Op-Amp Practical Applications: Design, Simulation and Implementation
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Lecture – 34
Design and Implementation of ECG Preprocessing Stage: Part 3

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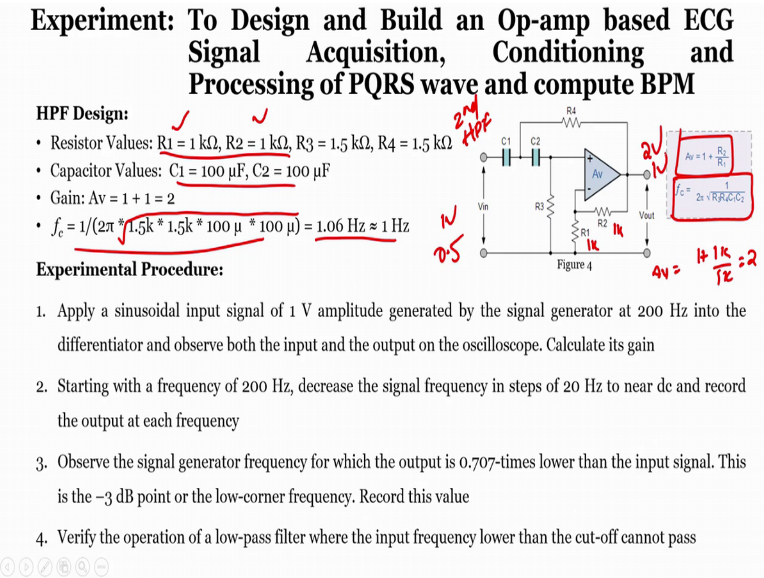

Now, so, previous one we have seen the first order low pass filter. Now this is our second order high pass filter right. Why this is called second order? When we see we have 2 combination of R and C capacitors, 2 combination of R and C pets right. So, one if I have one combination of C and R it is called first order high pass filter, if I have 2 combinations this is called second order high pass filter.

Now, because, we have a 2 capacitors and 2 resistors the cutoff frequency will be calculated as 1 by 2 pi into root of R 3, R 4 and C 1, C 2 right. This recall our high pass filtering the 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 a 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 plus R 2 by R 1. So, the resistance that we use, the values of resistors R 2 and R 1 that we choose decides the complete gain of the system right. So, in this case we required 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 a 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 1 by sorry, there is a wrong in the formula it is nothing, but 1 by 2 pi into root of root of R 3, R 4 and C 1, C 2.

So, in this case we have chosen R 1 and R 2 as 1 kilo and 1 kilo. So, when we you observe this is a 1 kilo ohm, this is 1 kilo ohm. So, when we calculate gain, gain is nothing, but 1 plus 1 k by 1 k which is nothing, but 2. So, if I apply 1 volt I will get an output as 2 volts, if I apply 0.5 I will get an output as 1 volt right. Apart from using R instrumentation amplifier some amount of gain can also be give can also be applied by using this operational amplifiers 2 right.

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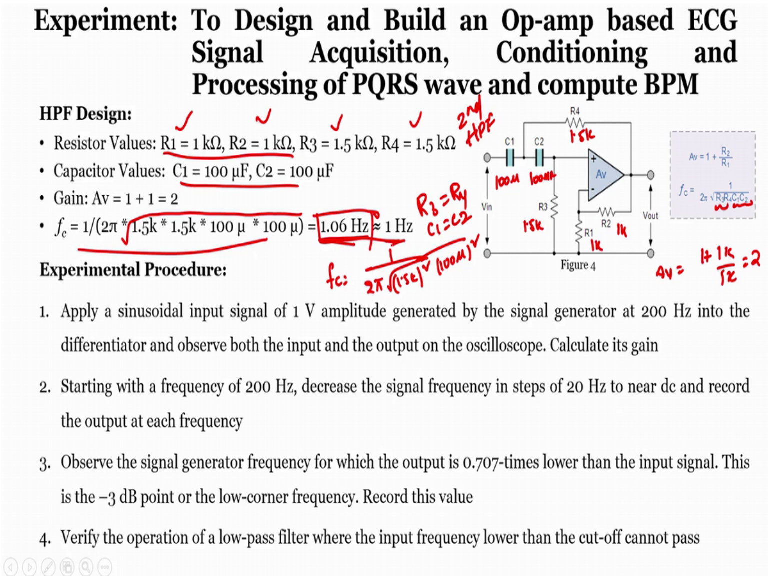

Then we have chosen R 3 and R 4 resistances 1.5. So, this is 1.5 k and this is also 1.5 k right, and what about C 1, C 2? So, both C 1, C 2 we have use 100 microfarad and this is also 100 microfarad.

