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NPTEL PROGRAMME ON TECHNOLOGY ENHANCED LEARNING

INDIAN INSTITUTE OF SCIENCE, BANGALORE

Electronic Modules for Industrial Applications using Op-Amps

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Experiment on On-amp based ECG Signal Acquisition, Conditioning and Processing for Computing BPM

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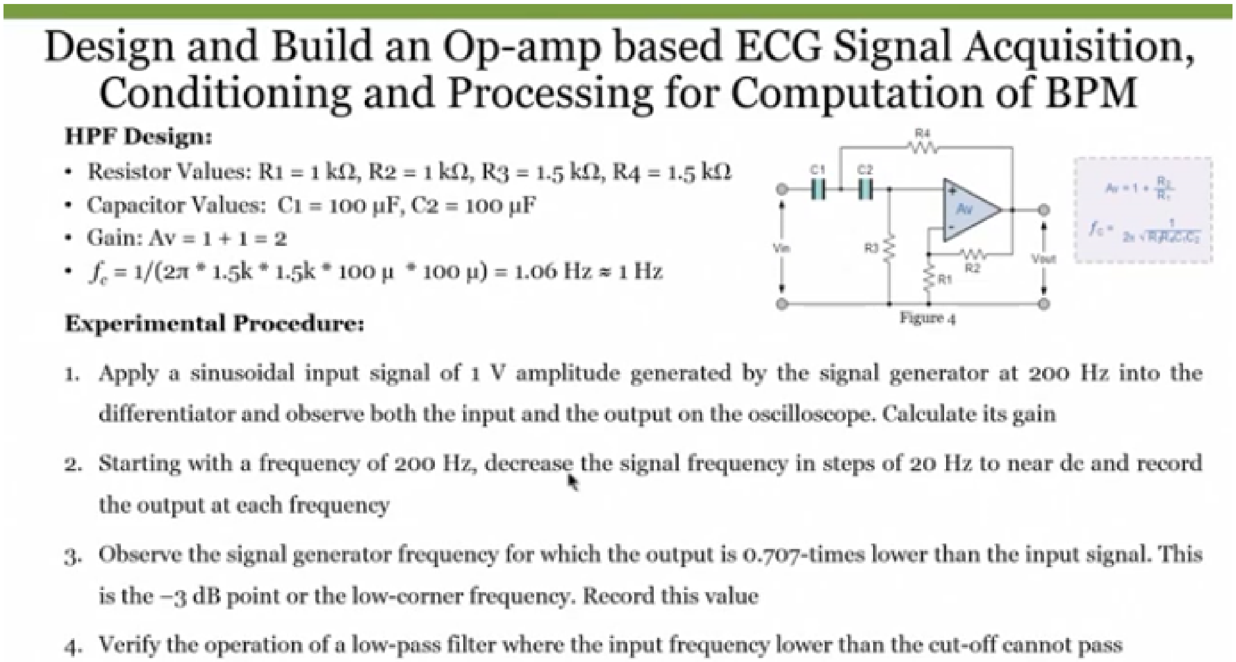

Now so previous one we have seen the first order low-pass filter. Now this is our second order high-pass filter, right, why this is called second order? When we see we have two combination of R and C capacitors, two combination of R and C pairs, right, so one if I have one combination of C and R it is called first order high-pass filter, if I have two combinations this is called second order high-pass filter.

Now because we have a two capacitance and two resistors the cutoff frequency will be calculated as 1/2 pi into root of R3 R4 and C1 C2, right, just recall our high-pass filtering sessions, you can easily understand that, and since this is connected to the positive terminal, the input is connected to the positive terminal of an operational amplifier, this is an non-inverting type, right, since it is a non-inverting type high-pass filter, so high-pass filter the gain of the system is nothing but 1+R2/R1, so the resistance that we use, the values of resistors R2 and R1 that we choose decides the complete gain of the system, right,
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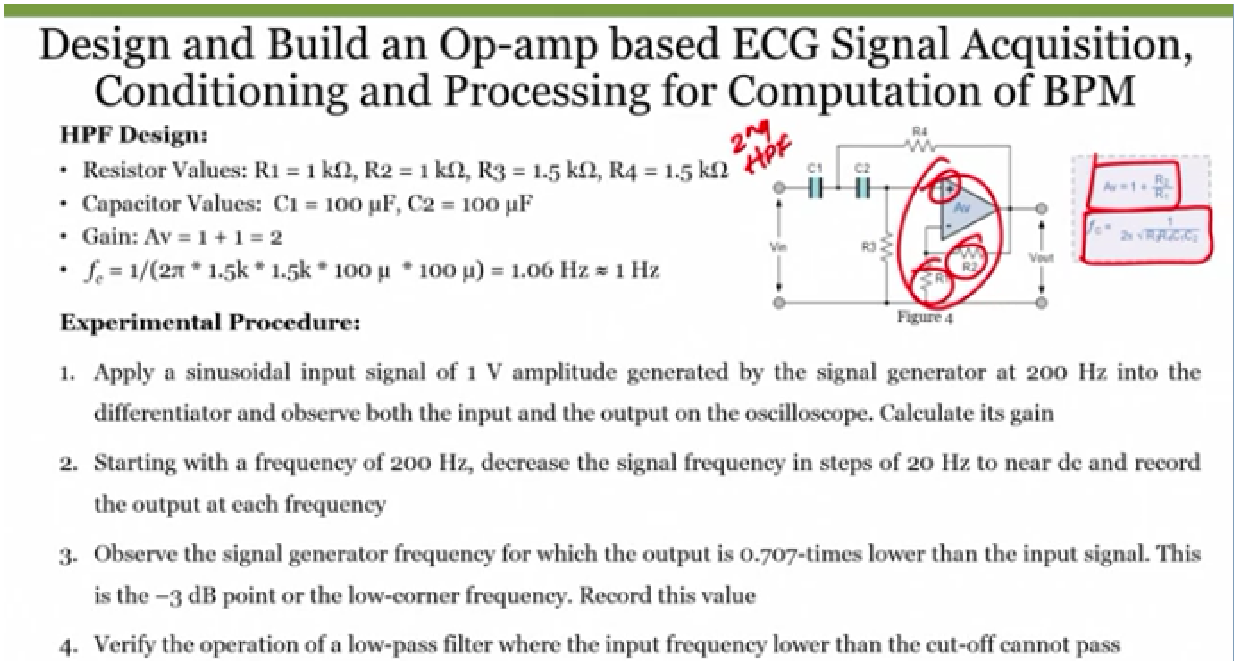

so in this case we require to design a cutoff frequency somewhere around close to either 0.5 hertz or 1 hertz, right, so in this case we choose, we have chosen a resistors values as well as the capacitance value so that when we calculate cutoff frequency, we got a value as 1 hertz.

But how do we calculate? The cutoff frequency is 1 by, sorry, there is a wrong in the formula, it is nothing but 1/2 pi into root of R3 R4 and C1 C2, so in this case we have chosen R1 and R2 as 1 kilo and 1 kilo, so when you observe this is a 1 kilo ohm, this is 1 kilo ohm, so when we calculate a gain, gain is nothing but 1+1K/1K which is nothing but 2, so if I apply 1 volt I'll get an output as 2 volts, if I apply 0.5 I'll get an output as 1 volt, right.

Apart from using R instrumentation amplifier some amount of gain can also be applied by using these operational amplifiers too, right, then we have chosen R3 and R4 resistance as 1.5, so this is 1.5K and this is also 1.5K, right, and what about C1 C2? So both C1 C2 we have used 100 micro farad and this is also 100 micro farad, so when I calculate FC, FC is nothing but 1/2 pi into root 1.5K square into 100 micro square,

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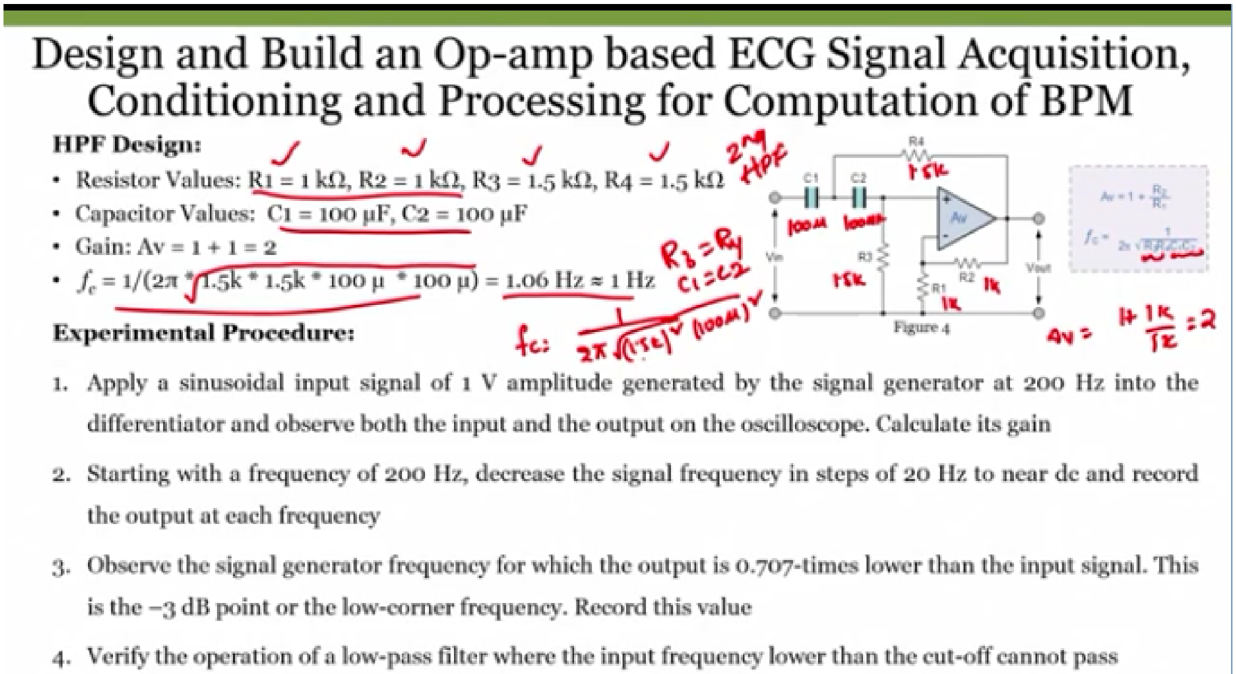

right, because R3 = R4 in this case as well as C1 = C2, so C1 C2 I can write it as C1 square, R3 R4 I can write it as R3 square, so 1.5K whole square and 100 micro square, so when we calculate the value will be almost equal to 1 hertz, the value we got is 1.06 hertz, so which is equal to 1 hertz, right.

Now how do we understand? So similar to that of our low-pass filtering circuit even in this case what we do is that we will connect, we will connect this particular circuit, we will do the circuit designs simulation software, we are using multisem, we'll go with a multisem, we'll use the same resistance values and capacitance values, since this is a cutoff frequency of 1 hertz we'll go from somewhere around 10 milli hertz to some greater than 100 hertz somewhere around 200 hertz also we can go, right, we'll slowly increase from this frequency to this frequency, and we'll use the input signal of 1 volt.

Now since a gain is 2, we'll get an output as 2 volts that we also we can observe, and as long as output is 70.7% of my input, so since we are using the output is of 2 volts so that means 1.414 as long as the input is lower than 1.414 that means a signal is completely attenuated that is the 3DB line, so when the input is higher than 1.414 that means the signal is being passed that is greater than or 3DB line so that point wherever it is almost equal to 1.414 volts I can say this is our cutoff frequency, right, this is the cutoff frequency of our high-pass filter.

