INDIAN INSTITUTE OF SCIENCE

NPTEL

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

Welcome to the module, in last module we were discussing about ECG signal conditioning and signal processing using operational amplifiers. So to continuation with our previous module, so in last module we have also discussed about what are all the factors that influence our output ECG signal, and what processing steps that we are doing in order to remove the unwanted signals those are available in the ECG.

In this module we will see the other type of filtering unit which is essential in order to remove unwanted signal in that, so last module we have sign high-pass filtering, low-pass filtering, and what frequency to be used we discussed in the last module. In this module we will see a notch filtering which is used to remove the power line interference and we will be using a narrow band notch filter the reason is that we require only to remove 50 hertz signal and anyway the odd multiples of the power line interference was removed by using low-pass filtering, so our range of, the complete interest is in the range of removal of 50H signal, that is due to our power line interference or the operating frequency of our systems, or as a AC input signal.

So since we are not interested in any other frequencies, if we can design, if we can design a notch filter with narrow band with that interest, the removal interest is only 50 hertz it will be really great, even if it is not as long as our QRS detection is able to do that as long as if you design a filter which cannot remove the actual requirement of our input signal, our job is done.

So now we will see how do we do the notch filtering using operational amplifiers, how to verify the functionality of the system and what all the connections that we are making it, right, and experimentally as well as simulation wise so we will see the frequency response as well as in the time domain response to understand whether the notch filter is filtering at the 50H frequency or not, okay.

So similar to that of our previous filtering modules even in this case we'll be using an active filters the reason is because of very high input impudence due to the operational amplifiers the output impudence and the gain is easy to set using our operational amplifiers.

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Design and Build an Op-amp based ECG Signal Acquisition, Conditioning and Processing for Computation of BPM

Notch filter Design:

- $f_o = 1/(2\pi * R1 * C1) = 1/(2\pi * 12\ M * 270\ p) \approx 50$ Hz
- R1 = R2 = 2 R3
- C1 = C2 = C3/2

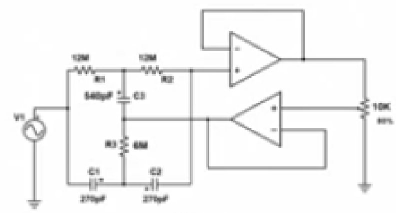

Figure 5

Experimental Procedure:

1. Apply a sinusoidal input signal of 1 V amplitude generated by the signal generator at 50 Hz into the filter (Vin)
2. Observe both the input and the output voltage on the oscilloscope
3. Change the input frequency from 30 Hz to 80 Hz in steps of 10 Hz and record the output at each frequency
4. Observe the signal generator frequency for which the output is 0.707-times lower than the input signal. This is the -3 dB point. Record this value
5. Verify the operation of a Notch filter

Now when we look into our experiment to design and build an op-amp based, ECG signal acquisition, conditioning and processing of free care compute BPM, we will see how to do the notch filtering using the operational amplifiers here, so if you see as we know the, how you know the importance of a notch filtering and application if you see and we also know how to use a passive notch filter in circuit, it's similar to that of our passive notch filter, so we are using two different resistors which are 12 mega and 12 mega, and capacitors C1 C2 which are all 270 picofarad, and other resistor 6 mega and 540 picofarad.

Now what makes us to select this particular values, so since our interest is completely on elimination of 50 hertz signal, if we can calculate our cutoff frequency as we already know the way to calculate our cutoff frequency is 2 pi R1 C1, so when we substitute the value of the capacitor as well as a resistor, so we get approximately of 50 hertz, and the selection of R2 and

R3, R1 R2 R3 should be such a way that, so R1 and R2 should be same, I followed R1 R2 to be same as well as even C1 C2 be same.

Similarly the relation between R2 and R3 is R3 value should be double than that of our R2 value as well as, sorry, R2 value should be double than R2 and R1 values are double to that of our R3 values, so that's a reason since we are selecting R1 R2 as 12 volt mega, so R3 should be of 6 mega, and similarly C3 value should be double than C1 and C2 values, so we are taking C3 capacitors somewhere around 540 picofarads, right.

Now how do we test the circuit? So similar to that of our previous thing, we will connect our input from the signal generator which is of an amplitude of 1 volt, and since if you observe here op-amps are just used to provide some buffering or some impudence matching, so we are not using any kind of a gain in this case, so when you apply input signal of 1 volt we get an output also as 1 volt, so when you keep on change our input signal from 1 hertz to somewhere around 100 hertz.