So, when I calculate f c, f c is nothing, but 1 by 2 pi into root 1.5 k square into 100 micro square right because, R 3 is equal to R 4 in this case, as well as C 1 is equal to C 2. So, C 1 C 2 I can write it as C 1 square, R 3 R 4 I can write it is R 3 square. So, 1.5 k whole square and 100 micro square. So, when we calculate the value will be almost equal to 1 hertz the value we got it 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.

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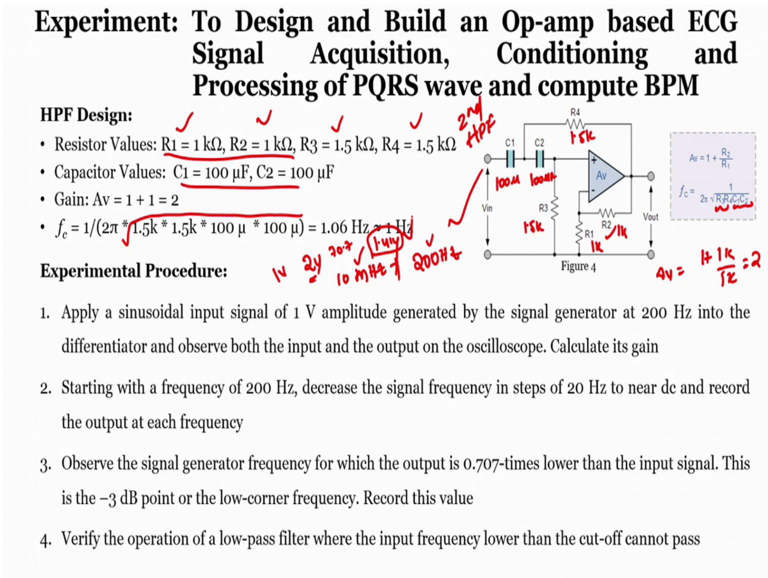

We will do the circuit design in a circuit design simulation software, we are using multisim, we will go with a multisim. We will use the same resistance values and capacitance values since, this is a cutoff frequency of 1 hertz will go from somewhere around 10 sorry 10 milli hertz to some greater than 100 Hertz, somewhere around 200 hertz also we can go right. Will slowly increase from this frequency to this frequency and we will use an input signal of 1 volt.

Now, since a gain is 2, will get an output as 2 volts that we also we can observe and as long as long as output is 70.7 percent 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 complete 18 Newton that is the 3 dB line**.**

So, when the input is higher than 1.414; that means, the signal is being past that is greater than are 3 dB line. So, that point wherever it is almost equal to 1.414 volts I can say this is our cutoff frequency right, this is a cutoff frequency of our high pass filter. Now, we will go to we will go to are simulation I will create one more circuit.

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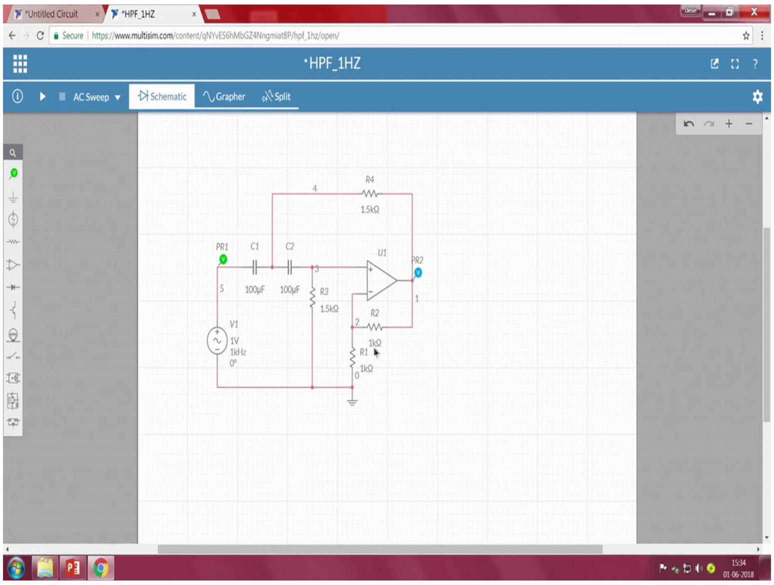

So, I will save this circuit as high pass filter. Save, name I will write it down as high pass filter and the cutoff frequency we are using is 1 hertz in this case so, 1 Hertz.