Now we will go to our simulation, I'll create one more circuit, so I'll save this circuit as high-pass filter, save, name I'll write it down as high-pass filter and the cutoff frequency we are using is 1 hertz in this case so 1 hertz, okay, so what we need? We need to use operational amplifier, I'm taking operational amplifier and we are using two capacitors and two resistance and what resistance value we have considered? When you see R1 and R2, R1 and R2 we defined here as feedback and normal resistance,

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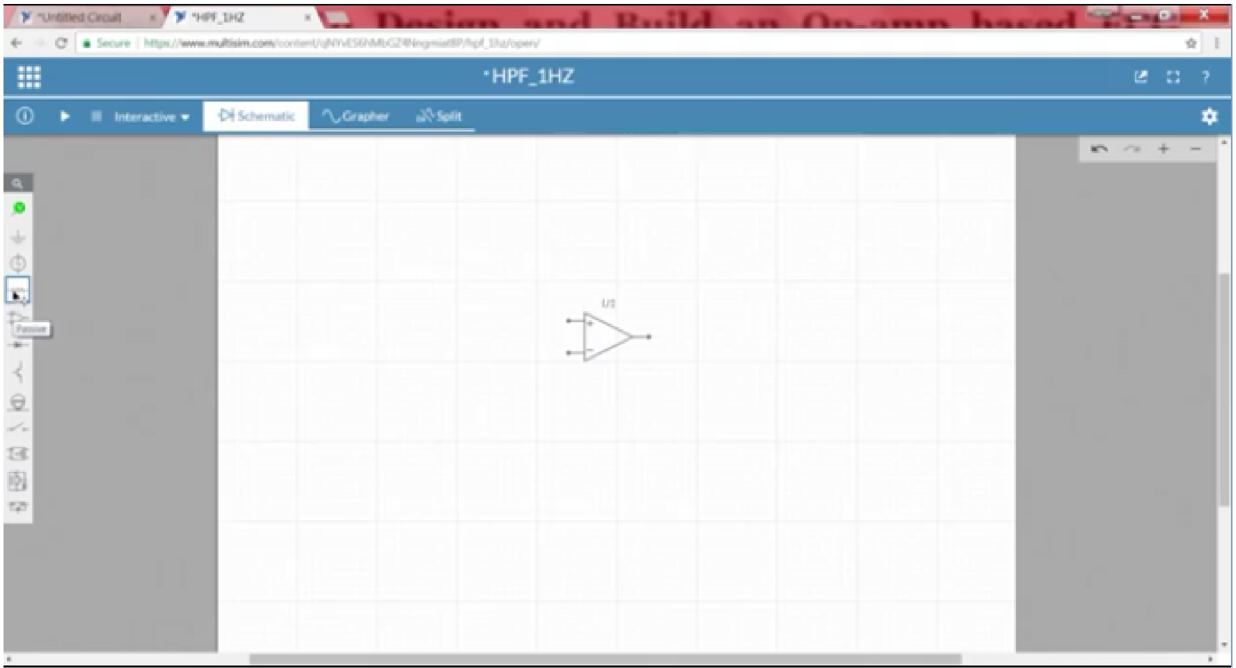

right, this is R1 and this is R2, so I'll use the same resistance value as well as same R1 the notations too, so R1 I'm keeping it here and rotating it, and I'm also taking R2, this is R2, R1 R2 are same resistance value so I don't have to change the resistance, I'll be connecting it here.

Negative feedback, right, so the gain, the input resistance and the gain resistance,
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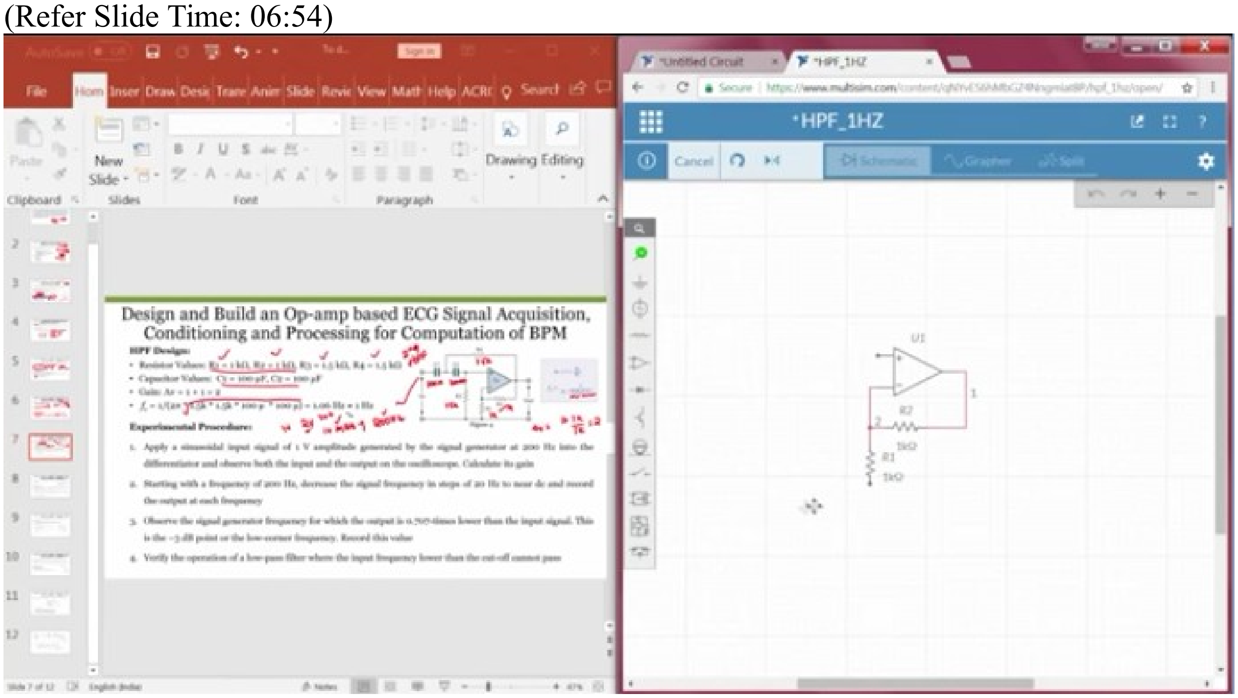

the feedback resistance which decides the gain of an op-amp is done, now what else? We have to do the filtering part which is nothing but C1 R4 is one part, C2 R3 is another part, so I'll take two resistors again so one is R3, this is our R3 resistance and the value that we choose is 1.5K change is to 1.5, sorry, this should be 1.5K, right, then we will choose one more resistor as a feedback which is a positive, 1.5K at this point and this terminal should be connected at this point and this should be connected at the positive terminal.

Now what about the other one? Other one has to connect it to ground, then what else?
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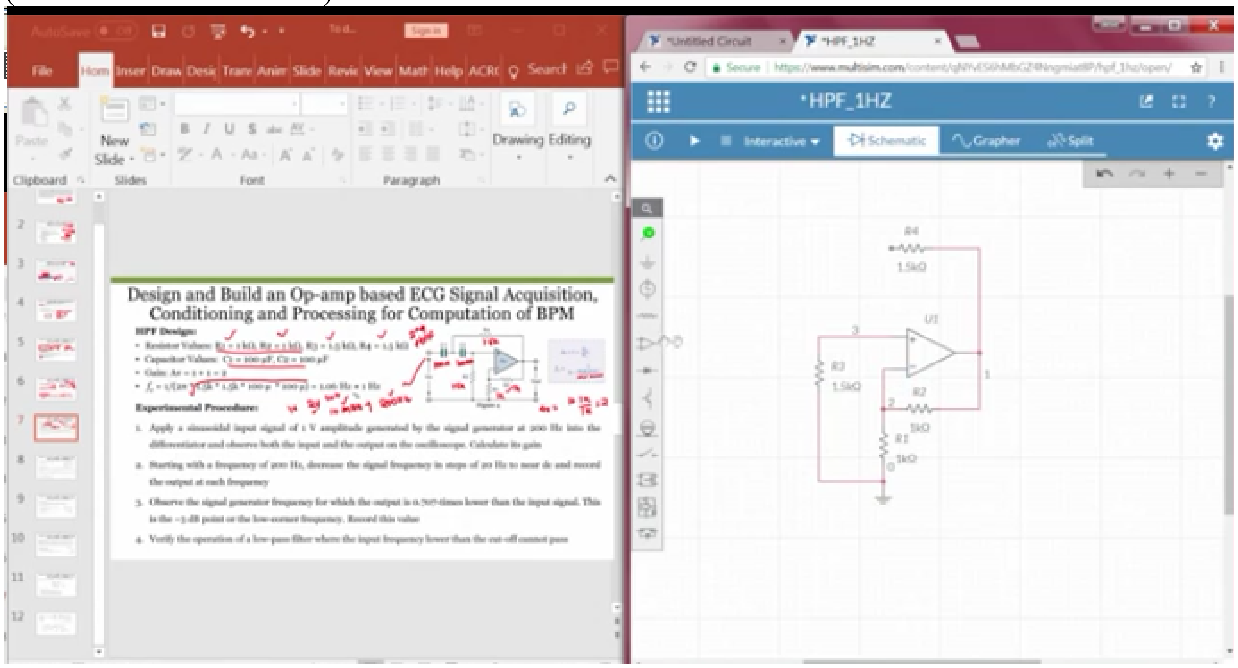

I have to take capacitance, so I will go with two capacitance one is C1, and other one is C2, so the value of capacitance that we use is 100 micro farad, even here 100 micro farad. Now let me make a connections here, so this particular point has to be connected here and this point has to be connected here, right,
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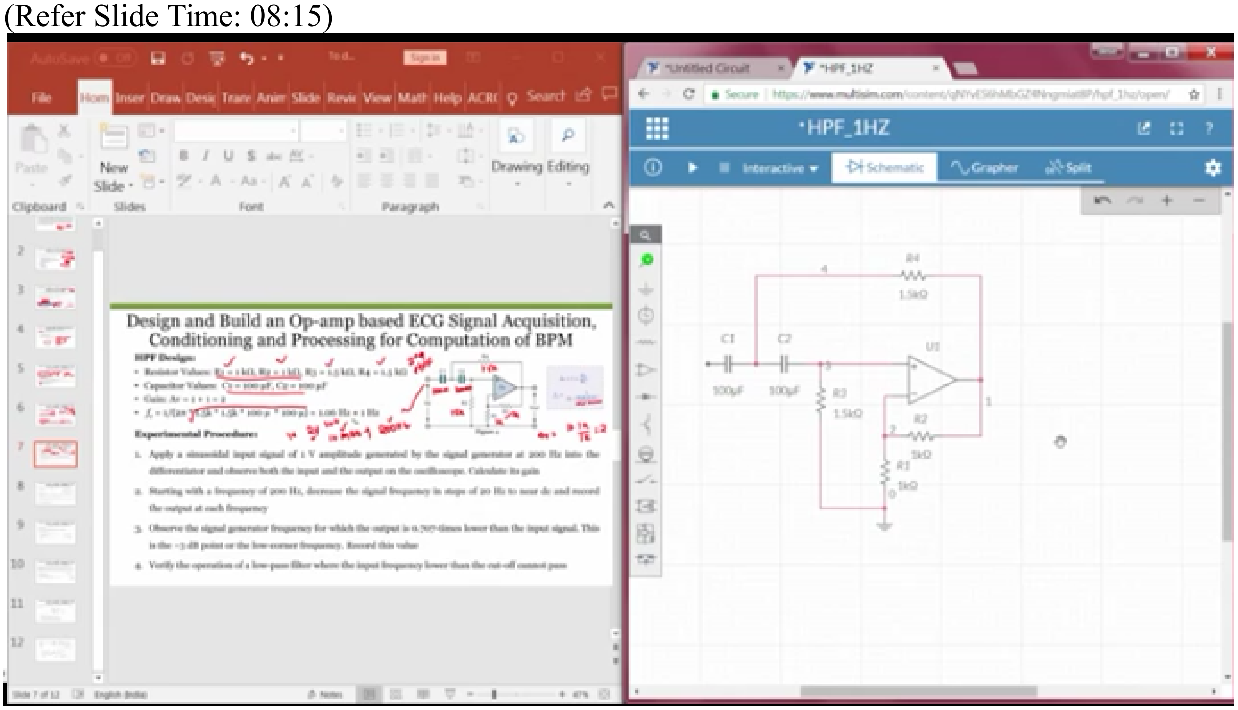

so with this combination of a circuit we can observe high-pass filtering at a cutoff frequency of 1 hertz, so in order to observe that signal so we have to connect the input source, so I'll take an AC voltage, I'll connect it here and this is grounded, so one terminal, one probe I'll be connecting at the input so both the input and output I can visualize, other one is at output side, so this is nothing but our green colour represents the input signal and the blue colour represent output,

