Op-Amp Practical Applications: Design, Simulation and Implementation

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Lecture – 13
Understanding the Range of Feedback Amplifiers

Hi, welcome to this module. Now, in this module we will look at the Range of Amplifiers, so Range of Feedback Amplifiers in particular. However, in the next set of modules we will be looking at several signal conditioning circuits including how to design a voltage control oscillator which is VCO, we will also see how to measure the ECG signal bits per minute, right and what kind of electronics signals or circuits we can design to grab those signals and to display it final in form of pqrs waves. We will also see circuits for temperature compensation in case of thermocouple. We will also see on off controller, proportional controller and several such electronic modules, right.

So, to start with every or most of the things that I am teaching here in theory we have designed in experiments, either the experiment is through simulations, or it is shown to you as an demonstration. Particularly one experiment which is very dear to me is ECG measurement, and we will be showing you how to measure ECG taking an example in reality, in real time. So, how to place the electrodes, and how to design the circuit and how to measure this, so this is the big experiment about 2-3 hours at a later stage of this particular course. So, let us see this particular module.

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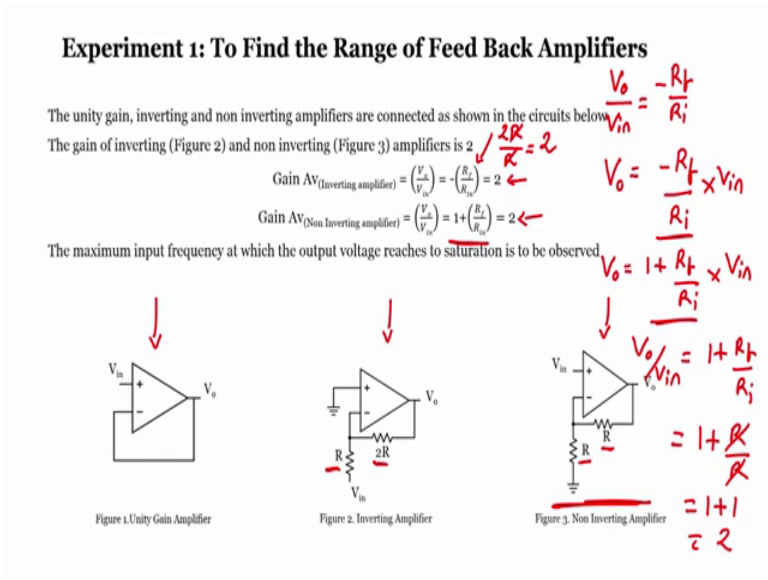

And like I said this module is focused on understanding the range of feedback amplifiers. Now, what do you mean by range? So, let us say now if you see this particular circuit this circuit is unity gain amplifier. What is this circuit? It is a inverting amplifier, this one non inverting amplifier, right. We have already studied in previous course. So, it is now very easy for understanding whether it is inverting or non inverting or unity gain amplifier just by looking at the circuit.

Now, if I talk about unity gain amplifier, what does it mean? The unity gain amplifier is amplifier which will follow the voltage, right and increase the current it can also be used as a buffer, right. So, the unity gain amplifier inverting and non inverting amplifiers are connected as shown in figure 1, 2 and 3. The gain of inverting amplifier and non inverting amplifier is 2.

Now, how this possible see this is 2R, this is R, right. Here is R and R still we are saying that gain of inverting and non inverting amplifier is same, right because we already know that the gain is nothing but V o which is output voltage equals to minus R f which is feedback resistance divided by input resistance into V in, right. This is for our inverting amplifier. If we talk about non inverting amplifier our output voltage is nothing but 1 plus R f by R in into V in, correct. So, if you see, then what is the gain? Gain is this gain here gain is this one, right. So, if I say V o by V in equals to minus R f by R i this is this equation. And if I substitute a value for inverting amplifier what is R f? 2R. So, this is equal to this if you I if I place it this 2R divided by R which is 2, right. So, this we get 2.

