need to learn today. And if you see, in the next slide you see here this is the experiment, right?

(Refer Slide Time: 09:43)



So, how to perform or how to calculate the gain of an inverting amplifier. Now given that you are have, R 1 equals to 1 kilo ohm this one, right. Feedback resistor R f equals to 10 kilo ohm, what will be the gain of this particular amplifier? So, first thing we have to understand what is the circuit, if you see closely, right what actually the circuit is? The circuit is that the input signal, the input signal is given to inverting terminal right; that means, it is an inverting amplifier.

Next, what we have to see next is, what is the value of R in, what is the value of R f. Now we already know what is the value of, what is the formula for V out, for inverting amplifier V out is nothing but minus of feedback resistor R f, divide by input resistance R in into input voltage V in, right? This is the formula we know we know this formula, right?.

So, what we have to do first? So, first thing is connect the circuit as shown in figure, this is the figure we will connect it, right. Next apply one-volt peak to peak, sine wave at one kilohertz to v 1. Here we have to apply a sine wave, right peak to peak to peak, right. Which is one volt, right 1 volt 1 volt. So, let me just rub it down so, it becomes easy to understand, right.

What we are doing second point this one, alright? Concentrate on this what we have seen apply sine wave ok, one-volt peak to peak, peak to peak is one volt, right. Frequency is one kilohertz, one kilohertz is a frequency, alright? Nice, now what is the next one, observe the output, V out you have to observe output, and note down the peak to peak value in the table below.

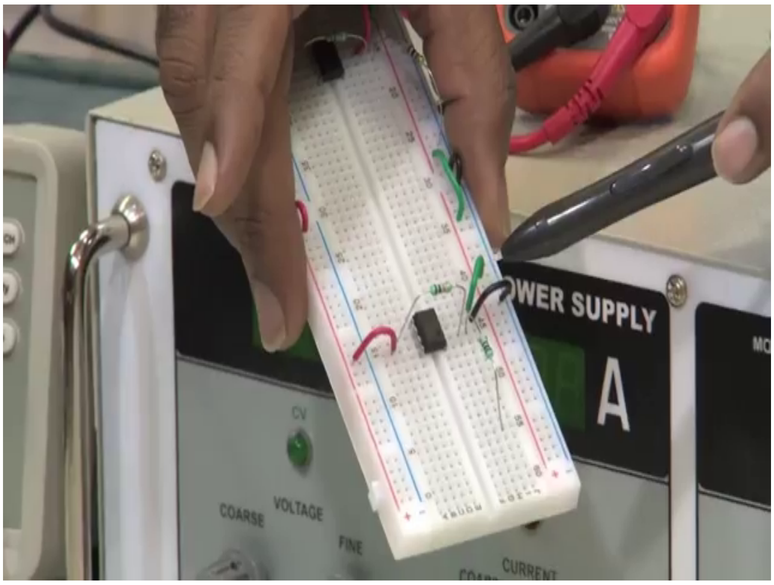
So, what is the given? Table given table is V in, V out. These 2 things are given, right? What is gain? Gain is nothing but V out by V in. So, this is V out, right this is formula for V out, from there how can we find the gain. So, earlier when I was talking about V out, V out is nothing but minus R f upon R in into V in, what is the gain? V gain is nothing but V out by V in. So, V out by V in will give us the gain, right?

So, what is the gain? What is the actual gain? That is the experimental gain and what is the theoretical gain. We can measure both the things, and let us do this experiment, today another thing is repeat the experiment for higher and lower amplitudes and note down the observations. So, we will just change the amplitude, change the amplitude of the signal, and we will see what is the change in the gain, alright? Calculate the gain observed in the table and compare it with the theoretical gain. So, there are several things that we have to do in this experiment. Let us start one by one. First thing is we will take a breadboard, we will take a breadboard, and we will connect the circuit as shown in figure, right.

So, for today I will request my another teaching assistant for this particular course, and he will be showing you how we can perform this experiment. I will tell you and he is performing the swimming, right. So, Suman Chatterjee he is a teaching assistance, Suman, please can you please come? So, if you see there so, the people can also look at you yeah. So, he is Suman Chatterjee, and he will be performing the experiments today, alright?

So, first we will start with the inverting amplifier. So, Suman do we have the PCB, breadboard? Ready, ok, cool. So, can you please connect it? Inverting amplifier, this one, right.