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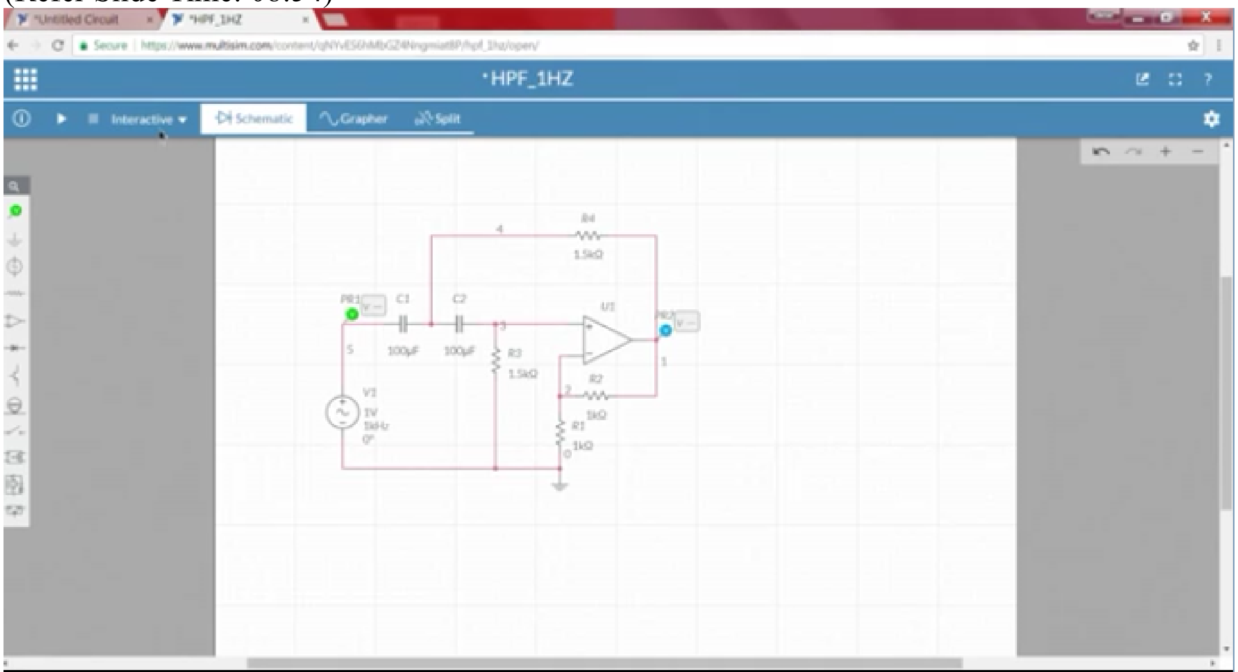

so to visualize in a frequency domain I'll change the settings from interactive to AC sweep.

So what do you mean by AC sweep? AC sweep is an internal function, what it does is that rather than you keep on changing your input frequencies, at particular frequencies the system has already preprogrammed such a way that the input signal frequency will start from 1 hertz to the minimum frequency that you set to the maximum frequency that to set with an intervals of some default parameter, default values, it will keep on increasing the values and you can observe the output voltage at this particular point, right.

So I'll go to the graph here, let me run it we can see the signal, now since you also have a phase,

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I don’t want to look into the phase so I’ll remove both the phases, now here we can see input is green, right, and output is this one, isn’t it? Now what I need? The input frequency and this frequency, so this I’ll make it as 200 whereas this I’ll make it as somewhere around 0.01 hertz, so in this case for the sweep configuration I’ve change some setting parameters, we change the start frequency as 0.1 hertz and the stop frequency as 1000 hertz here, and the points per decade is 10,

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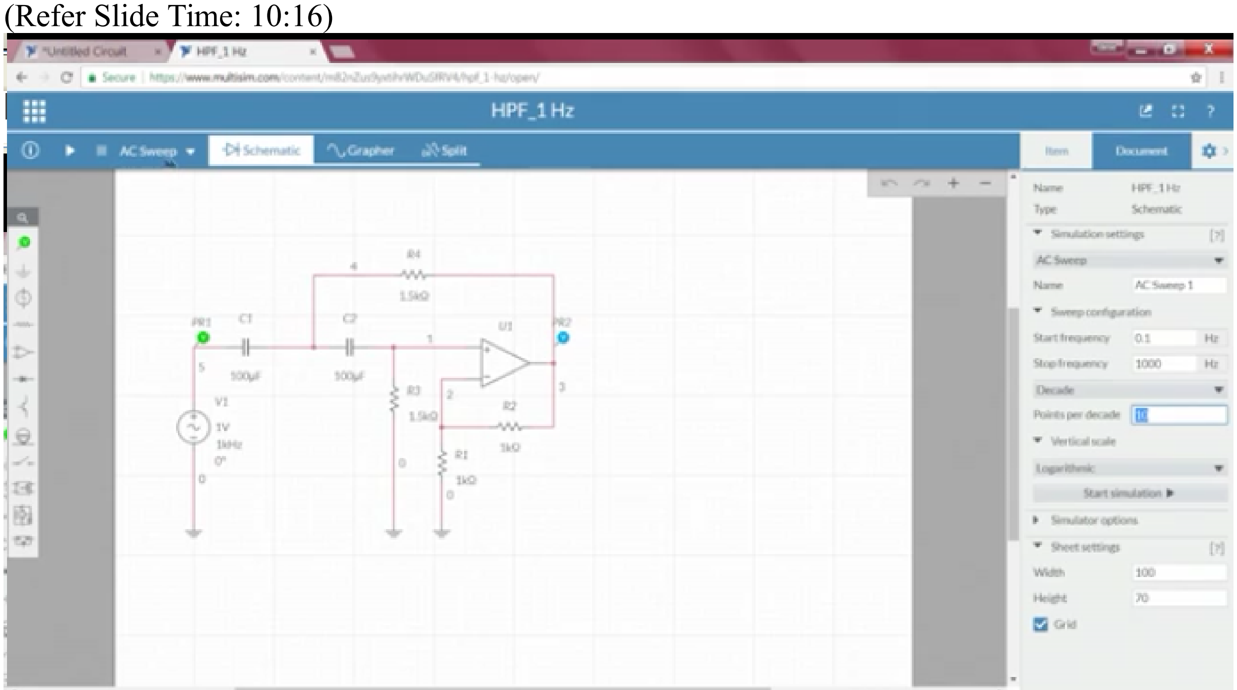

so only thing what we have to do is that once we select the sweep we have to go to the settings, from the settings here we have to change the parameters to 0.1, 1000 hertz, and how many points per decade we require? Once it is done, when we start simulation it starts you know simulating here,

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so in this case even if you observe the input is green and output is blue, so what I'll do is that I'll change, since I may not require both the phases, I'll remove both the phases, I have both the magnitudes, I'm making cursors temporarily off right now, so observe carefully here, the green indicates our input signal,

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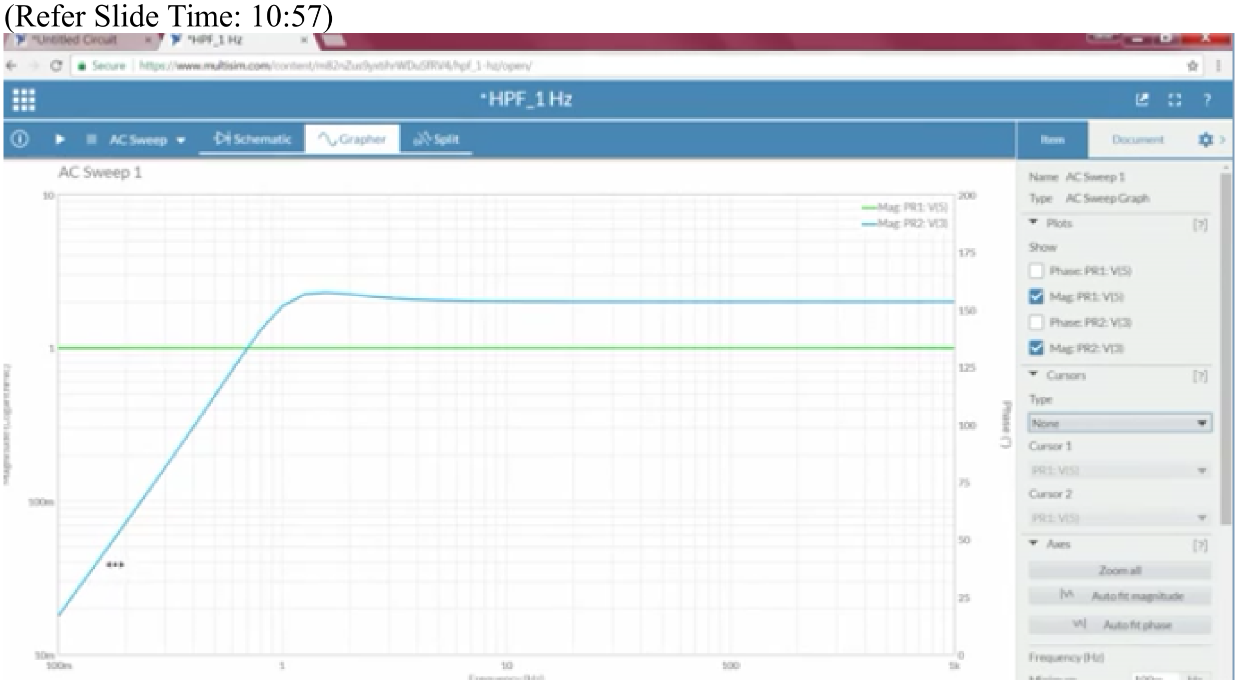

and the blue indicates our output signal, right.

Now so this is a logarithm scale, the magnitude is completely logarithmic here we can see the magnitude is completely logarithmic and the green is at 1DB, 1 magnitude, but what about the blue? Why it is in 2DB? If you remember correctly the gain of an op-amp is 2, so that's the reason the output is having double than that of the output amp magnitude is double than that of the input magnitude.

Now what about at different frequencies? When you see no matter what at what frequency are at, the input is always having an magnitude of 1, but whereas the output? Depends upon the frequency it is slowly increasing, increasing, increasing and one particular point it has become to 2DB, now if I want to calculate the cutoff frequency of this particular filter right, the characteristics if I see it looks like our high-pass filter characteristics, so whatever we design is also high-pass filter, one at cutoff frequency.