So, what we need? We need to use operational amplifier and taking operational amplifier and we are using 2 capacitors and 2 resistance. And what resistance value we have considered? When you see R 1 and R 2 R 1 and R 2 we defined here as a feedback and normal resistance right. This is R 1 and this is R 2. So, I will use the same resistance value as well as same R 1 the notations 2.

So, R 1 I am keeping it here and rotating it and I am also taking R 2 this is R 2, R 1 R 2 are same resistance value. So, I do not have to change the resistance, I will be connecting with you negative feedback right.

So, the gain, the input resistance and the gain resistance, 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 C 1 R 4 is one part C 2 R 3 is another part. So, I will take 2 resistors again. So, one is R 3 this is are R 3 resistance and the value that we choose is 1.5 k change it to 1.5 sorry this is we should be 1.5 k right. Then will choose one more resistor as a feedback which is a positive 1.5 k at this point and this terminal should be connected at this point and they should be connected at the positive terminal.

Now, what about the other one? Other one has to connected to ground, then what else I have to take capacitance. So, I will go with 2 capacitance, one is C1 and other one is C 2. So, the value of capacitance that we use is 100 microfarad 100 micro even here 100 microfarad.

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. So, with this combination of a circuit we can observe high pass filtering at a frequency at a cutoff frequency of 1 Hertz.

So, in order to observe that signal so, we have to connect the input source. So, I will take an AC voltage, I will connect it here and this is grounded. So, 1 terminal, 1 probe I will be connecting at the input. So, both the input and output I can visualize other one is at output side. So, this is a nothing, but are green colour represents the input signal and the blue colour represents output.

So, to visualize in a frequency domain I will 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 then you keep on changing your input frequencies at particular frequencies the system has already preprogram the such a way that it the input signal frequency will start from 1 hertz to the minimum frequency that you said to the maximum frequency that to set within 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.

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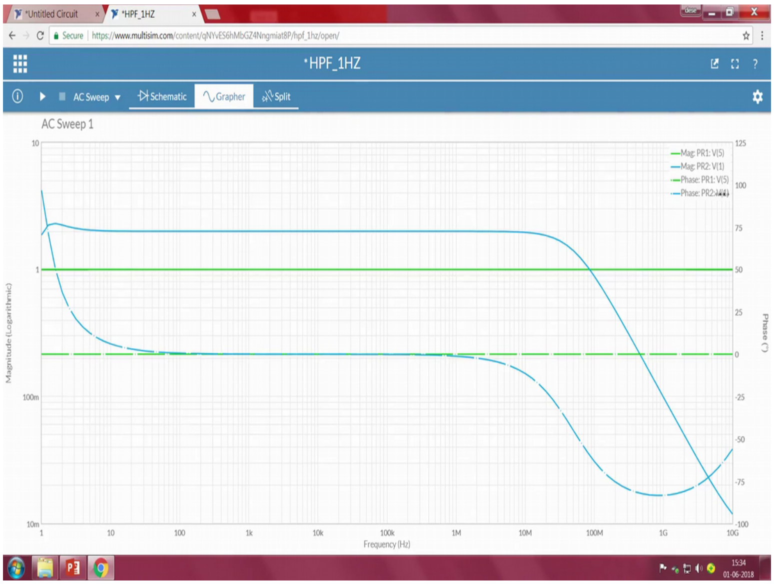

So, I will go to the grapher, let me run it we can see the signal now. So, since you also have a phase I do not want to look into the phase. So, I will remove both the phases. Now, here we can see input is green right and output is this one, isn't? Now, what I need? The input frequency and this frequency; so, this I will make it as 200 whereas, this I will make it as somewhere around 0.01 Hertz.

So, in this case for the sweep configuration I have change the some setting parameters, we change the start frequencies 0.1 hertz and the stop frequency as 1000 hertz here and the points per decade is 10. 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 it.