(Refer Slide Time: 13:24)

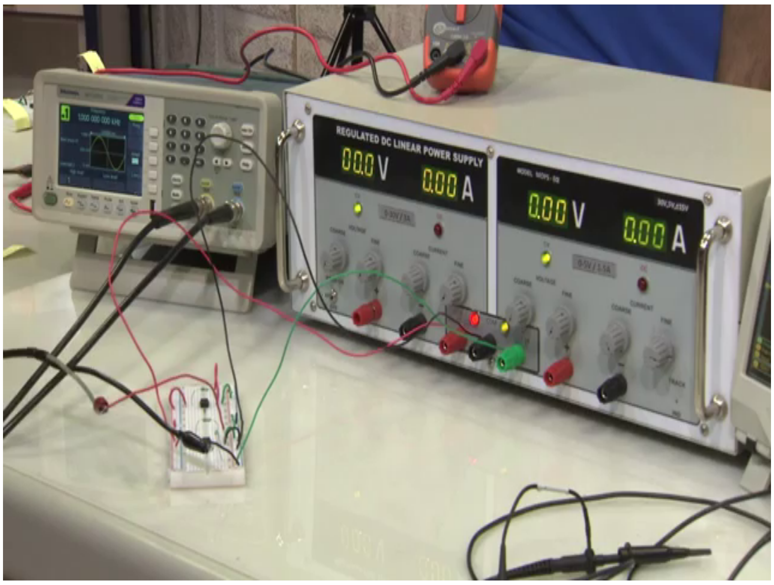


That means that if you if you again remember what was the circuit on our screen, it was that there is a op amp, there is 2 feedback, there is one feedback resistor, and one input resistor ok.

Now, we can focus again on my hand, yes. So, we have a operational amplifier here, right. And then we have 2 resistors R in and R f connected in the same way shown in circuit. Then, what is the next? We have to apply plus 15 minus 15 to operational amplifier, correct, this much is easy. Now, we will apply input signal, input signal to the inverting amplifier, non-inverting amplifier non-inverting terminal, sorry about that. we will applied input signal to the to the inverting terminal, and the non-inverting terminal would be grounded, why? Because this is the inverting amplifier, alright? So, let us see how you can do it. So, I am placing it here, right?

Now, we have here on this DC power supply, DC power supply, plus 15 minus 15 right.

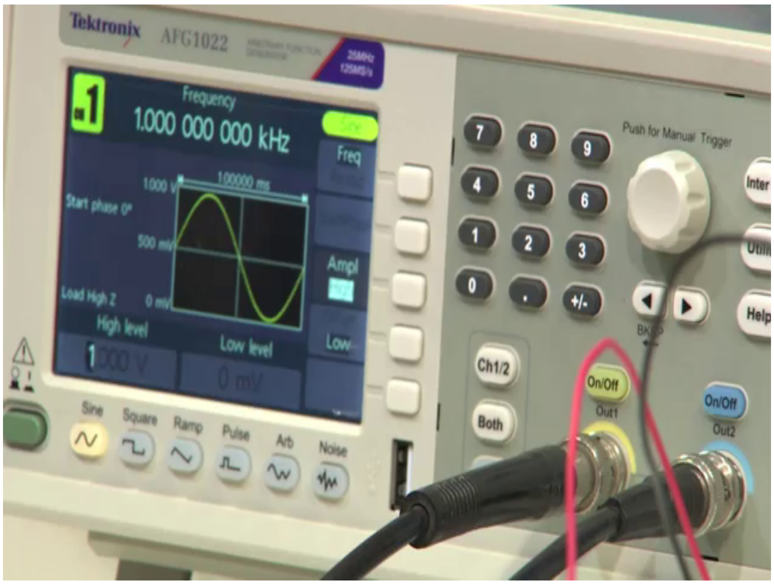
(Refer Slide Time: 14:21)



Here we have plus 15 minus 15. So, we can first connect it here, and then we can apply the DC power supply, first we can connect and then if you apply, alright. So, what he is, right now performing is he is connecting the bias voltage is plus 15, minus 15 to the inverting amplifier using op amp, alright? And we already have grounded.

Now, we can start the DC power supply, and we you do not have to see this particular voltages ok, do not do not concentrate this in the first module in the experimental section I have see, I have said that this particular power supply it has plus 15 minus 15 here red black and green, right. From here we can get plus 15 minus 15, alright. So, that plus 15 minus 15 is directly given to the operational amplifier circuit, and now we are applying the signal at the inverting input, inverting input of the operational amplifier, what was a single? So, if you see the frequency generator, frequency generator, this one, you will see we have we are applying one kilohertz frequency, right?