Why do we not to go with below 1H and why do we not to worry about more than 100 hertz? The reason is that we've already, this particular chase of filtering is comes after passing through high-pass filtering and low-pass filtering, and we already know that the high-pass filtering, the cutoff frequency is somewhere around close to 1 hertz, and low-pass filtering cutoff frequency somewhere around 100 hertz even though when you are looking for the frequencies lower than that as well as higher than that which are not in our interest we don't have to even test our circuit in that operation line, so the complete area of interest or the complete frequency of our interest is between 1 hertz to 100 hertz frequency.

And this particular circuit is designed to remove the narrow band of 50 hertz, so since 50 hertz is also between this particular frequency, the purpose and the requirement can be completely monitored using this particular range of frequency.

And when we apply input, we'll slowly change different frequencies from 1 hertz to 100 hertz with a factor of 10 hertz in steps, and we'll see observe at what particular frequency the output amplitude is 0.707 times lower than that of the input signal, that 0.707 times is because of our -3DB point, so if we can calculate the -3DB point or if we can know at what frequency that the output is smaller than 0.707 milli times smaller than of the input that particular frequency gives us the information of our cutoff frequency of our notch filter, right.

Why this is called notch filter the reason? As we know that when we see the frequencies, this is how the representation of our notch filter, this particular frequencies will be completely allowed, as we already seen in our other modules,
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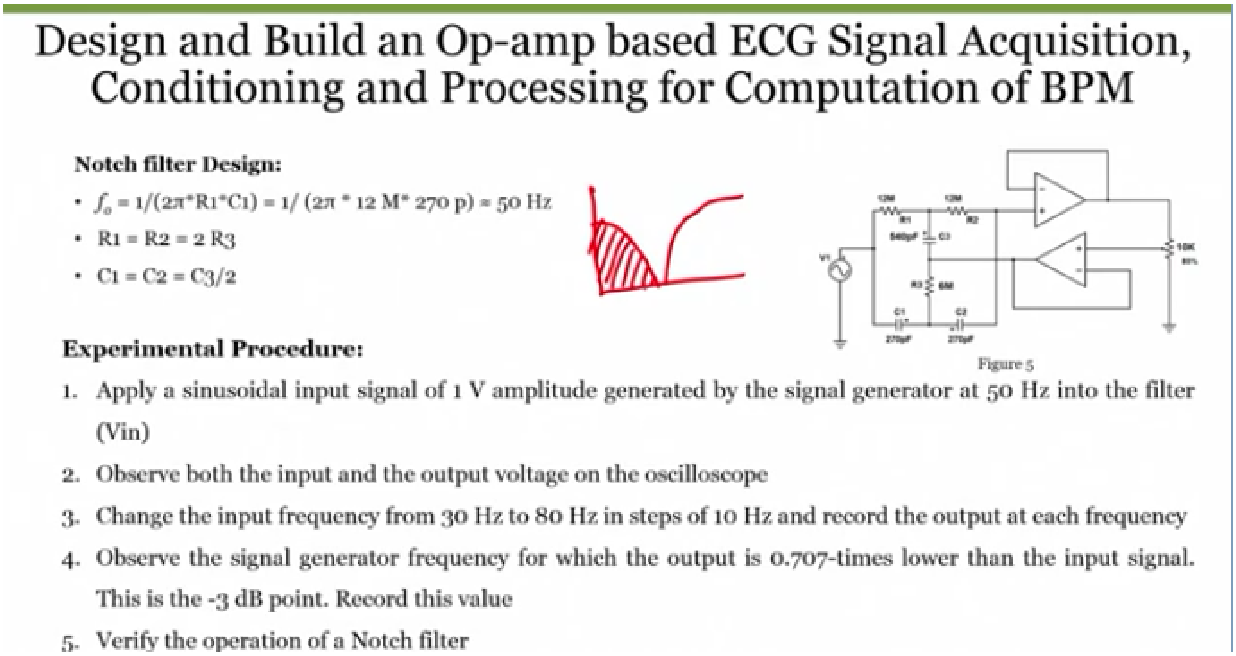

and this particular frequencies is also completely allowed, but this particular frequency which is nothing but a center frequency are this particular band of frequencies will not be allowed, that's a reason it is called notch,