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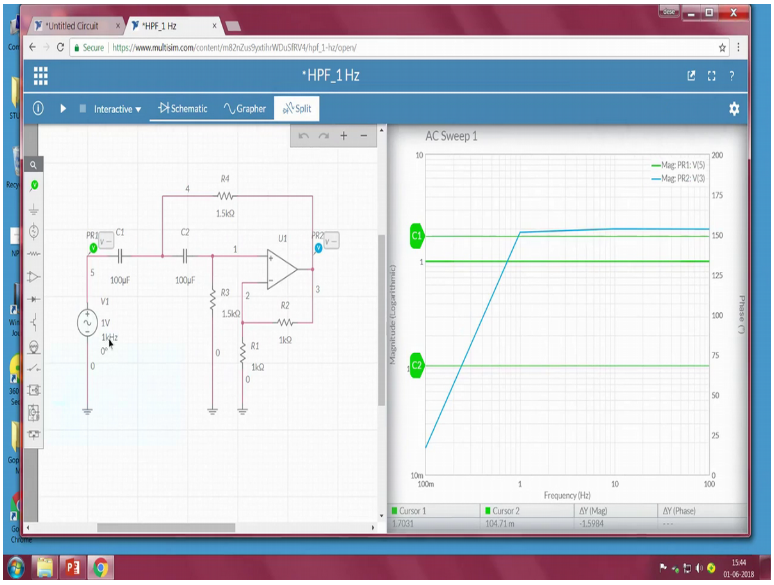

So, in this case even if we observe the input is green and output is blue. So, what I will do is that I will change since, I may not required both the phases, I will remove the both the phases, I have both the magnitudes, I am making cursors temporally of right now.

So, observe carefully hear the green indicates are input signal and the blue indicates are output signal right. Now, so this is a logarithmic scale the magnitude is completely logarithmic here we can see the magnitude is completely logarithmic. And the green is that 1 dB 1 magnitude, but what about the blue? Why it is in 2 Db? If we remember correctly the gain of an Op-amp is 2. So, that is a reason the output is having double than that of the output of magnitude is double than that of the input magnitude.

Now, what about at different frequencies, when you see no matter what it 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 2 dB. 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 it is cutoff frequency. Now, if I want to visualize what I will do is it I will take a cursor. I will go with an amplitude cursor y axis cursor and I will put C 1 at 1.7 right because, that 3 dB line is nothing, but 3 dB 2 our maximum amplitude. Maximum amplitude is 2 so, 2 minus 3 dB so, the magnitude should be 2 minus 0.3, it should be somewhere around 1.7 right.

So, I will keep somewhere around close to 1.7 value 1 point minus 1 point sorry this is C 1 1.8 sorry. So, I will be keeping close to 1.7 that is our 3 dB magnitude of minus 3. So, here this point is nothing, but our so, when I observe that 3 magnitudes. When you observe that this is very close to the 1 hertz right or one way to look into that is rather than going into this we can go to interactive session interactive. And we will split it let me closes, will split it will change the frequency from 0.1 hertz itself right let me run it.

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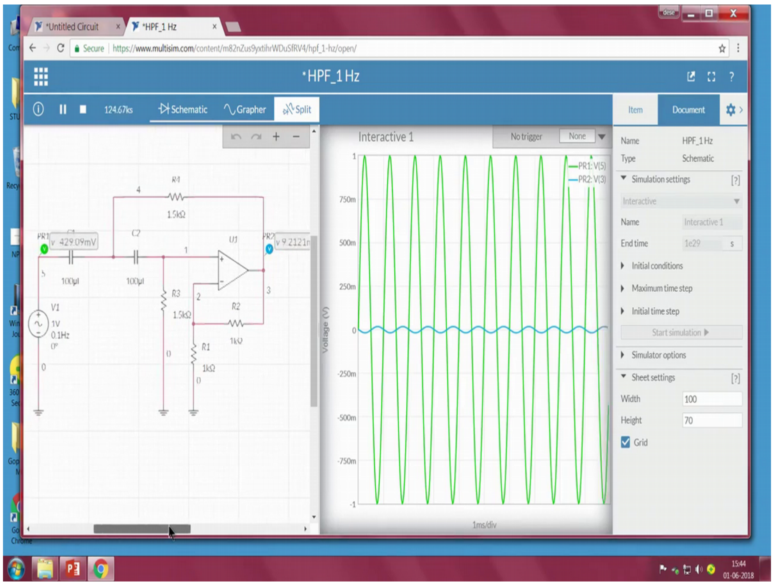

So, we will change the settings to right. So, what is happening? Now, the peak voltage that we get is nothing, but 2 volts right as we know that. So, in order to understand that what I will do is that, rather than going with a low high value will go from lower value. So, make it has 100 Hertz.