(Refer Slide Time: 15:48)



Let me just yes, so, if you see here, we are applying one kilohertz frequency. What is the voltage? We are talking about peak to peak voltage, right. So, you see what is the peak to peak voltage, peak to peak voltage is one volts, right, you see there is a 1 volt. Now this signal we have to apply to the inverting terminal. So, when you see that you will see the probe, which is holding in his hand. So, you see this probe that is holding here, look at this probe, right.

So, one is your single, and second is your ground, second is your ground right. So, he is applying signal, and you will connect this ground which is black 1 to the ground of the circuit, that is on the pc on the breadboard, alright. So, please give signal to the inverting amplifier. So, what he is right now trying is, he is giving a input signal, right? To the inverting terminal of an operational amplifier, alright. So, very easy, very easy extremely simple experiment, that is why we have said it is a these are basic op amp circuits, right.

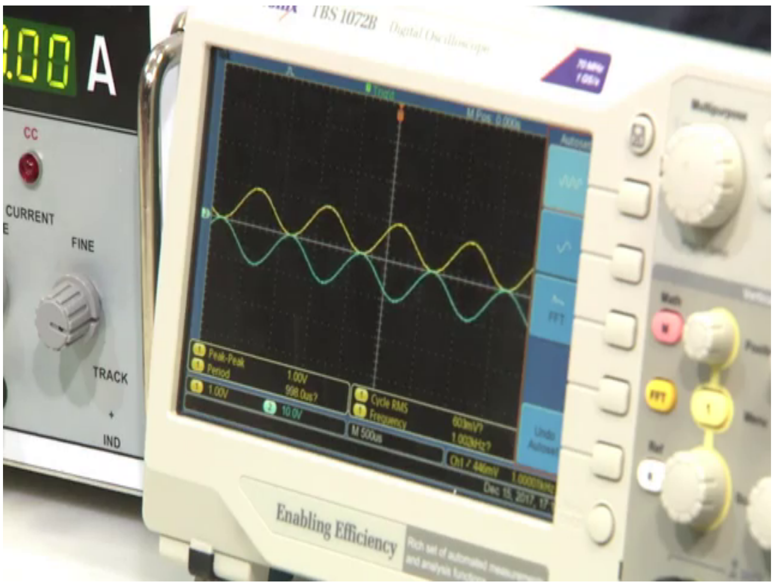
So, we are now connecting the signal to the inverting terminal, or you can take another wire longer wire. So, it is easier take this one, ok, connect it, alright. So now, he has given the input to the inverting terminal of the operational amplifier, right. Now we have to check the output, we have to check the output, that is what is given in the screen. So, if you if you see the screen once again, right. what was the table? Table is we have a input voltage, we have a input voltage, we have the output voltage, and we have a gain, correct? We have input voltage we have output voltage, we have gain; that means, we have given already this input signal, we have given this input signal, if you see in the table, right to the inverting terminal right. So, we have seen in function generator what was the peak to peak voltage, peak to peak voltage was one volt, right. What was frequency? Frequency was one kilohertz, correct?

Now, what we have to check? We have to check the output voltage, right isn't it? So, we have to connect the , we the oscilloscope with the operational amplifier circuit. So, that we can see the output signal, alright. So, that is what we are trying to do, of checking the output of the operational amplifier. So, what he has done? He has just if you look extremely complicated, but it is not complicated, guys.

So, we have just connected the frequency generator which is here on my, right side, right. And we have given the signal to the op amp, and we are just checking the output on the oscilloscope. Because of because of probes, it looks complicated it is very simple. One red wire from the frequency generator, that is the signal to the inverting black to the ground from the output one signal to the oscilloscope ground connected to the ground. So, it is extremely simple.

Now, if you really see that when we have applied the input signal which is one-volt peak to peak, right. One kilohertz what is the output that we have to see right. So, we if you focus on oscilloscope what we see here? What we see here on the oscilloscope? Can you please focus oscilloscope?.

(Refer Slide Time: 19:54)



Yeah, yes, peak to peak voltage. So, what is the output? Output is see he is he is placing his finger so, that we can see the output, right?

So, this blue line is your output, the yellow line is your input signal. What we see? What you see? You see that the output is 180-degree phase shift to the input signal, isnt it? So, when you see this yellow line, and when you see the blue line, these are 180 degree out of phase, 180 degree out of phase right so, this is ok.

So, what is the output voltage let us see, what is the output? Voltage output voltage is 10 volts. What is the input voltage? Input voltage is one volt right; that means, that we have amplified the signal, right? And we got 10 volts at the output, why we got 10 volts at the output? That is different case, we will see.