Now if you want to visualize what I'll do is that I'll take a cursor, I'll go with an amplitude cursor, Y axis cursor and I'll put C1 at 1.7, right, because that 3DB line is nothing but 3DB to our maximum amplitude, maximum amplitude is 2,
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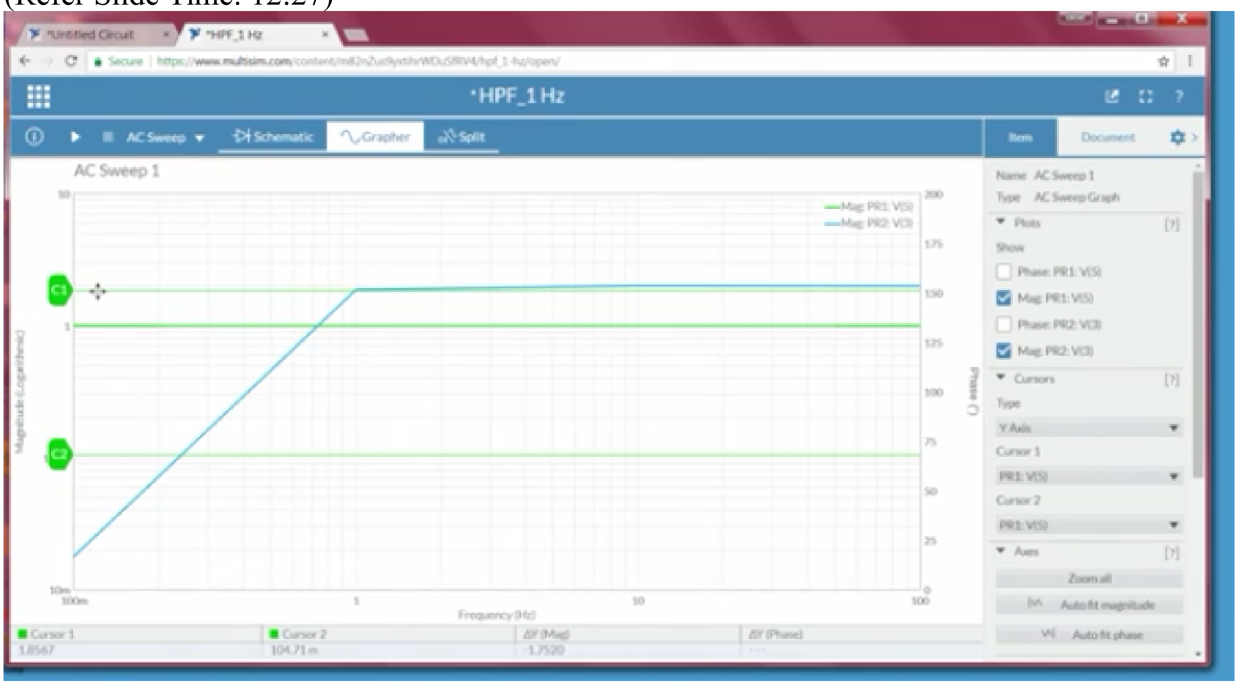

so 2 – 3DB, so the magnitude should be 2 -0.3, it should be somewhere around 1.7, right, so I'll keep somewhere around close to 1.7 value, -1., sorry, this is C1, 1.8 sorry, so I'll be keeping close to 1.7 that is our 3DB magnitude of -3, so here this point is nothing but our, so when I observe it pre-magnitudes, when you observe that this is very close to the 1 hertz, right, or 1 way to look into that is rather than going into this we can go to interactive and we'll split it, let me close this, we'll split it, we'll change the frequency from 0.1 hertz itself, right, let me run it.

So we'll change the settings to, right, so what is happening?
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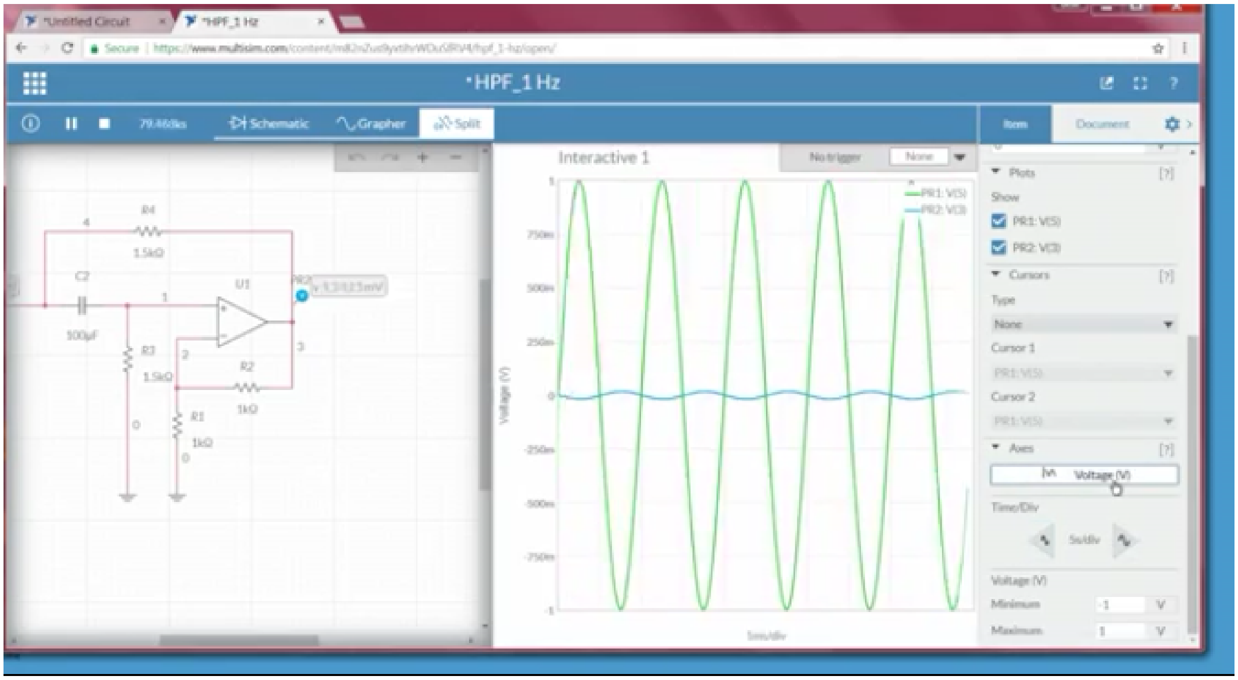

Now the peak voltage that we get is nothing but 2 volts, right, as we know that, so in order to understand that what I'll do is that rather than going with a low high value, we'll go from lower value, so make it as 100 hertz, now go to the settings, so we can see 2 volts to 2 volts I'll increase, I'll decrease the time division, so that we can see the signal,
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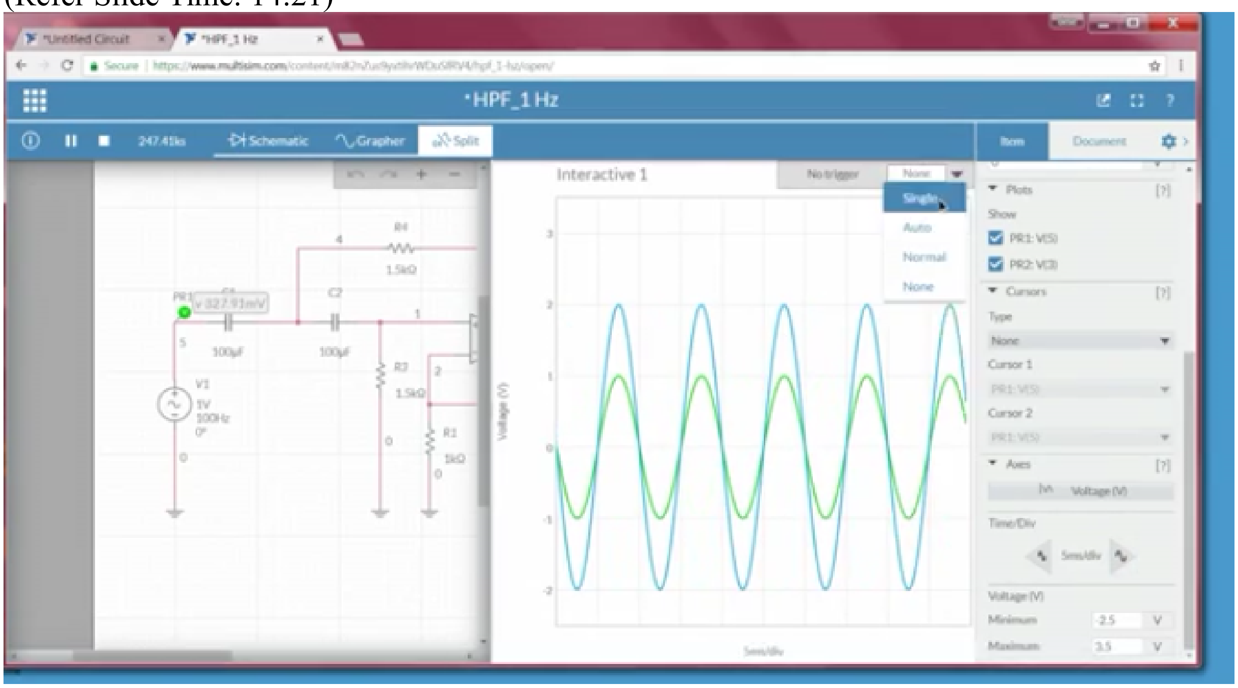

from here it is clearly observe that the input is green colour, output is blue in colour, the peak to peak value is 2 volts, the input signal whereas output peak to peak is 4 volts, since it is a 4 volts, right, why this is 4 volts? Because of the gain as 2, the gain here is 2, and moreover since it is a non-inverting type of input we cannot see any change in the phase shift, it is always following the input, right, that we can clearly observe.

Now to understand that we'll create a cursor, so cursor should be put it, so I'll take Y axis cursor, the amplitude cursor and this should be place at 1.414 volts, so I'll be moving this cursor, we'll move the cursor,

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okay Y axis cursor to 1.414 if you observe here, this is at 1.6 slowly to 1.412, 1.412 approximately 1.41, so whenever the input voltage, so what I'll do right now, right now I'm at 100 hertz, I'll slowly decrease from 100 hertz to 10 milli hertz, so at what point, at what frequency the input is equal to this even threshold is nothing but our my cutoff frequency, so what I'll do? I'll decrease slowly with a factor of 20, so go with 80, I'm going with 80, so I'll make it as auto, right, so automatically it will change it, then I'll go with a, oh sorry, 800 it has gone, go to 60 we can see still it is at 2, 40 still the same,

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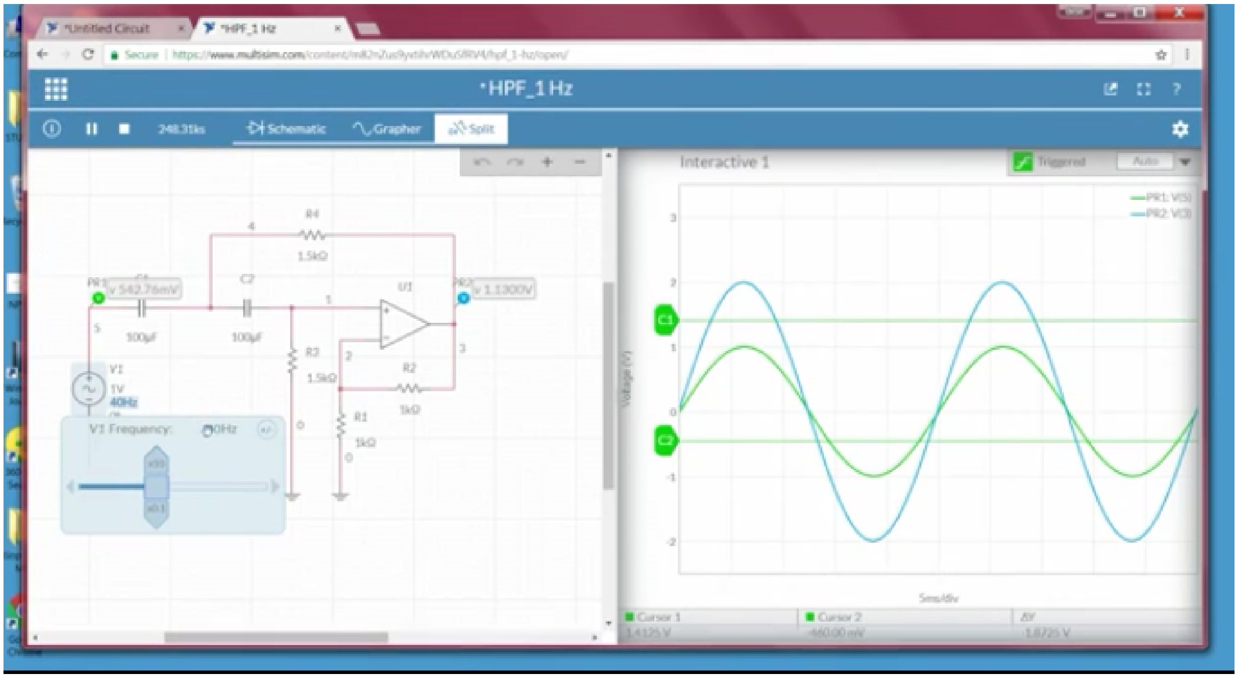

20 still the same, so since we have to observe even at a smaller values, smaller frequency I'll increase the time division, so easy to visualize.