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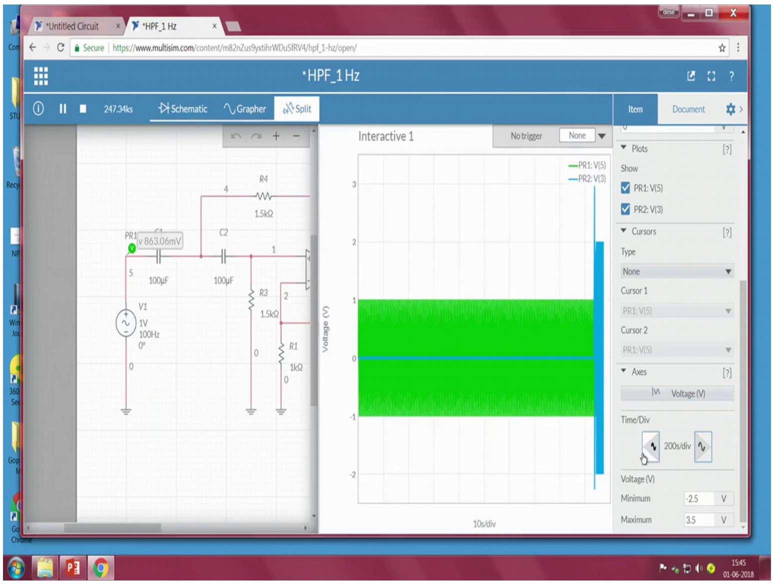

Now, go to the settings so, we can see 2 2 2 volts to 2 volts I will increase I will decrease the time division so, that we can see the signal. From here we it is clearly observed that the input is green colour, output is blue in colour, the peak to peak value is 2 volts, the input signal where as output 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 will create a cursor so, cursor should be put at. So, I will take y axis cursor the amplitude cursor and these are should be place it 1.414 volts. So, I will be moving this cursor will move the cursor y axis cursor to 1.414. If we observe here this is at 1.6 slowly to 1.41 to approximately 1.41.

So, whenever the input voltage so, what I will do right now, right now I am at 100 Hertz, I will slowly decrease from 100 hertz to 10 milli Hertz. So, at what point at what frequency the input is equal to that this C 1 threshold is nothing, but are my cutoff frequency.

So, what I will do? I will decrease slowly with a factor of 20. So, go with 80 I am going with 80 so, I will make it as auto right. So, automatically it will change it then I will go with a 6 sorry 800 it has gone, go to 60 we can see still it is a 2, 40 still the same, 20 still the same.

So, since we have to observe even at a smaller values smaller frequency I will increase the time division. So, easy to visualize then change the frequency slowly from here to 10 same, then slowly decrease 9.5 7, 6, 5, 4 slowly decreasing it.

Now, if we 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 the frequency close to the cutoff frequency value right, that we have seen. This is because of our Butterworth filter, it is a second order high pass Butterworth filter is not it.

So, when will 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 to. Slowly decrease again see when are it is 1 hertz started decreasing it. 500 milli hertz it is even lower than that of our C 1. So; that means, the value somewhere between 1 hertz to 500 milli Hertz.

So, in order to understand what I will do is that here I will 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 will go with the 0.9 right.

So, the cutoff frequency somewhere around 0.8 to 0.9. Now, I will 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 right. So, this is the cutoff frequency, but theoretically we got somewhere around 1.06, why do not we calculate the value?