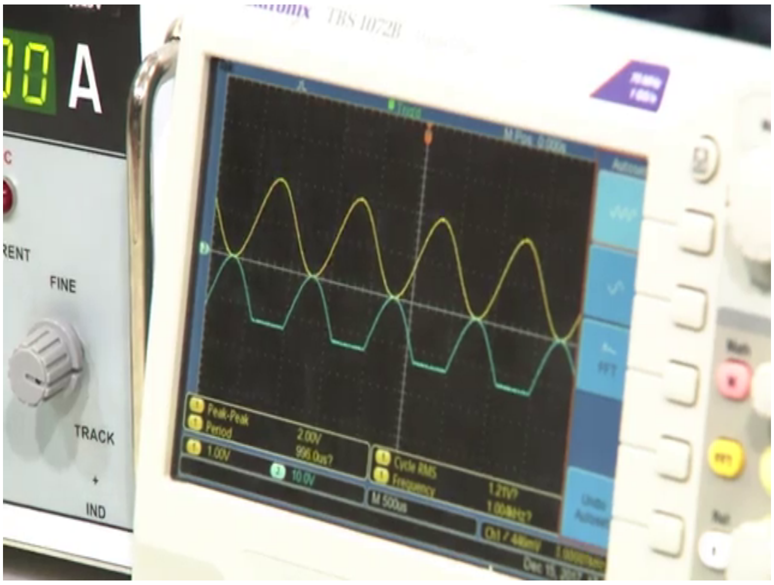
Now, if you come back to the screens, I have, I know I much applied I have applied voltage input signal. 1 volt, what was the output signal? 10 volts, right? So, what is V out by V in, 10 by 1, that is 10, that is 10. So, simple so easy to understand, right? What is theoretical gain? Theoretical gain is same thing, 10 by 1, again it is 10. So, we see that, you know, not much difference happens when we calculate experiment gain with theoretical gain in this particular case.

But what happens if we change the amplitude, right. That was the second case. So, you could see now, right? 180-degree phase shift, one thing, second thing was that the output signal is higher compared to the input, that is the voltage at output is 10, voltage at input is 1, because R f by R in R f by R in is nothing but 10 by 1 which is equals to 10; that means, it will amplify by 10 times the input signal. Input signal was 1 volt, output signal will become 10 volts, right, this what we have seen.

Now, let us see another one, another one; that is, we will apply higher or lower amplitude and note down the observation. So, again if you can focus back on the frequency generator, what we are now trying to do? We have cap the frequency as it is, and we have we are trying to change the input voltage, we are trying to change the input voltage. So, what is the input voltage now? 2 volts, alright so, we applied 2 volts, alright?

Now, let us see when we applied 2 volts, what happens? When we applied 2 volts instead of 1 volt, what is the output? What is output let us see, alright. So, if you see in the oscilloscope, it is stripped, that is the reason that we want to apply 2 volts.

(Refer Slide Time: 23:04)



Now, the first question that should come to your mind is, it amplified how many times? 2 into what is the gain we found the gain was R f by R in right. So, 10 by one is 10, 10 is your gain, how much voltage? You are applying 2 volts, 2 into 10 will be 20 volts. So, we should see a signal which is 20-volt signal is out of phase that is correct, right. Yellow and blue it is the out of phase, but why it is the now clipped here why it is clipped, right. That is because the supply voltage the supply voltage at the bias voltage is plus minus 15 volts right. So, we cannot see enough amplification of 20 volts at the output signal, alright so, that is the reason.

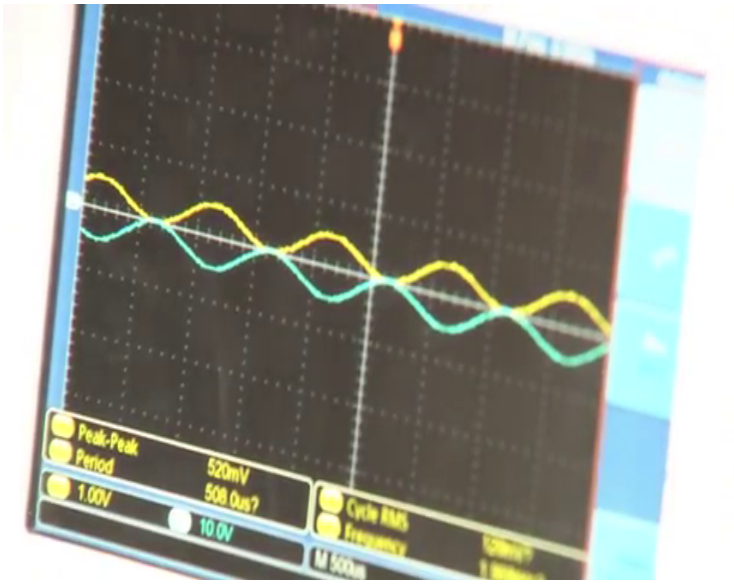
Now, if what happens if we decrease the input signal? Now do not do not go with this that it does not look like 20 volts, it does not look like 15 volts, right. Because we have adjusted the oscilloscope, such that even the this peak to peak is 15 that is the blue one is 15 if I if I put it here, right. The blue one is 15 and this one so, peak to peak is 20, alright? Peak to peak is 20, but this is clipped it is clipped here.