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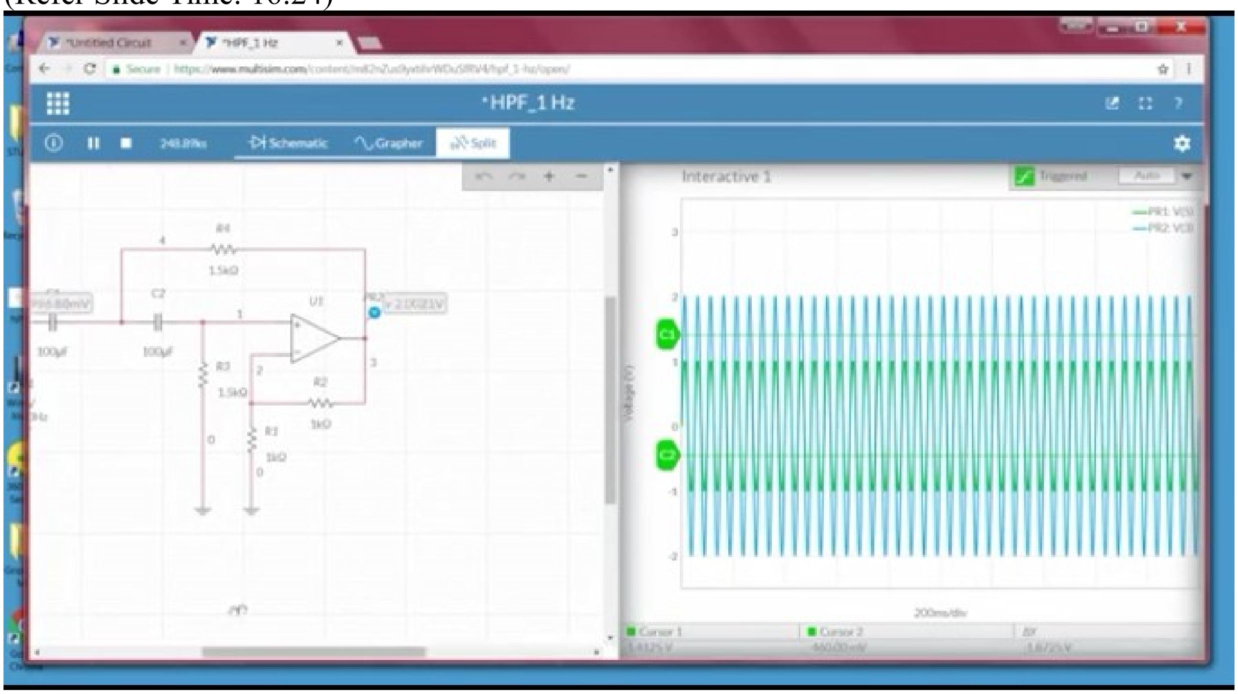

Then change the frequency slowly from here to 10 same, then slowly decrease 9.5, 7, 6, 5, 4, slowly decreasing it, now if you carefully observe when we observe our characteristics, whenever it is coming close to the cutoff frequency, the input amplitude is little higher, even here we can observe at this point, right, the gain should be 2, but slightly there is an higher gain at a frequency close to the cutoff frequency value, right that we have change, this is because of our Butterworth filter, it's a second order high-pass Butterworth filter isn't it? So when we remember our, recall our Butterworth filter characteristics the gain will be slightly increase near the cutoff frequency, right, so the same thing we can even observe here too, slowly decrease, again see whenever it is 1 hertz started decreasing it, 500 milli hertz it's even lower than that of our C1,

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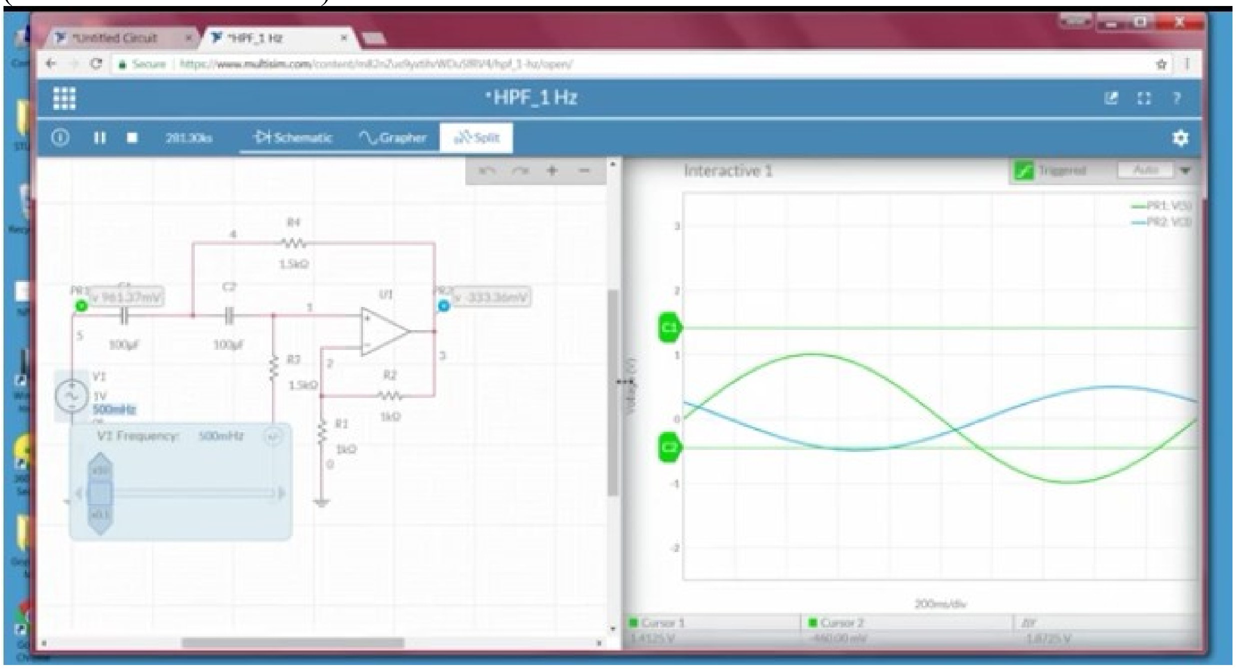

so that means the value is somewhere between 1 hertz to 500 milli hertz, so in order to understand what I'll do is that here I'll slowly increase to 600 milli, observe the value, no, then 0.7 hertz, 700 milli, not even close, go to 0.8705, sorry, 0.8 milli hertz coming close to that value, I'll go with the 0.9, right, so the cutoff frequency is somewhere around 0.8 to 0.9, now I'll decrease little bit 895, 870, 865 right, when I see somewhere around 825 to 830 milli hertz is the cutoff frequency of this particular filter,

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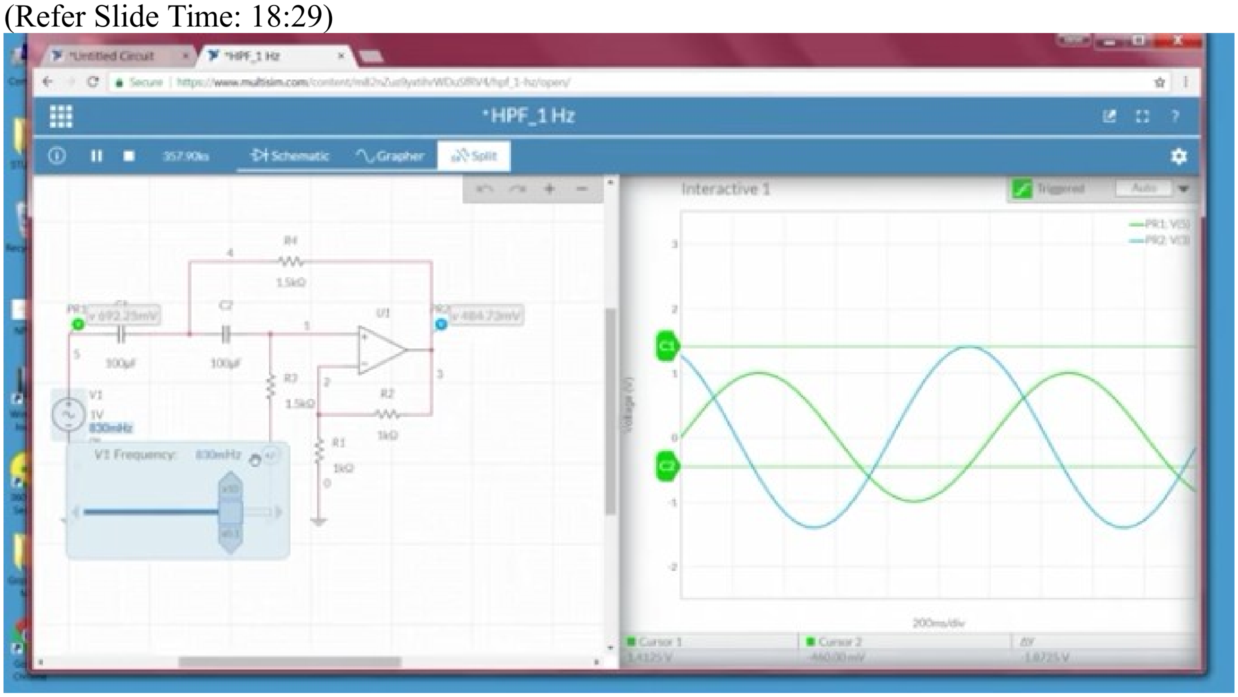

right, so this is the cutoff frequency.

But theoretically we got somewhere around 1.06, so because of the second order filter and that too it's a Butterworth filter, when we do the experiment, we got somewhere around 830 milli, right.

Now we will also look into, so I hope this is clear right now with the simulation, what we do is that we'll look into the board, we have already done the same circuitry using our breadboard, so we use the other part of the TL082, so previously we have seen low-pass filter, now we will see the high-pass filter on the same op-amp just next to that, but we are using the first side of an op-amp in this case.

Now when we look into our TA board here, TA board here so this part, this part, this part is completely high-pass filter circuit, so this part is high-pass filter this side, this side of an op-amp, this side is high-pass filter circuit, this is the low-pass filter circuit, if we can see two op-amps, sorry two capacitors here as well as different resistors, 4 resistance, 1, 2, 3, and one more here 4, so two resistors are for gain, and two resistors are for the filtering team.

And the input is nothing but, the input is, input should be given to the C1 and the output should be taken from op-amp output, so even in this case what we do is that so the board is right now switch 1, so now we'll replace input from here to the input side of capacitor, so this is the input side of capacitor, we've connected it to the capacitor, right, and output is 1 and this blue wire we will connect it to the same point, so we can see the input signal, input frequency in oscilloscope, and output connecting it to the first one, the first one is here.