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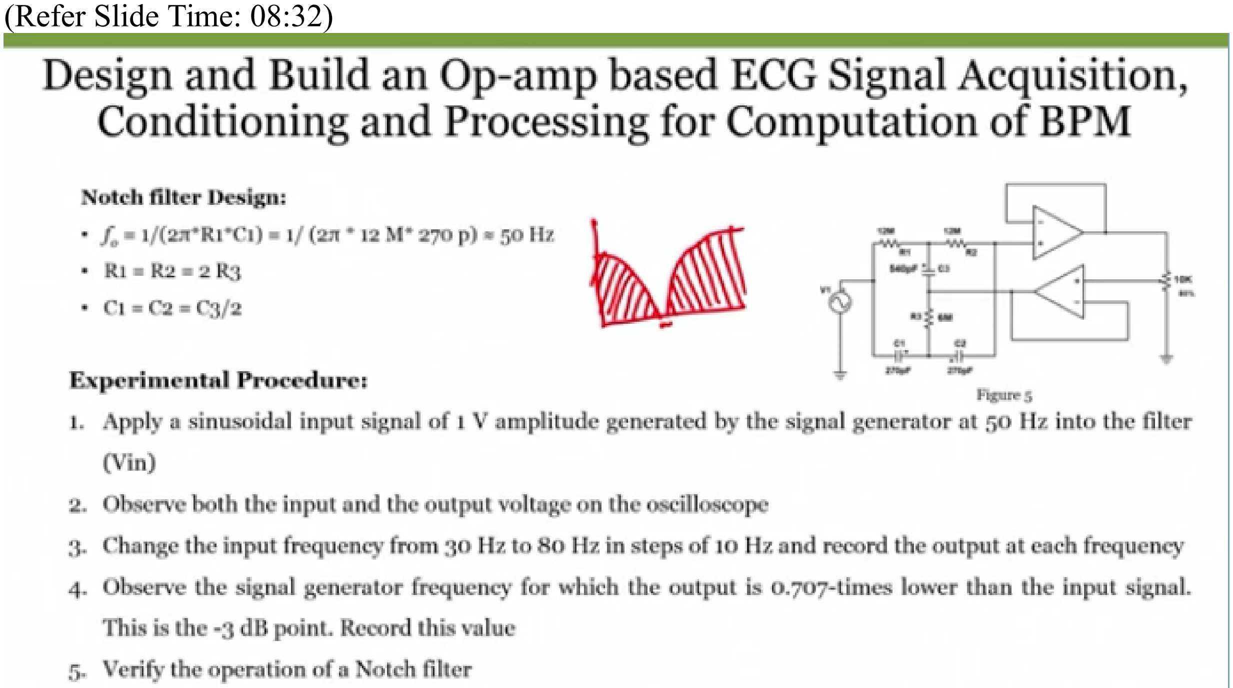

that particular notch, that particular band is not allowed, rather than that particular band all other frequencies are allowed. Not allowed in the sense it is nothing but attenuated, we cannot say completely remove, we can say attenuated.

Now we'll see the simulation of how exactly the notch filter works by designing the same, the same filter right, and output will be taken at this point, okay. Now if you see that as similar to that of our previous experiments how we have done, so we will go to multisem, we'll try to design the same so we'll take 3 resistors and 3 capacitors, if you remember correct R1 and R2 should be double than that of our R3 values, so what I will do is that I'll take 3 resistors, the value of this is 6 mega, so I'm replacing the resistance with 6 mega, and other resistors should also be 6 mega sorry 12 mega, 12 mega, and 1 resistor should be 6 mega, so this should be 6 mega resistor, and let me delete this, so easy to create, then other one should be 6 mega, R3 resistance should be 6 mega.