And yellow one is peak to peak is 1 volt. That is why it does not represent that 20 volts is it looks bigger waveform or one volts which smaller both look same. But we adjusted in the oscilloscope so that you can see clearly, right. So, do not get confuse that the signal is not looking higher and it is not 20 volt it is 20 volts. We can change the it by changing the norm in the oscilloscope, that we have already discussed.

Now, let us see if we apply a less voltage um. So, again you can focus on the frequency generator, let us see now we are applying 500 millivolts, alright. So, what happens if we apply 500 millivolts? Let see so now, we apply 500 millivolts, it goes to your circuit, right which is, right over here which is your breadboard. So, signal is connected to your breadboard, it is your inverting amplifier, inverting amplifier output is connected back to the oscilloscope so, from here to oscilloscope.

So, now what we are looking at oscilloscope? We are looking at some change in the output voltage.

(Refer Slide Time: 25:23)



What is the new value? You use again there is a phase shift the output voltage now is from one volts, it is about 5 volts. See peak to peak is 10, but the voltage that you can see at the output is nothing but 5 volts, alright. So, or you can say 520 millivolts. So, applying 500 millivolts at the input, sorry, 500 millivolts at the input what is the output that we have to see, right?

So, what we have seen until now is that you can change the input signal, and based on that, you can easily see the change in the output signal. One thing that remains constant is the phase shift, is the phase shift, right? You see yellow and blue these are out of phase. So, we can always change the input signal, we can always amplify whatever we want, but we cannot amplify more than what we I have given as the bias voltage, which is your plus minus 15. So, it is very easy, right?

So, then if I put this value I can calculate lot of things on my screen which is the table, right. I can see V in I can see V out I can see V out by V in, I can see theoretical gain, I can change the amplitude, and I can see the change in signal. Very easy experiment, extremely basic experiment, but important to understand.

Why important to understand? Because one thing that we understood in this particular experiment is that if we apply plus minus 15, right. What is the again of the operational amplifier, what was that if you remember, the gain of an operational amplifier was in finite; that means, that if then a question comes that, if the gain is infinite, if the gain is infinite then if I apply 1 volts at the input, if I apply one volt at the input, then my output should be infinite voltages, right isn't it?.

So, that means, that if I want to so, since I am right now in ISE, right? Indian Institute of Science, and I want to have power across whole ISE, right? I can use one op amp, one single op amp I see, and since his gain is infinite; that means, applying one volt at the input, I can get infinite voltage, and whole ISE I can run the power can be generated using one single operational amplifier. Is it correct?

Because infinite gain, but what we saw, right in experiment is that, even there is infinite gain, right. Now we had a gain which is limited about 10, but we can always increase the gain, even there is infinite gain, the output cannot reach to infinite value, but it is limited by the bias voltage; that means, that one op amp cannot run the whole power or cannot generate much power that whole institute requires, right?

So, this always remember do not get confuse that oh infinite gain means that we can have infinite voltage at the output, no, it depends on how much supply you have given to the operational amplifier, alright?; that means, that here the maximum we can go about 13.5 or close to 15, we will see that experiment also that what is the range, what is the range of the operational amplifier that can work on, alright. So, that does not mean that when we say infinite gain; that means, that we have infinite output voltage, alright?

So, this is very easy so, like I said, we will break this experiment into few parts so, that you can take a break in between after you have the class. So, for now, let us quickly recall what we have seen we have seen inverting amplifier, we have applied the input at a inverting amplifier, we measure the output from that output, V out by V in, we have measured the gain, right. Gain of the inverting amplifier, we have measured the theoretical gain of inverting amplifier. And we already know that V out equals to minus R f by R in into V in, that is the formula for your inverting amplifier.

Then we have seen a breadboard, and we have connected the frequency generator the signal to the input which is inverting some input. So, that the output is inverting that is out of phase 180-degree phase shift, which we can see on the oscilloscope, right. This is what we have done. Now in the next module, let us see how non-inverting amplifier would work alright. So, I will see you in next module. For now, let us take a break, alright?

Thank you.