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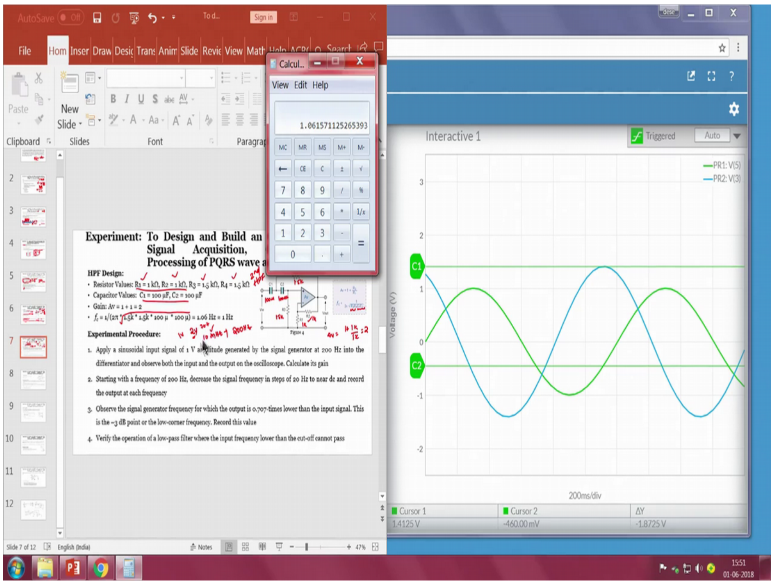

So, I have I will take a calculator. So, since square root and this is square I can cancel it down. So, I will calculate 1 divided by 2 into 3.14 sorry into 1.5 into 100 right the value is 0.00106.

Now, we have kilo and micro right. So, since it is a square root it will be left with k and micro. So, it will be 10 power minus 3 when we take it top it will be 10 power 3. So, if I multiply with 1000 into 1000. So, the values one point this is so, whatever we have written was right. So, because of the second order filter and that it is a Butterworth filter, but theoret when we do than experiment we got somewhere around 830 milli right.

Now, we will also look into so, I hope this is clear write know with the simulation, what we do is that will look into the board we have already done the same circuitry using our bread board.

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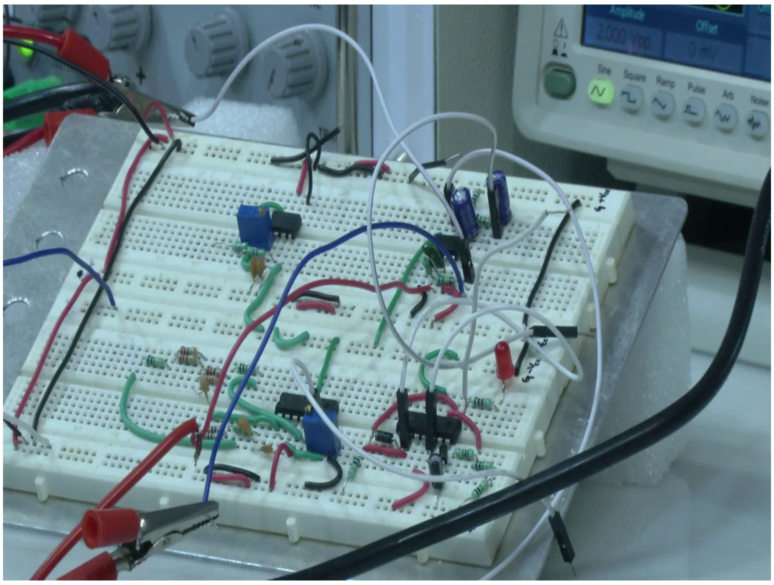

So, we use the other part of the TL082. So, previously we have seen low pass filter now we will see the high pass filter on the same Op-amp just next to that, but we are using the first side of an Op-amp in this case.

Now, when will look into our TA board here so, 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 a low pass filters circuit. If we can see 2 Op-amps sorry 2 capacitors here as well as different resistors, 3, 4 resistance 1, 2, 3 and one more here 4. So, 2 resistors are for gain and 2 resistors are for the filtrating. And the input is nothing, but the input is input should be given to the C 1 and the output should be taken from Op-amp output.

So, even in this case what we do is that so, the board is write now switched 1. So, now, you will replace input from this, from here to the input side of capacitor. So, this is the input side of capacitor you have connected to the capacitor right and output is 1. And this blue wire we will connected 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.