Now when we look into the output,
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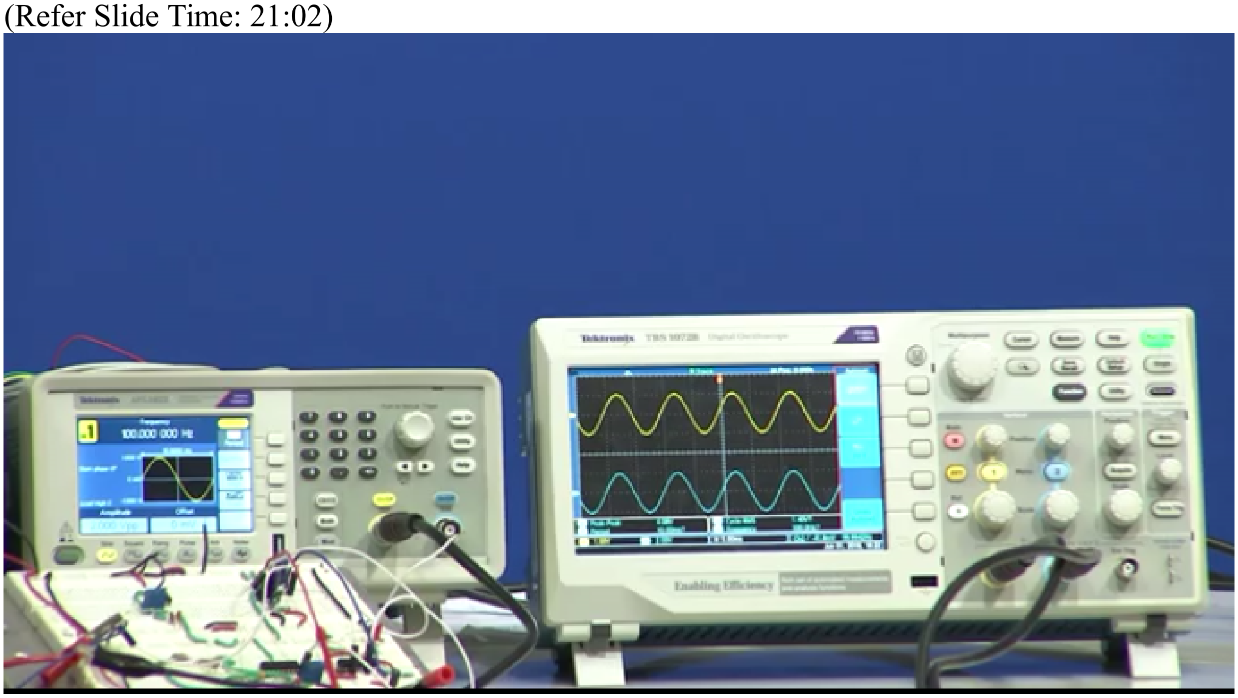

so right now the frequency that we have given as input to the op-amp is 100 hertz is the input frequency that we have given to this, then this is the output we got, so I'll put both the things to

the same point, so easy to understand right, and even this to little up to the, to zero-zero position,
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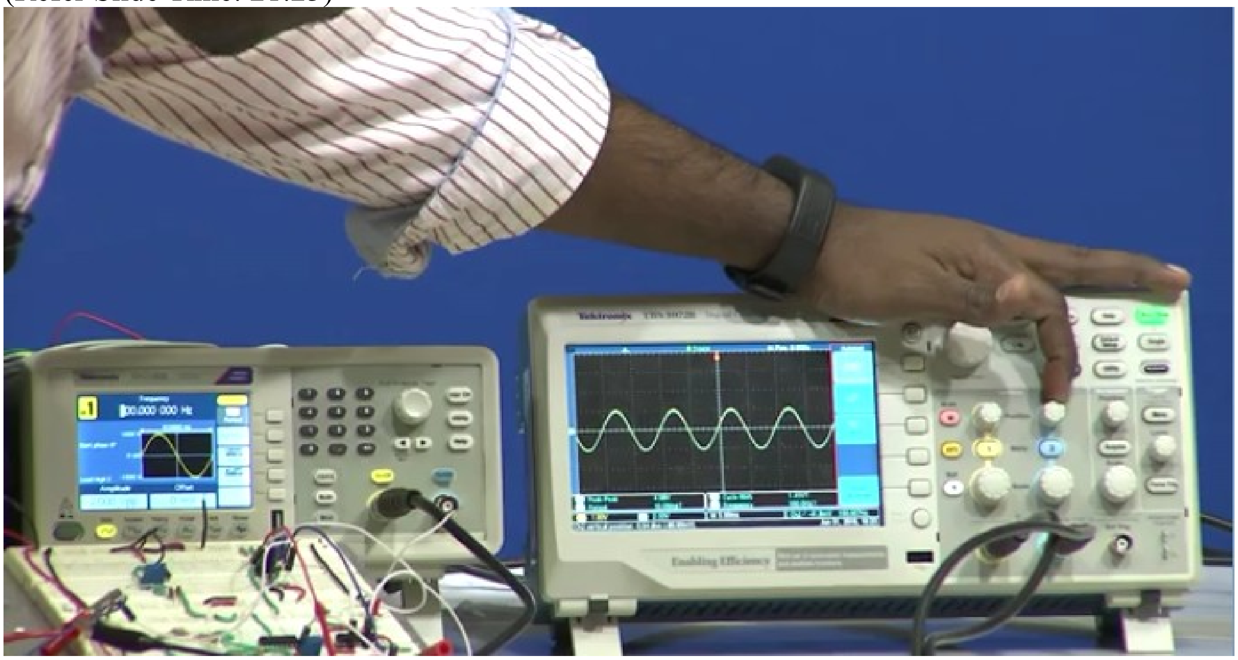

so both are right now at zero-zero position.

Now the scale if I observe, this scale is at 1 volt whereas this scale is at 2 volts, what have to do is that I'll increase, I'll put but scales at the same level, so that means one box even for the input as a first channel, as well as the second channel is one box = 1 volt, now if I observe that right here we can see, 1 volt and 1 volt, so what we can understand,
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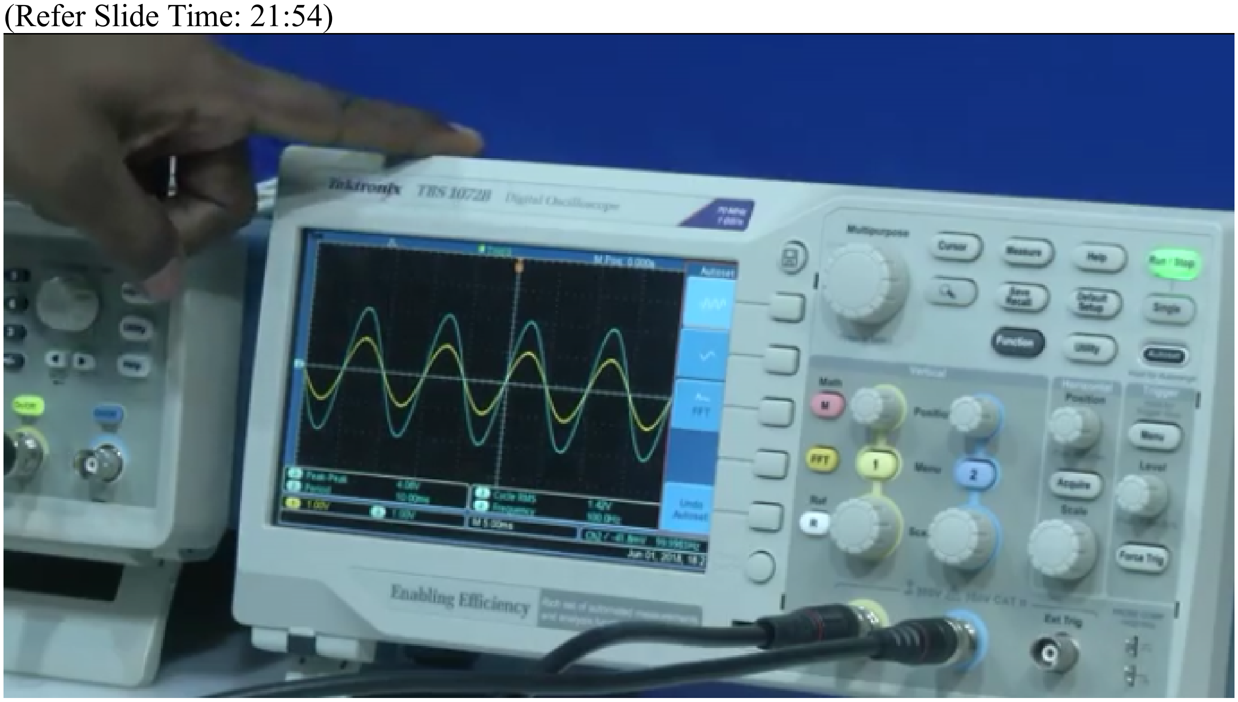

so we can see yellow is nothing but our input, and blue is nothing but our output, so what we can understand from the output, we can see that the input and output are following each other, that means there is no phase shift between your input and output, that is because of we are using second order high-pass Butterworth filter, right, the input is connected to the positive terminal, and because of that, because of the input is connected to the non-inverting configuration we do not see any phase shift.

Other one is the gain, since R1 and R2 resistor that which is of same value the gain is 1+R1/R2 which is nothing but, sorry R2/R1 which is nothing but 2, so we can see the amplitude changes double the amplitude of that of your input.

Now what we have to observe? We have to find out the cutoff frequency, see in order to observe our cutoff frequency what I do is that I'll create a cursor at a point of 1.414, right, so 707 into 2, so 1.414 because we have to create a 3DB line for our output voltage, output magnitude is 2, right, for 1 volt it is 0.707, for 2 volts it's 1.414, so I'll go with the cursor, I'll go as type amplitude, right, and let me put the cursor to 1.414, so if I observe here this is right now to 1.4, so I'll try to see whether it is possible to change it to 1.41, unfortunately it is not so what I'll do is that I'll fix it at 1.4,

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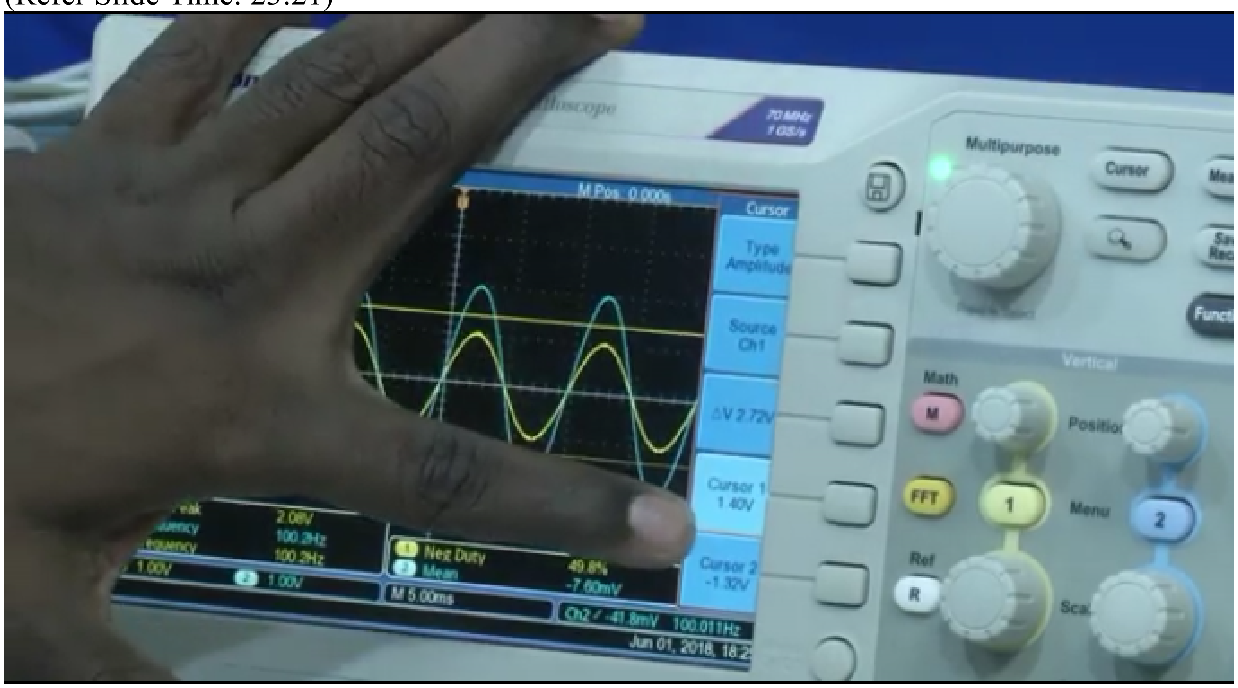

I'll slowly decrease, right now the frequency is at under hertz, right, so I'll slowly decrease at units of 20 hertz till we are at 20 hertz, after that we'll decrease to 10 hertz, then from 10 hertz slowly one by one, one by one will increase till we see the frequency at what, at what frequency the input voltage is lower than that cutoff point that we set.