Now, if you take a case of a non inverting amplifier then you can see our equation is V o equals to 1 plus R f by R in to V in. So, if I say V o by V in equals to 1 plus R f by R in this is the equation, correct. Now, if I substitute values then 1 plus. What is R f? R, in this in this particular circuit what is R f R, what is R in? R. So, R R gone, that means 1 plus 1 this is equal to 2, so here also we have 2, right. Thus, the gain of inverting and non inverting amplifier for the circuit shown are same or the gain is same. Now, the maximum input frequency at which the output voltage reaches to saturation is to be observed. So, at what input frequency the output voltage which is to be saturation? Let us see.

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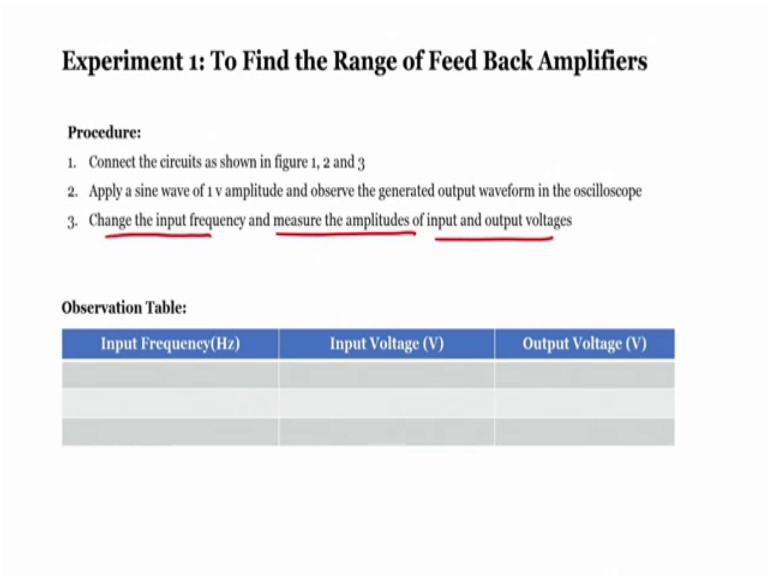

If you want to do that we have to perform an experiment, right. So, the procedure for finding the range of the feedback amplifier is connect the circuits as shown in figure 1, 2, 3 which is right over here 1, 2 and 3, right and then apply a sine wave 1 volt amplitude and observe the generated output voltage in the oscilloscope. That means, I will apply a sine wave 1 volt amplitude, 1 volt peak to peak amp voltage, right and I observe the output voltage is oscilloscope. In every case I will apply 1 volt here, here and here. And at the output I will I will see what is my value in my digital oscilloscope, ok. Then change the input frequency and measure the amplitudes of input and output voltages. If I if I change my frequency here, right I need to measure what is the change in my input and output voltage that is the third step.

So, if you see here what you will do? We will write input frequency, then we write input voltage, we measure output voltage we change the frequency and we see input and output voltages. We need to understand at what frequency our output voltage which is says saturation value, right which is a saturation value. This is the experiment; this is the experiment that we will perform to find the range of feedback amplifiers all right. This is very easy you can take an operation amplifier, right give the bias and start working on these particular experiments.

Now, to do that the things that we have seen particular about circuit designing my TA Seetharam and Anil the they will discuss about how the circuit operates. We have seen in theory in detail, but we just it to have quick recall of how circuit operates, they will show you about that circuit operation. I will request Anil to join us and show us how the experiment procedure can be carried out and this experiment I feel that if you learn it will be good for lot of other applications.