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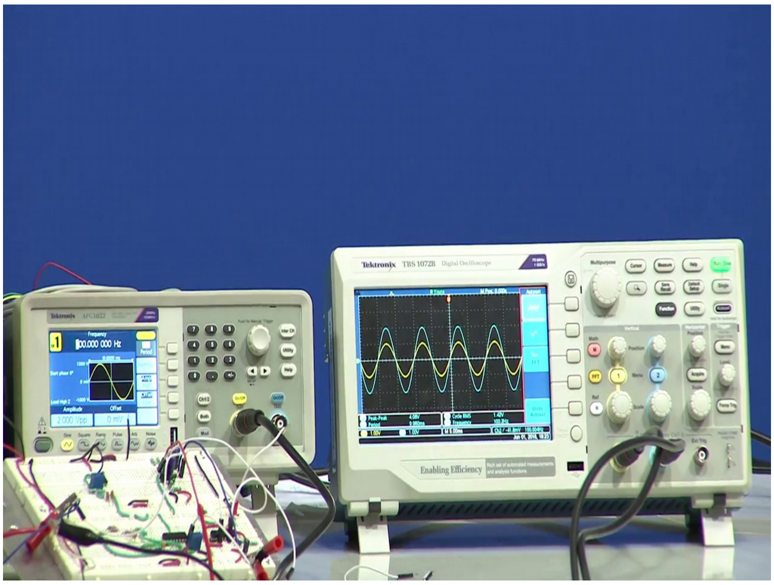

Now, when we look into the output so, write now the frequency that we have given as an input to the Op-amp is 100 hertz is the input frequency that we have given to this then these output we got. So, I will put both the things to the same as point. So, easy to understand right and even this too little up to the 00 position.

So, both are right now at 00 position now, the scale if I observe this scale is at 1 volt where as this scale is at 2 volts. What have to do is that I will increase I will put both scales at the same level. So; that means, 1 box even for the input as a first channel as well as a second channel is 1 box equal to 1 volt.

Now, if I observe that write here we can see 1 volt and 1 volte. So, what we can understand? 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, that there is no phase shift between here 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 R 1 and R 2 resistor that which is of same value the gain is 1 plus R 1 by R 2 which is nothing, but sorry R 2 by R 1 which is nothing, but 2. So, we can see the amplitude change of double the amplitude of none 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 will create a cursor at a point of 1.414 right so, 707 into 2. So, 1.414 because, we have to create a 3 dB line for our output voltage, output magnitude is 2 right. For 1 voltages 0.707, for 2 volts it is a 1.414.

So, I will go with a cursor, I will go as type amplitude right and let me put the cursor to 1.414. So, if I observe here this is right now at 1.4. So, I will try to see whether it is possible to change it to 1.41 unfortunate it is not. So, what I will do is that I will fix it at 1.4. I will slowly decrease right now the frequency is that under hertz right.

So, I will slowly decrease at a units of 20 hertz till we are at 20 Hertz, after that will decrease to 10 Hertz, then from 10 hertz slowly one by one will increase till we see the frequency at what frequency the input voltage is lower than that cut off point that we set.

So, I will set it to 80 right now, what I will 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 will go to 60, even now no change in the output. 40, even same right even the same decreases to 20 same, 10 same.

Now, I will slowly decrease 9, but in a simulation we have observed 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 practical it is that we can visualize are not right. 7, 6, 5, 4, 3, yes observe still let us 2 we are going to 2 hertz now. Yes, here if I observe so, what I will do is that I will go to measure I will 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 is fine, but we can see that the output value 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 am coming to one now when it comes to one here we can observe that. So, I will decrease the scale right from when we look in when we zoom the input towards the CRO here we can observe that the output is very close to that the cursor right, but still it is higher right. It is very close to the cursor, this cursor point is 1.4 right.

So, when you looking to the cursor the cursor, it has been change it should be 1.4 right. So, it is very close to the cursor value now, I will 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 when you zoom into that the gain is higher than 2 right. That is what even we have observed in our simulation 2, increase 6 even higher right 7 higher and 8 even higher. So, what I will do is that I will slowly decrease value.

Now, we will observe at what frequency right now it is 1.3 right now I am sitting at 1.1. So, even at 1.1 hertz the input value is higher than the cutoff the cut like what you call that the cutoff value which cursor point which is at 1.4. Slowly I will decrease to 1 hertz now, suddenly it has moved to 7 0 1.4 volts 3 dB line.

Now, I will 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 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 that 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 will 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 have decreasing from 1 hertz right.

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

Thank you.