Now we also require 3 capacitances, so capacitor 1 C1 I'm saying it as which is nothing but 270 picofarads, 270 pico then 2 capacitors and the value of capacitors should be half of that of our C3 capacitor, so C3 capacitor somewhere here, right, and the value of this should be double than that of our C1 and C2 capacitor which is 540 picofarad, so whatever they required, resistors, capacitors, we have arranged here and the only thing left is connections, so the passive elements connections will do now, then we'll move with our active elements required, right,
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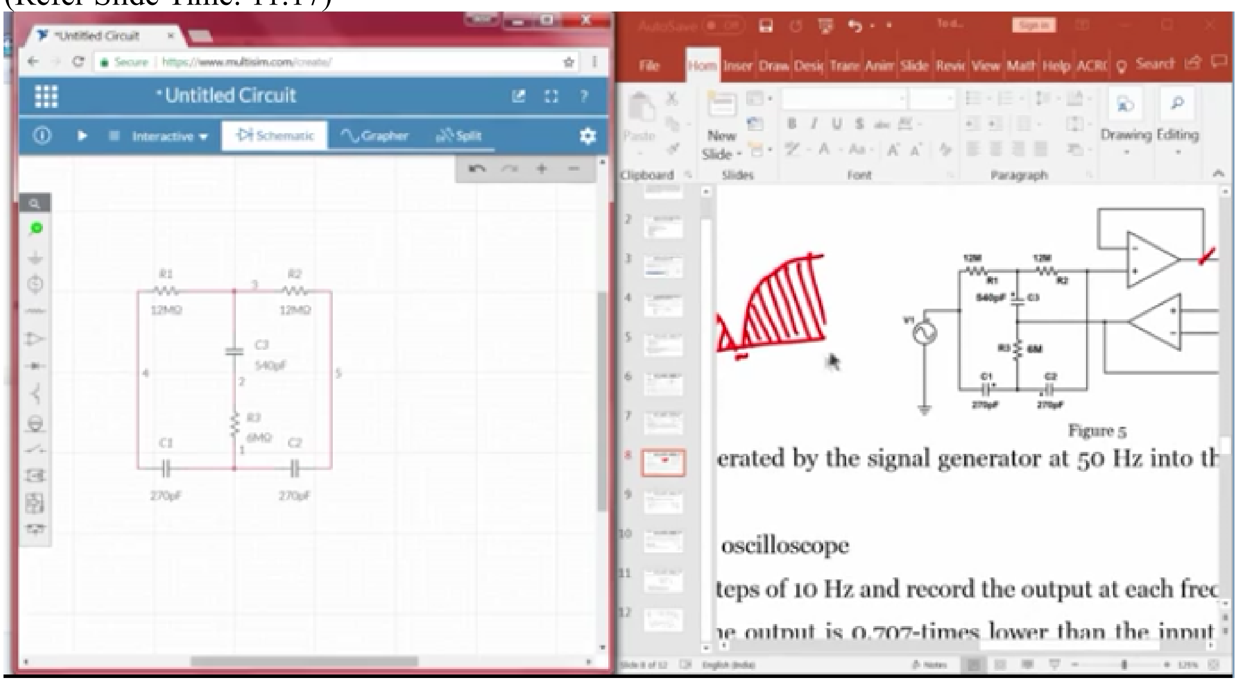

so which looks similar to that of our circuit if you observe here, right.

Now the input should be connected at this point so what I'll do is that I'll take AC voltage connected here, and other terminal should be connected to the ground, so we are expect, we are thinking to take a resistance value, sorry, the voltage source with an amplitude of 1 volt peak value, so peak to peak we can select it as 2 volts to, right,
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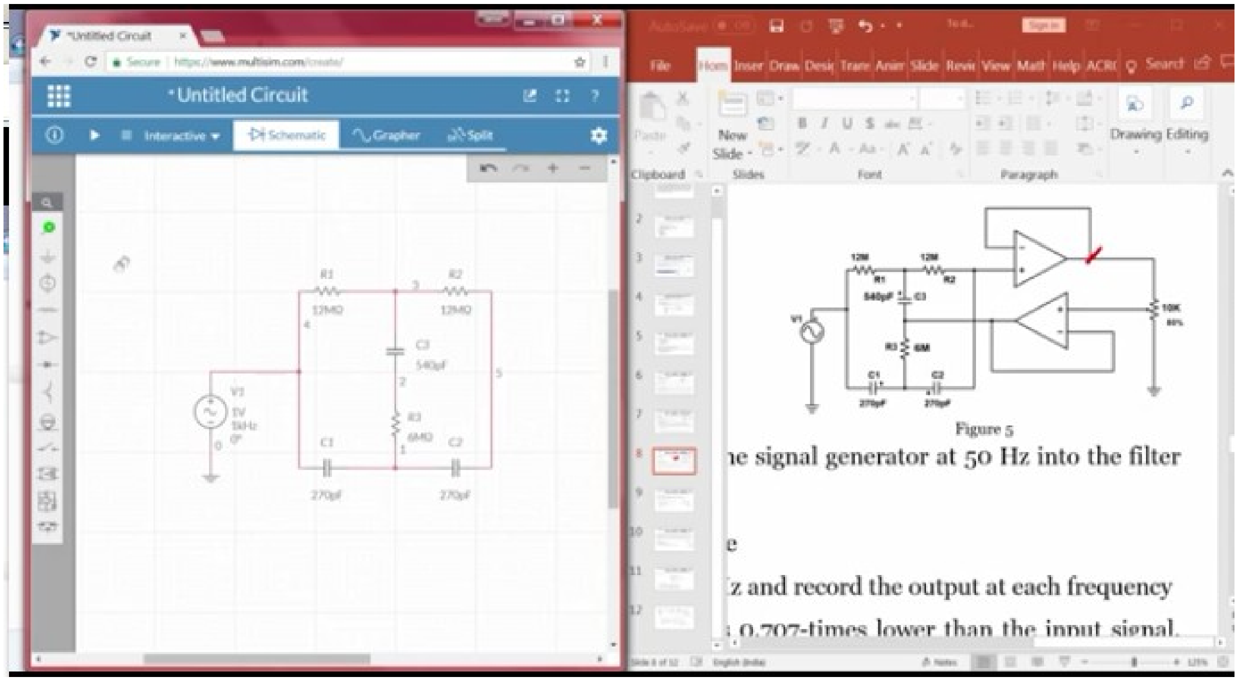