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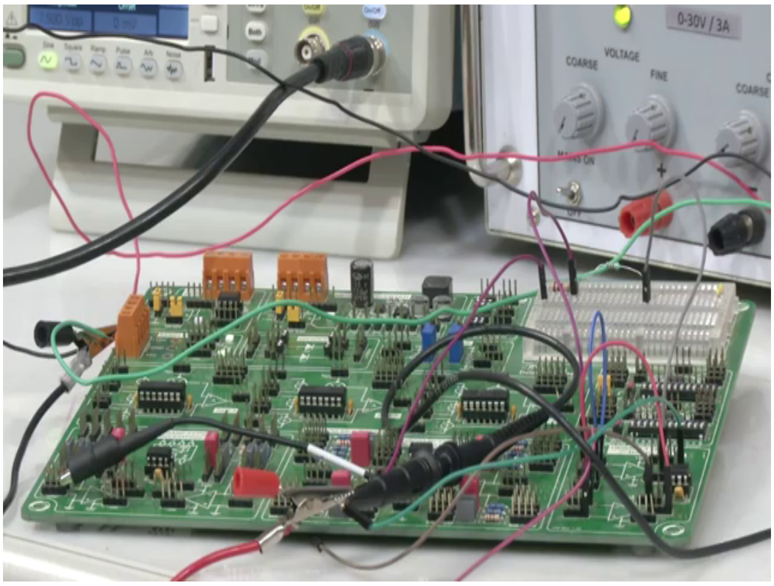

So, we have seen the theory section where we saw: what is the range of an op-amp circuit which is connected in negative feedback as an amplifier. So, what do you mean, just a quick recap what do you mean by the range is that. So, as we know the open amp saturation voltage which is around 13 volt 13.5 volt when the supply voltage is around

15 volt. So, because the op-amp has a gain when we give an input we get the output that is multiplied by the gain which is this gain here is close loop gain, ok. So, what is the range of the op-amp? As we have studied just the range of the op-amp is the range of input voltages that give corresponding output voltages without saturation, that is that is the in a practical term that is the range of an op-amp based amplifier circuit.

So, as you can see that range, that range is a very much dependent on the kind of gain that we have provided for the circuit. So, today in this experiment what we will do is we have connected an op-amp in its inverting configuration, and we have given a gain of 2.2, roughly to 2.2 5. So, the gain as you know is constructed by resistor combinations the gain of an inverting op-amp is given by minus R 2 by R 1, where R 2 is the feedback resistor from the output to the input. The input here is the negative terminal of the op-amp and R 1 is the input resistance if after which we give the input, correct.

So, the formula for gain is minus R 2 by R 1. Now, so we have to select resistors the resistors will have the tolerances. So, what we have selected here is 2.2 k resistor and 1 k resistor as R 2 and R 1. And we have (Refer Time: 09:17), but because of the small (Refer Time: 09:19) fluctuation we will get reasonable similar gain. So, what is the gain? Theoretically would be 2.2. We will see practically what is the gain we are getting and more importantly we will see: what is the range of input that is giving an output that is not saturated.

By telling that output is not saturated is that output does not get clipped off at the saturation voltages of around 13, 13.5 volt. So, let us quickly see how we have connected the circuit in the board. So, here as you as you are aware this we have connected the circuit in the op-amp section of the development analog circuit development board. So, we have used the basic type 3 op-amp section. We have connected it in the non inverting in sorry inverting configuration. So, the input this pink wire, ok.

So, if you can see this yellow wire, we have we can see that the probe is connected. So, the input comes from this probe, and it goes through a resistor on this breadboard you can see and so it is there here. And then this pink that this pink wire goes to the inverting terminal of the op-amp here, and then the positive terminal of the op-amp is grounded because it is a inverting op-amp and the output is connected across a resistor here back to the board back to the input, and we see the output from the output terminal. So, how do we see the output? So, output is seen from the output terminal using this probe, ok. This is the this is very simple circuit, but the understanding that to get from this connection is very profound which can which can help you in further building of more complicated analog circuits.