So I'll set it to 80 right now, what I'll do is that go to frequency point and make it as 80 hertz any change in the output when you look into the oscilloscope, right there is no change in the output, then I'll go to 60 even now no change in the output, 40 even same, right, even the same, decrease it to 20 same, 10 same, now I'll slowly decrease, 9, but in a simulation we have observe that when the input frequency is getting close to 1 hertz we have also observed the output voltage is increased, we will also see whether a practicality it is that we can visualize or not, right,

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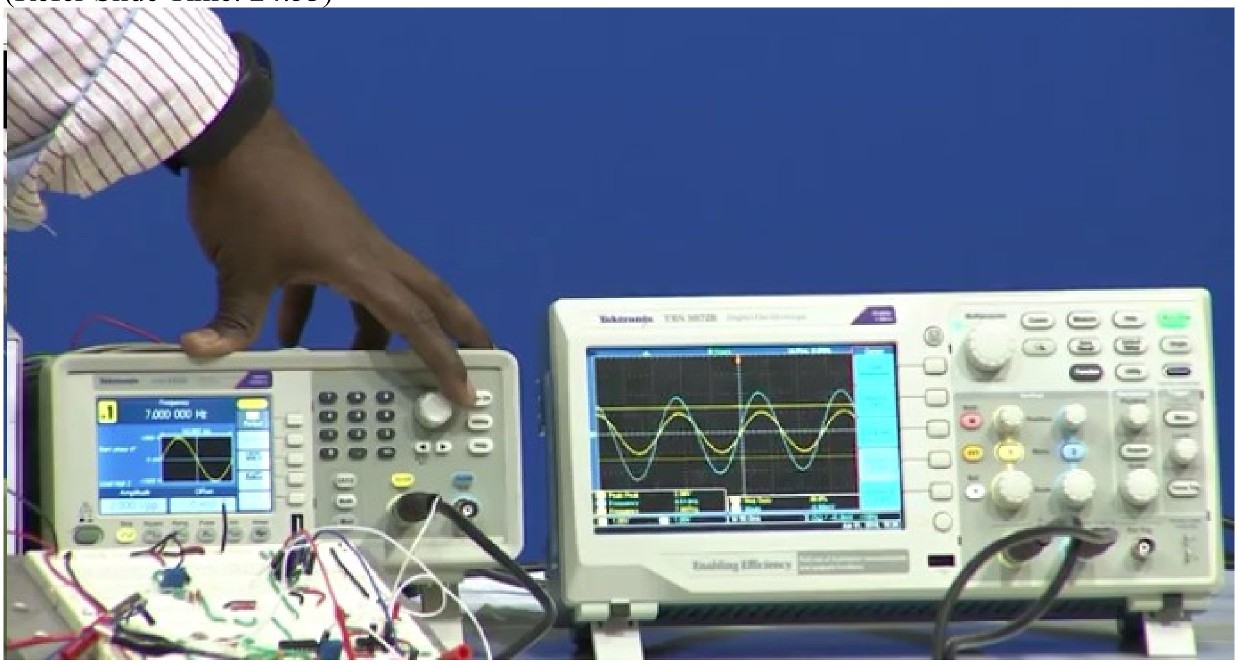

7, 6, 5, 4, 3, yes observe, still it is 2, okay, we are going to 2 hertz now yes,

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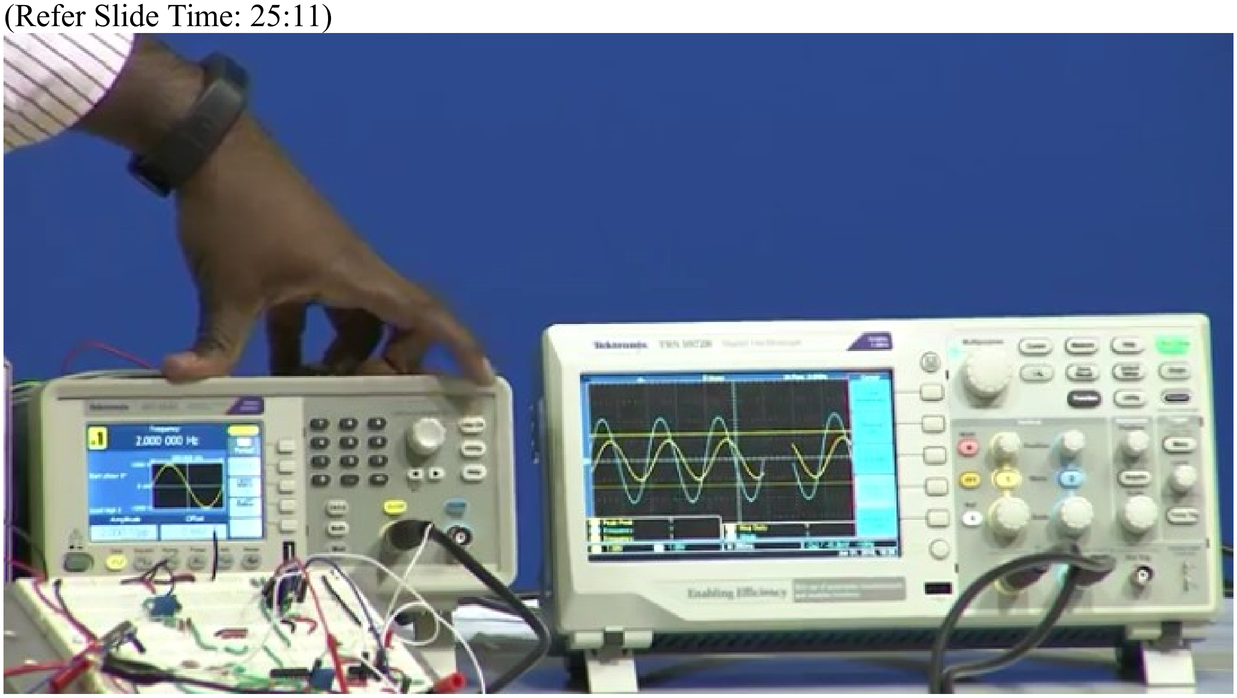

here if I observe so what I'll do is that I'll go to measure, I'll create channel 2 peak to peak value, so from the peak to peak value we can easily understand, sorry this is unable to measure, but that's fine, but we can see that the output value,

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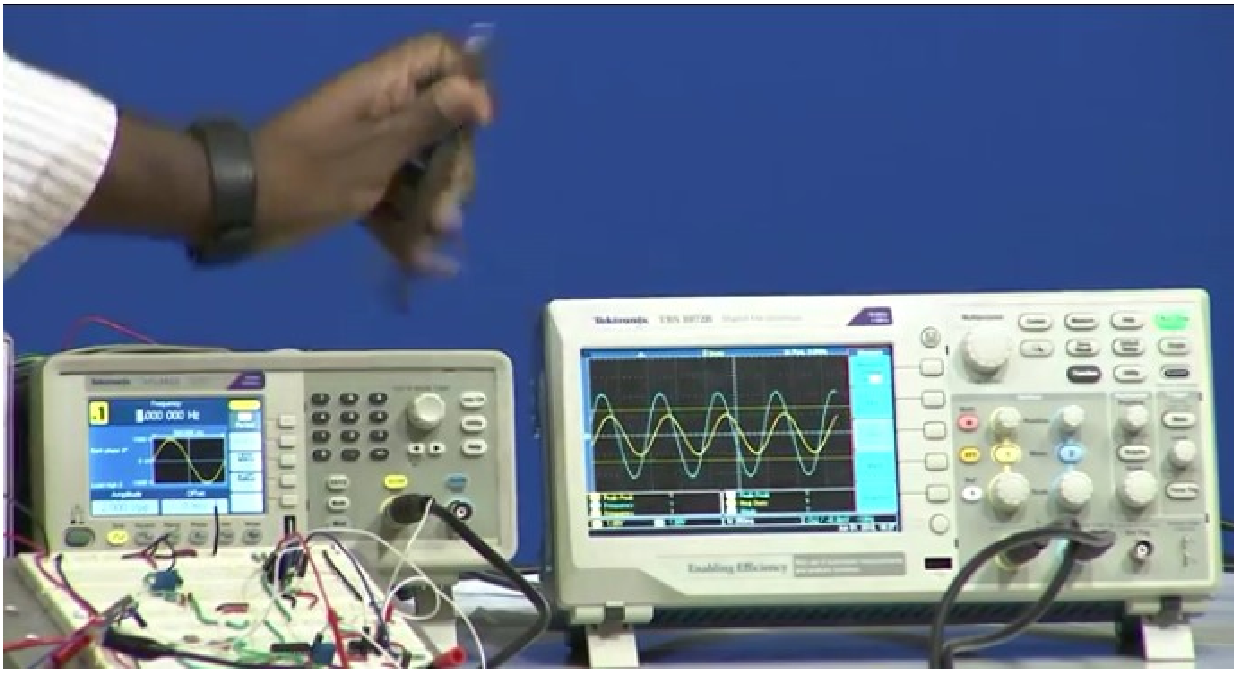

the blue colour one is slightly higher than this second box, right, so that means right we can see here it is slightly higher than this second box, that means the gain is increasing.

Now I'm coming to 1, now when it comes to 1 here we can observe that, so I'll decrease the scale, right, from when we look in,
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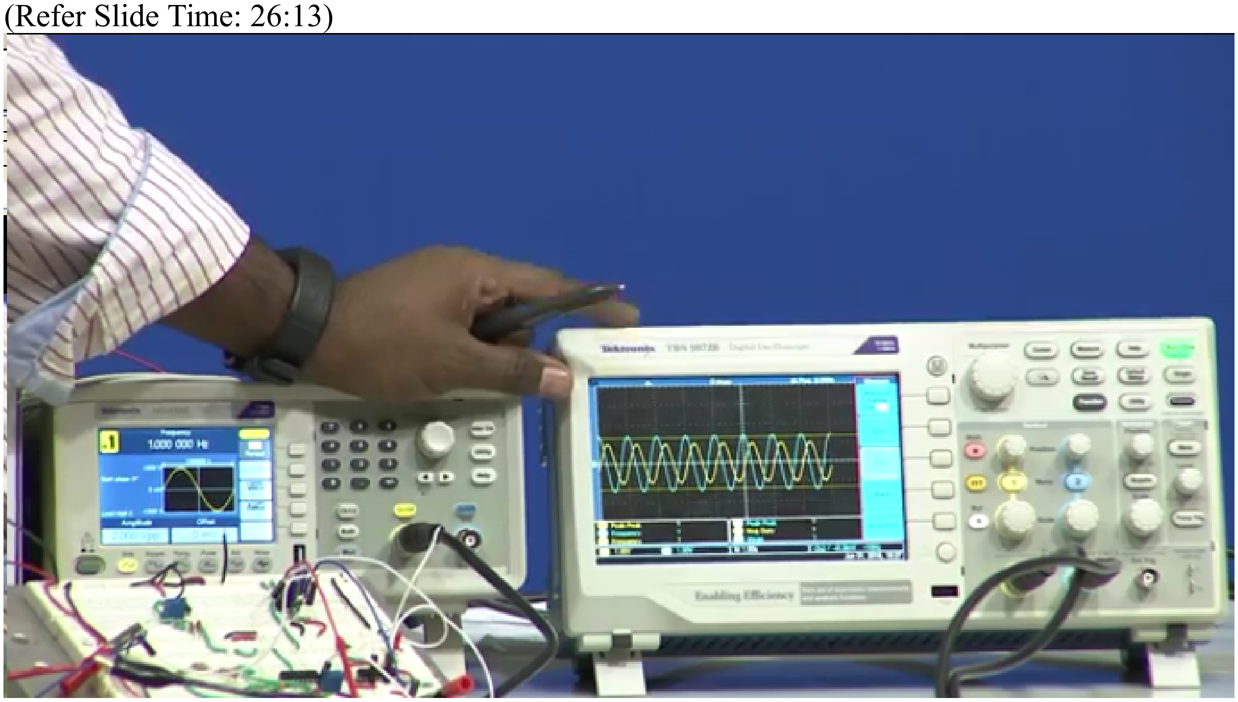