so it’s easy to understand relatively it is easy to understand our output voltage, so and we need 2 op-amps, so 1 op-amp we are taking it here and as the purpose of this op-amps are one is to provide and you know impudence mismatching, other one is to provide some offset to the system, so what we do is that, we will flip the op-amp so the op-amps looks similar to that of our the connections, we’ll look similar to that of our connection that we see in their circuit board, right.

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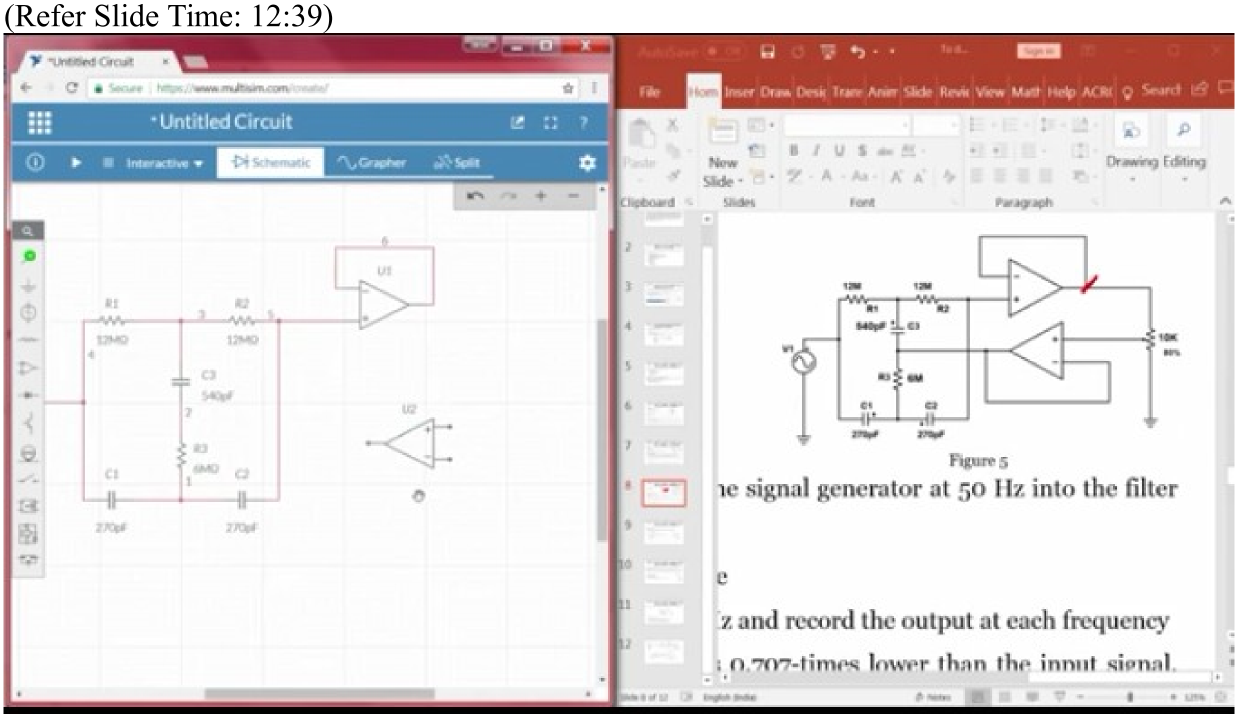