So, this is how the circuit has connected. So, now, let us check the how the (Refer Time: 11:08) circuit is working. For that let first let us see the functioning generator to see what is the input that we are applying. So, let us see the function generator. So, this is the functional generator from this we are applying the input. As we will be able to see we are giving 10 kilo hertz sinusoidal input voltage and the if the input voltage that we are starting off with is 1.5 volt 1.5 volt peak to peak a voltage. So, that is like the simple excursion one side excursion around 0.75 volt. So, we are giving 1.5 volt peak to peak.

So, what is the gain of our op-amp? So, the gain of the op-amp we have given is around 2.2 volts, so 1.5 into 2.2 it will be around 3.5 volt it is not exactly you have to multiply and see, but it will be above 3 because 1.5 into 2 is 3. So, 1.5 into 2.2 it is around 3, 3.5 volt peak to peak should be your input clear. So, this is the input. Now, next what we will do is we will not see the function rate again in the function rater by changing the input with this knob we can increase the voltage. So, this way I will be increasing the input voltage from 1.5 volt to 2.5 volt, 3.5, 4.5, 5.5 etcetera. And we will see at what voltage we are seeing clipping action taking place in the output, by clipping action meaning the output is getting saturated.

So, we will concentrate its change the input and see how the output is changing. When I am changing the input here I will tell which voltage is being fed through the functional (Refer Time: 12:34), but we will focus we have seen the circuit how the circuit is connected and we have seen that the oscillator is connected to the output terminal. So, now, henceforth for this experiment we will focus on the oscilloscope and see the output on the oscilloscope and I will accordingly tell: what is the input that we are giving from the function generator. So, now, let us see the oscilloscope. Yes. So, we can see the oscilloscope.

So, as you can see this is the output from the (Refer Time: 13:00) terminal. If you remember we have given 1.5 volt peak to peak for the input. So, if you see the output here the output here is 3.2 volt here, 3.2 volt peak to peak 3.2, 3 volt peak to peak. So, this aligning with our gain formula which is we 2.2 it is a gain. So, 2.2 into 1.5 it gives you around 3.2 volt. So, this is like we are getting almost with 95 percent accuracy we are getting the output. So, this is the output voltage.

Now let us change the input. So, I am change I am going to change it the input in steps of 1 volt. So, from 1.5 volt I am changing in to 2.5 volt, ok. So, let us do an auto scale, so that we can see the whole signal. So, we can see the whole signal. So, the now the output voltage is 5.3, 5.32 volt which is again matching, correct, so 2.5 volt. Now, again I am increasing it to 3.5 volt, 3.5, 3.5 volt. What about is your output? We will get 7.5 volt again matching with the 2.5 volt gain formula, again we are making it 4.5 volt. So, 4.5, 4.5 volt we are still getting a beautiful sinusoidal without much noise in it with the peak to peak output voltage of 9.68 volt, ok.

Now, we are increasing it again now it is 5.5 volt, ok. So, like that now the output voltage is 7.7 volt. So, let me keep increasing it. So, this is 6.5, 7.5, ok. So, as per formula, so we know that the saturation voltage of the op-amp is when supply voltage is 15 volt is around 13 to 13.5 volt. So, that 13.5 volt will be the single phase single side excursion. So, positive side should be 13.5 volt negative side should be 13.5 volt when that voltage is reached the output saturates, correct.

So, with the gain of 2.2 let us first try to calculate what is the input voltage for which the saturation means begin to occur. So, as per that, so 2.2 is the gain. So, around 13 volt 13 volt is the single side excursion, correct. So, 13 volt single side excursion means 26 volt peak to peak, correct. So, 26 volt peak to peak by 2.2 will give you the input voltage for which saturation will start to occur which is what 26, 26 by 2.2 is around is less than 13 volt more than 12.5 volt. So, around 12.5 volt input you should you should begin to see the saturation. So, if when you begin to see the saturation the input voltage will be 12.5 peak to peak.