when we zoom the input towards the CRO here we can observe that the output is very close to that the cursor, but still it is higher, right, it is very close to the cursor,
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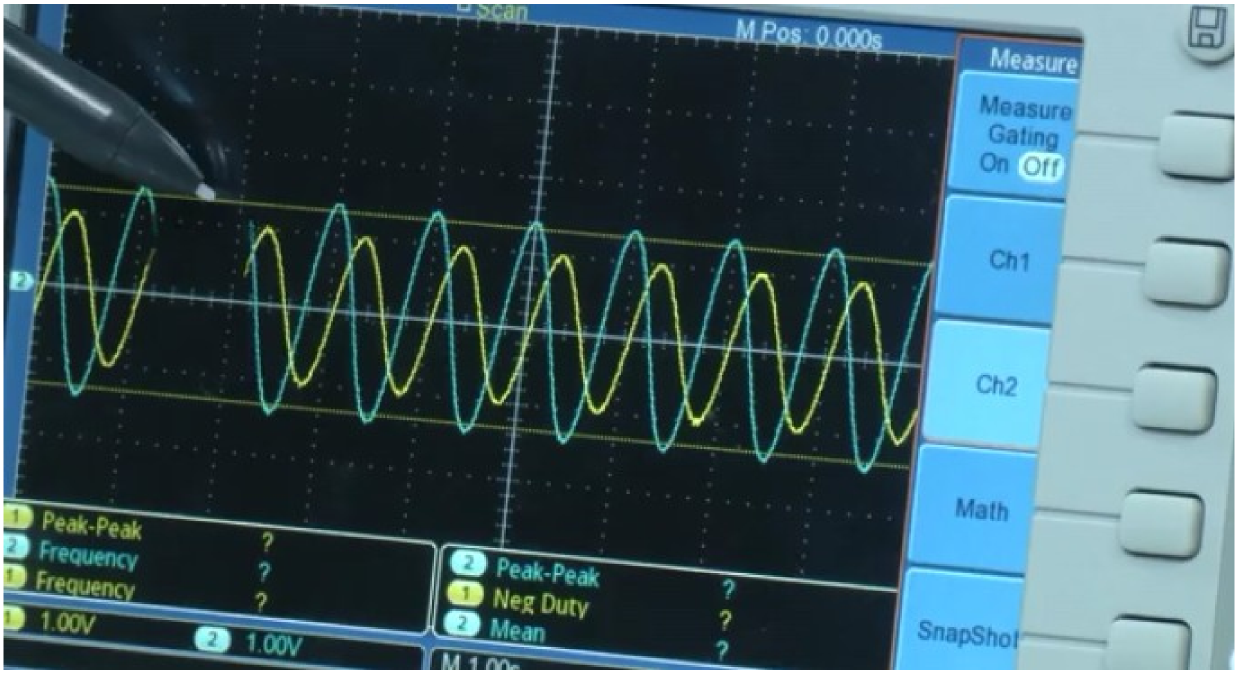

this cursor point is 1.4, right, so when you look into the cursor the cursor O it has been changed, it should be 1.4, right, so it is very close to the cursor value.

Now I'll slowly increase, let me see what will be the change, 1.4 hertz right now, 1.5, now when it is at 1.5 hertz the gain, when you zoom into that, the gain is higher than 2,
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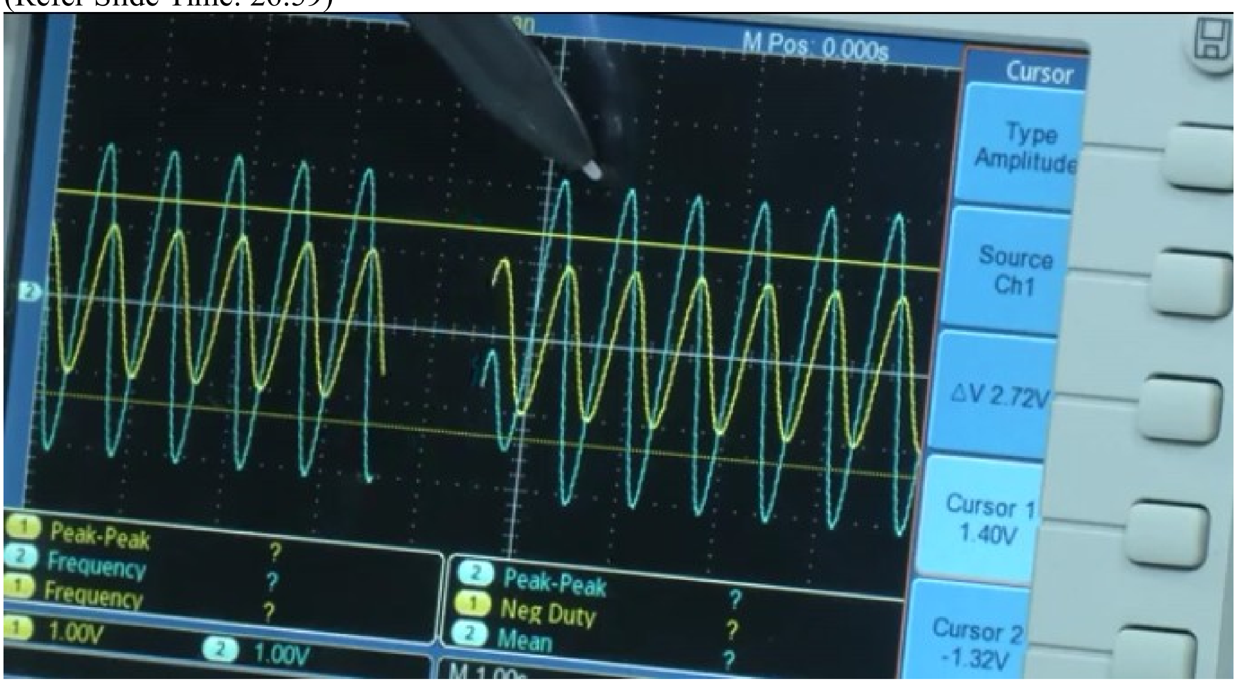

right, that is what even we have observed in our simulation to increase 6 even higher, right, 7 higher, and 8 even higher, so what I'll do is that I'll slowly decrease value, now we will observe at what frequency, right now it is 1.3, right now I'm setting at 1.1, so even at 1.1 hertz the input value is higher than the cutoff, like what you call that the cutoff value cursor point, which is at 1.4, slowly I'll decrease to 1 hertz.

Now suddenly it has move to 1.4 volts 3DB line, now I'll slowly decrease, we can see the output is below that cutoff, right, when I zoom into the oscilloscope we can observe that the output is below the cutoff

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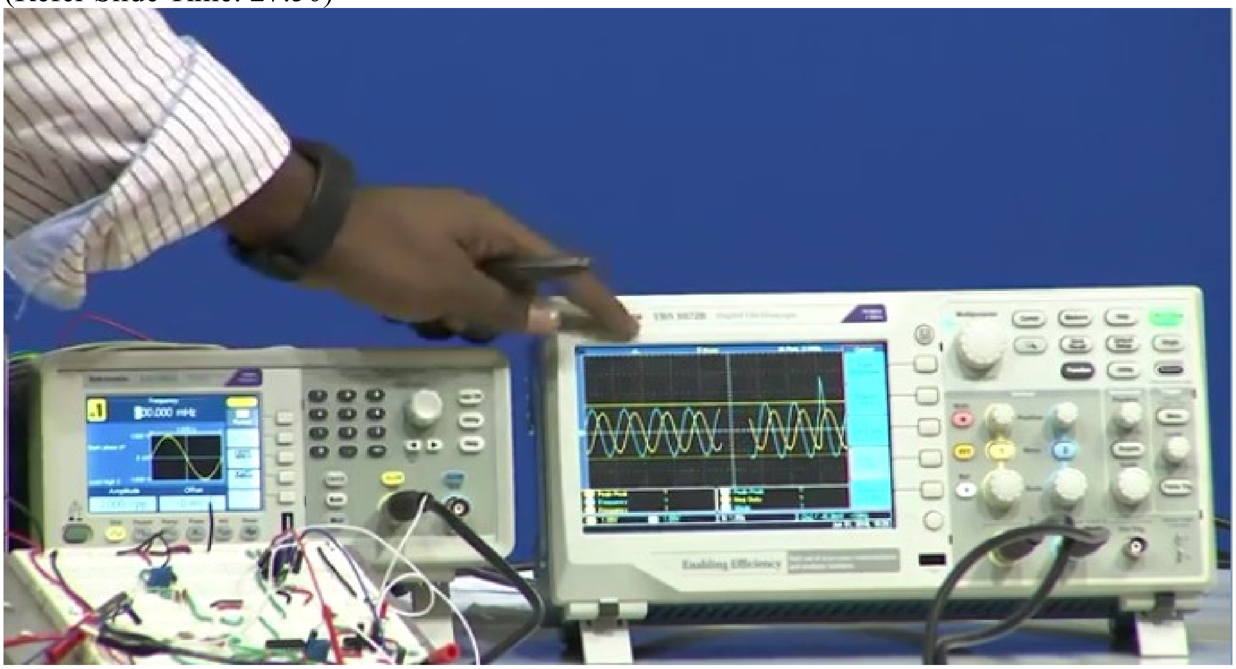

which means that 1 hertz, theoretically when I see, sorry theoretically we have seen that it is at 1 hertz even if the practical we can observe that it is at 1 hertz itself, right, but when I slowly decrease it, it is going below the cutoff value, even if I go even beyond lower value below that, so that means one thing we can clear that for a high-pass filter below the cutoff frequency the phase, sorry, the amplitude will be attenuating, it'll not be completely removed but amplitude will be attenuated, from the cutoff frequency and here we can clearly one more thing we can understand that since it is second order filter we can see the drastic change from 1 hertz to you know when we are decreasing from 1 hertz, right.

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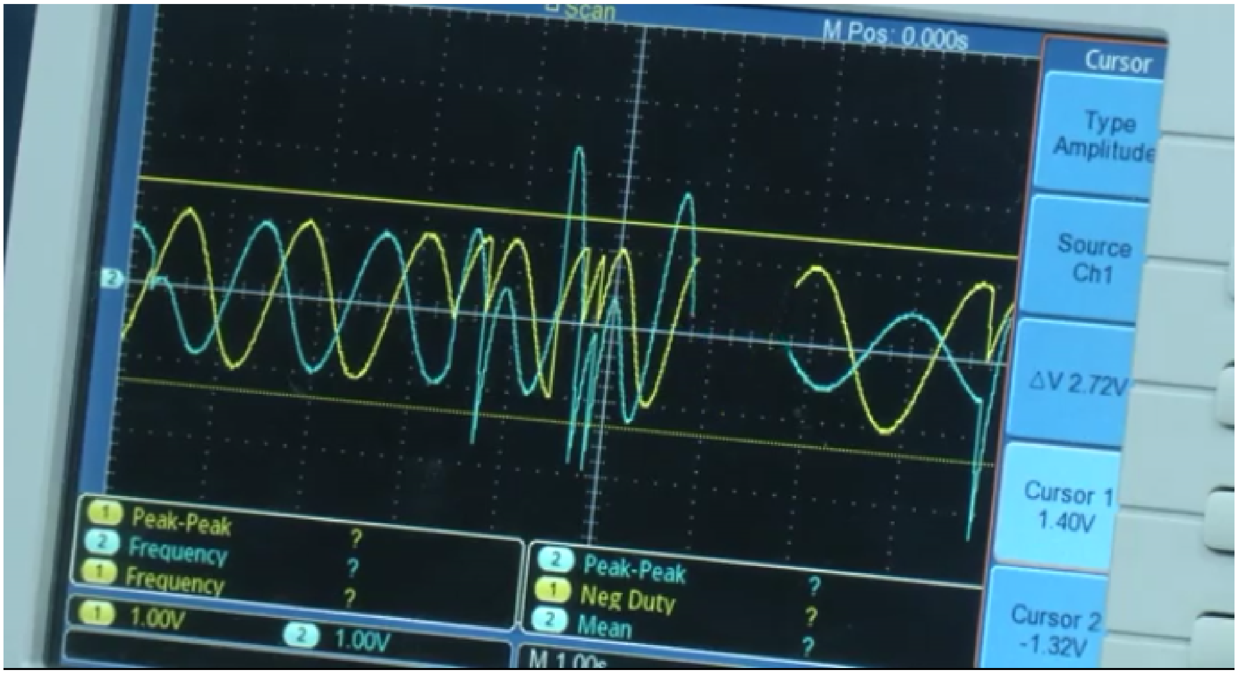

So I hope this is clear about our high-pass filtering, and the high-pass filter is also working as per our expectations, right. Now we'll stop at this point, we will see other filters in the next module. Thank you.