So, then we start it from 0 volt till 12.5 volt peak to peak then the point where saturation begins and from the input start value 0 to 12.5 volt peak to peak or 0 to 6.25 volt sinusoidal wave would be the range of the operation amplifier, right. So, let me increase the input again. So, now, it 8.5, now it is 9.5, 10.5, 11.5, ok, so next it will be 12.5. So, this 12.5 now let me increase it in more fine duration so that you will see when the clipping starts to happen.

So, now its 12.5, I am making it 12.6. So, if you if you properly see it, you can begin to see as slight clipping happening here, ok. So, let me increase it further, 12.8, ok. Now, you are seeing very nicely you are seeing the clipping action, right. Now, it is around 13, 13 volt, ok. So, 13 volt peak to peak so that is around 6.5 volt input for input voltage you are getting the clipping action. Now, the peak to peak voltage here is 26.4 volt, ok. So, you are seeing the clipping clearly if I increase it further you can see that the saturation effect becomes more profound and more expressed, correct.

So, now you can see that the output has become clipped, it has become it is trying to become like a triangular wave. So, what is; so this is not the decide output as per decide. So, what is; from this experiment what you can see? The range of the op-amp is from 0 to around 12.5 to 13 volt peak to peak input or 0 to 6 to 6.5 volt peak, volt peak sinusoidal wave is the range of the op-amp. By range of the op-amp we mean the input range input signal range. Now, from these experiments it is very clear to you that the range of the op-amp is determined by the gain that is given on the op-amp, correct.

So, then for us to get maximum range what should be the gain? The gain should be unity, correct. So, we will see now what is what is a operational amplifier with unity gain it is called voltage followers circuit or the unity feedback circuit for the voltage follower or the unity feedback circuit we will get the input range maximum, ok. So, the output will follow the input. So, we will see next that circuit and then we will understand the importance of the gain that we apply on the output, sure. So, let us just see that.

So, we have just now seen the op-amp as inverting amplifier connected as inverting amplifier with a gain of 2.2, we have seen how the input is vary output is varying with the input and how the what is the input range, correct. So, now, best circuit to demonstrate the effect of gain and the range of an amplifier is the voltage followers circuit. So, we have connected the voltage followers circuit in the board. So, what is the voltage follower circuit? Voltage follower circuit is a is an op-amp circuit that has a unity gain. So, it is also called the unity gain amplifier; so, for that we need to use the op-amp in it is non inverting configuration. Why? Because what we do in the circuit design point of you is we connect the output back to the input.

So, we you we connect the output back to the we need negative feedback, right. If it is positive feedback the output is simply saturator oscillator. So, we convert the output back to the like inverting input terminal, ok. So, the what is your R 2 resistance? Then your R 2 resistance is 0, R 1 resistance you can you can even input resistance because that does not have an effect because the gain. So, so if you if you use the inverting amplifier only as the circuit forward voltage for your gain relationship will be what minus R 2 by R 1, right, but your R 2 is 0. So, your gain will be 0. So, that is why we use the non inverting configuration. So, for a non inverting configuration the gain is 1 plus R 2 by R 1. Here your R 2 because you are connecting from the output back to the input is 0.

So, 1 plus R 2 by R 1 gives you effectively 1 plus 0. So, the gain is 0 the gain is 1. So, the you get a gain of 1 and we are connecting it in a non inverting configuration. So, that is the overall idea of how the circuit is deciding. It is very simple circuit, but it has lot of applications the unity follower or buffer amplifier it can be call it, you can call it or the voltage follower. Thing is that it gives a good, it access a good impedance stage and also helps you to invert it output. So, let us say you use the inverting amplifier stage to get the output and you want to have a output which is having the same phase relationship with respect to your input.

So, you add one another unity follower after that that inverting amplifier block. So, you get the output in phase with the input. If you just use the inverting amplifier your output will be out of phase because the gain is minus 1, correct. So, that is the overall idea. So, that is not related to what we are doing today the just we just mentioned into that. So, today we are seeing the range of the amplifier, and we have already seen the range when the gain is 2.2. So, now, let us see what will happen now. So, we have connected its very simple connection not much see. So, the this red wire connects from our output to the negative terminal, input terminal, this pink wire connects the input to the non inverting terminal of the op-amp and the input is given through this yellow wire from the function generating. That is all, that is the circuit.

So, let us see the functional unity now, ok. So, we are seeing the functional generator. We are applying frequency of 10 kilo hertz. So, we are starting of like this previous experiment we will start off with the voltage of 1.5 volt. So, we are giving 1.5 volt peak to peak. So, now, what we will do is just like the previous experiment we will see the output wave form see what is the voltage level for that, and we will not see the function generator I will keep increasing the input voltage and we will see what is your output voltage and where it is saturating. Thereby we will calculate: what is the range of this configuration and compare it against the range that we saw last time. If you remember the range we saw in the previous experiment is that the sinusoidal wave of around 12.5 to 13 volt peak to peak or 6.15 volt peak sine wave was causing saturation. So, the input voltage range was 0 to 6.5 to 7 volt, 0 to 6.5, 6 to 6 6.5volt that is what.

So, now, let us see the oscilloscope yeah. So, we are seeing the oscilloscope now what was our input voltage or input voltage ranges 1.5 volt peak to peak and we are getting an output voltage of around 1.68 volt. So, it is almost unity gain. So, its least minus fluctuations will be there because of internal and input resistances the non infinite, non ideal characteristics. So, 1.7, 1.7, 1.68 volt is the input voltage, correct. So, now, let us we increase the voltage. So, I have increased it by 1 volt 2.5 volt. So, let us see. So, the output voltage is around 2.8 volt. So, it is almost a unity gain. So, let us keep on increasing the input. So, if you see it is like following the input with same phase also. So, that is why it is called voltage follower, correct.

So, now it is 5.5 volt peak to peak we are getting 5.7 volt, 6.5 volt, 7.5 volt, 8.5 volt you can see here how the voltage is changing 9.5 volt, 10.5 volt, 11.5 volt. See that, it is still not saturating, correct. I am just giving auto scale so that you can see the waveform properly. Now it is 13.5 volt, still see earlier with 13.5 volt we were seeing saturation at the output. Now, we do not see that, because what? Because the gain is unity you have more range at your input, now this 14.5 volt still this output waveform is beautifully sinusoidal without any saturation 15.5 volt, 16.5 volt, 16.5 volt you are getting 17.4 volt; so, almost unity gain, correct.

See, is following nicely. So, this is the (Refer Time: 23:27) that the function generator can provide. So, we have given almost 20 volt peak to peak input and we are getting 20.4 volt output, ok. Still the output is faithfully reproduced, input is faithfully reproduced. So, the range will go on if you if you are able to supply more voltages. So, when does the op-amp saturation when its single excursion goes to the 13.4 volt or the peak to peak voltage goes to around 26 or 27 volt. So, when we give around 26 volt input we will get 26, 26.4 to 27 volt output. So, the range of the op-amp will be 0 to 26 volt peak to peak input where in the earlier case the range this range was 0 to 12.5 to 13 volt peak to peak input voltage.

So, thus this range was reduced because of the increased gain so, but we, but in my lot of applications we need the gain, correct we need to amplify your signal. Suppose it is a feeble mic input we will need to amplify the signal. So, amplification is necessary. So, this is how this is the trade off, this is our circuit design will happen. So, that is the tradeoff for our increased gain you have to sacrifice your input voltage range. So, that is why range of an amplifier is an important concept to understand and this is something that you need to inculcate or observe within yourself before you delve into more complicated circuit design.

So, one part we have seen as an experiment where we change the amplitude of the input and for different gains and seen at what amplitude the output starts getting affected or clipped off. So, that is one part one story about the range of an amplifier. Another aspect of range of amplifier which professor has discussed in the class is about the input frequency. You might have seen the experiment one description where we have seen the change we have changing input frequency and seeing how the input and output voltages are changing, correct.

So, this is related to what is called gain band width product, ok. So, the gain and bandwidth product of an feedback amplifiers circuit remains a constant. So, if you have higher gain the bandwidth that you get will come down. Accordingly if you have a lower gain the bandwidth you can get is higher. So, that is the overall idea which is what in the theory class we tried to see we and which is what professor has tried to explain it to you. So, now, so this is another part of our first experiment itself which we are continuing. In the first part just now we saw how by changing input voltage, for a fixed gain how the output voltage is changing and for what input voltage was the output voltage distorted.

Now, what we will do is we will repeat the same experiment. So, what we did in the previous experiment? We used one inverting operational amplifier configuration with the gain of 2.2 and we saw how an input and output voltage is fair related. So, we are using the same circuit because we are just recording. So, we are just capturing that same experiment. So, what we are doing is same inverting amplifier circuit is there, now what the input how we feed the input only we will change this time. So, circuit connection remains the same as we discussed just now.

So, what we will do now is we will keep the input voltage constant at 7.5 volt peak to peak, ok, but we will change the input frequency and see till what frequency we are getting faithful output. By faithful output what we mean is say we have made the gain as 2.2, correct. For 7.5 volt peak to peak we should get around 15 to 17 volt peak to peak as the output which is the faithful output with respect to the gain. So, till what frequency are we getting this faithful output gain, and from what frequency is it going down that is what we will see now in this experiment. And we will see the same thing for a unity gain amplifier also where the gain is lesser, correct.

So, accordingly we should observe that the output remains faithful to the input for much longer much higher frequencies. So, this is how that is how the range of frequencies, this is also an aspect of range of feedback amplifier. Here what is the range? Here the range is the range of input frequencies which we can apply. In the first part of this experiment what did we see? We saw the range of input voltages that we can apply.

Now, let us just quickly see the function generator. We are applying sinusoidal wave at 7.5 volt peak to peak and at 10 kilo hertz, ok. Now, you this is what we are applying, now we will not see the function generator like (Refer Time: 27:44) we will only focus on the oscilloscope. And what I will do is I will change the inlet us I will just show it you here I will keep changing the frequency say by 100 kilo hertz. So, the this is 10 kilo hertz, 100 kilo hertz, 210 kilo hertz, I will just keep changing it and we will see the output. So, for 7.5 volt peak to peak we should get around 16 volt peak to peak because the gain is 2.2, ok. So, we will see till what frequency this 16 volt peak to peak output we are getting, ok.

Now, we can see the oscilloscope, now our input frequency is 10 kilo hertz, and we can see the output voltage see here its around 16.4. So, this is the faithful output as per our criteria. So, now, I am changing the frequency just considerably observe the output voltage. Now, this is 110 kilo hertz, so still it is 16.2 volt, now its 210 kilo hertz, 310 kilo hertz, 410 kilo hertz 510 kilo hertz as you can see the output voltages coming down. So, the actual, so you can may be see till around V m by root 2 you can put threshold value till where you want to consider that the this output is good enough for your applications. Finely it is about your own choices like the further: what are the further circuits to which you want to connect the circuits.

Let us say your ideal output is 16, 16 volt, but you are, with working till around 13 volt you can go on till more frequencies, ok. So, I am increasing the frequency. So, we can see that at 16 kilo hertz itself the output has become instead of 16 volt we are getting 11 volt which is less, correct. So, if we keep increasing the voltage it is again and again coming down amplitude, correct now it is 8.2, now it is 7.8, 8 volt, frequency is 1 megahertz now, and it has become very low, correct.

So, we can see that if you if you if you put a very hard constrained then you are getting the 16 volt peak to peak output, only till around 300 to 400 kilo hertz, maximum around 400 kilo hertz, even at 500 kilo hertz you are getting only 13 volt peak to peak which is what we are seeing here. So, you understood, right. So, our gain is 2.2, for that gain we are getting faithful output only to till around 300 to 400 megahertz depending on the threshold or constrained that you keep, 300 to 400 kilo hertz as what we are seeing, depending on the constrained we are keeping. 300 to 400 kilo hertz by then after that it is coming down, correct with our gain of 2.2. Now, what we will see we will see other circuit we will connect the input to the unity feedback amplifier, and then see.

So, let us connect it you just looking at you just keep looking at the oscilloscope, let me just switch off the input for now because we are giving we are going to connect it. So, whenever you are changing circuits or connecting it you have to switch off your supply everything and then give. So, now, right now we are in the board we are connecting the other circuit, ok. So, we have connecting it now let us just one second, ok. So, now, we have connected the unity feedback circuit now. So, now, the gain is 1 instead of 2.2, ok, now let us see till what frequency we are getting faithful output.

Now, here the gain is 1, so what is our faithful output? Our faithful output is suppose we are giving again we are let us look at the functional generator once quickly. So, this is the functional generator. So, again we are giving the same 7.5 volt peak to peak output now we will start off with 10 kilo hertz, ok. Now, for this circuit what is the faithful output? We are our gain is what? So, our faithful output is an output that is around 6.5 to 8 volt, or may be depending on your constraints if it want if you want to get to go down let us around 6 volt that is also fine. So, till then, so till what frequency are you getting this faithful output voltage is what we have to see.

So, now, let us. So, the circuit connection everything remains in the sense for unity feedback that is like our previous experiment, now let us look at the oscilloscope, ok. So, you are seeing the oscilloscope. So, we have got 8.2 volt peak to peak output and we are for a input 7.5 volt peak to peak which is, correct because our unity gain its around 1.1, 1.2 there are there will be some non idealities, but this is fairly accurate.

Now, let me increase a frequency now its 10 kilo hertz, it will become 100 kilo hertz, 2100 kilo hertz, you can see that output is still constant at 8 volt, ok, still constant at 8 volt now it is 210 kilo hertz, 310 kilo hertz, 410 kilo hertz still you can see that output is 8.0 volt. For same for the other circuit at 400 kilo hertz we saw the output coming down considerably from 16 volt peak to peak it had come down to 12 volt peak to peak, correct, but here it is remaining concept. You see the difference. It is 510 kilo hertz, still it is remaining constant see its 8.2 volt, 16 kilo hertz still constant, 710 kilo hertz still constant, 810 kilo hertz constant, 910 kilo hertz constant, 1 megahertz constant, 1.1 megahertz now it is slightly decreasing, now it will slowly increase. So, see what was this our gain ratio let us say now let us compare both the circuits.

Now, what we got? Around 1 megahertz around 1.2 megahertz, 1 or 1.2 megahertz we are seeing the output getting attenuated or distort. Now, our first circuit had a gain of 2.2, our second circuit had a gain of 1. So, what is the gain ratio between the two circuit, it is around 2.2. Accordingly our first circuit had a frequency range of around 400 to 500 kilo hertz, our second circuit having a gain range of around 1.1 to 1.2 megahertz. So, you can see very clearly, right. For a 2.2 gain we have a range of 500 kilo hertz, the product is around 500 into 2.2, correct it is around 1100

For the circuit second circuit gain is 1 and the range of frequency is 1.1 megahertz or 1100, again the product is what 1.1 or 1100 kilo hertz into 1 or 1100 there also 500 into 2.2, 1100. So, you can see that gain bandwidth product is remaining same and the both aspects the gain and the frequency will affect the range of the op-amp here by range we need both the range of input voltage is that you can apply for a given gain and also the range of inputs frequencies you can apply until when you can get your faithful output. So, this completes the experimental section of understanding the range of feedback amplifier.

Thank you.