And we’ll take one more op-amp, rotate it, okay, so this one should be connected to the second point, the junction of C3 capacitor and R3 capacitor, and one part we’ll take potential meter, so the output some percentage is passing through R input, so this particular terminal has been connected here, right,

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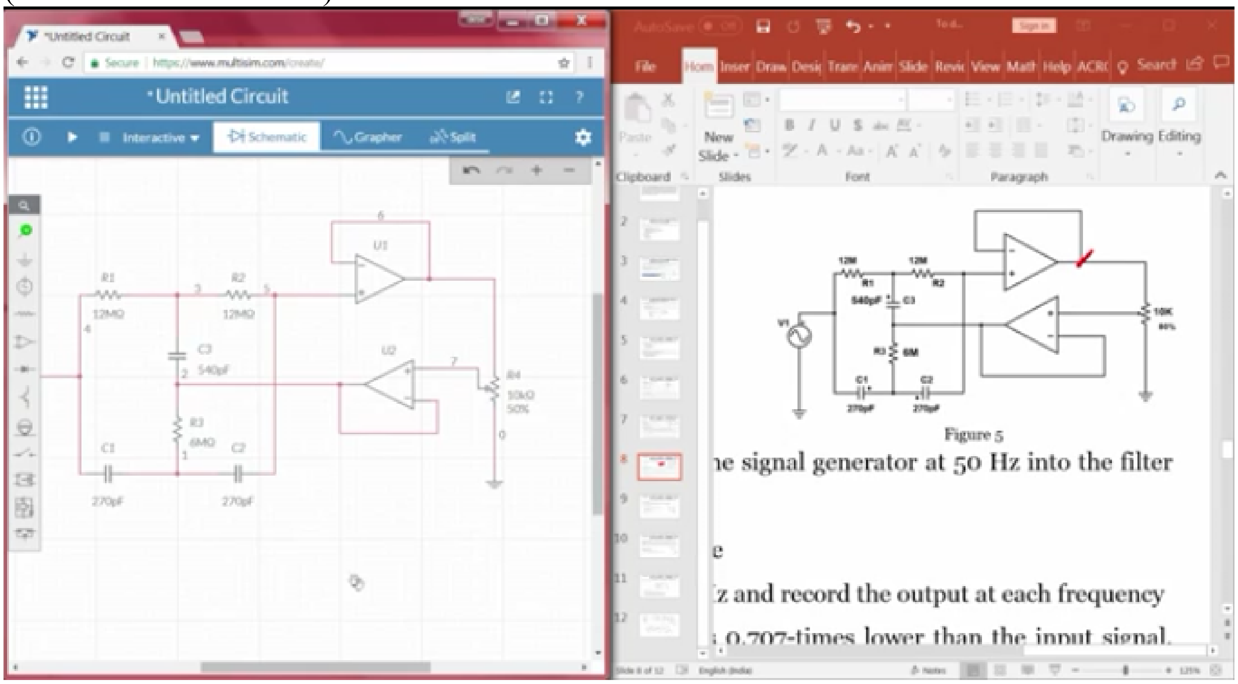

so you made the connections whatever we required.

Now we’ll test for the similarity, so as we are following the frequency analysis in order to see how exactly the frequency domain looks like, so as remember the notch filter will pass a frequencies from 1 hertz to somewhere around you know except the narrow band frequencies it will pass all other frequencies, so in order to verify we’ll go to AC sweep, we’ll keep some settings here, 1H and the soft frequencies we may not required up to 1 E power then so we’ll go up to somewhere around 200 hertz, and the decade value will say points per decade, 10 points per decade, then logarithmic scale, then start simulation, but in order to visualize we have to put our voltage points to 1 green, indicates our input voltage and blue represents our output voltage, so when we start our simulation and we look into the grapher, one thing is clear that if you clearly observe,

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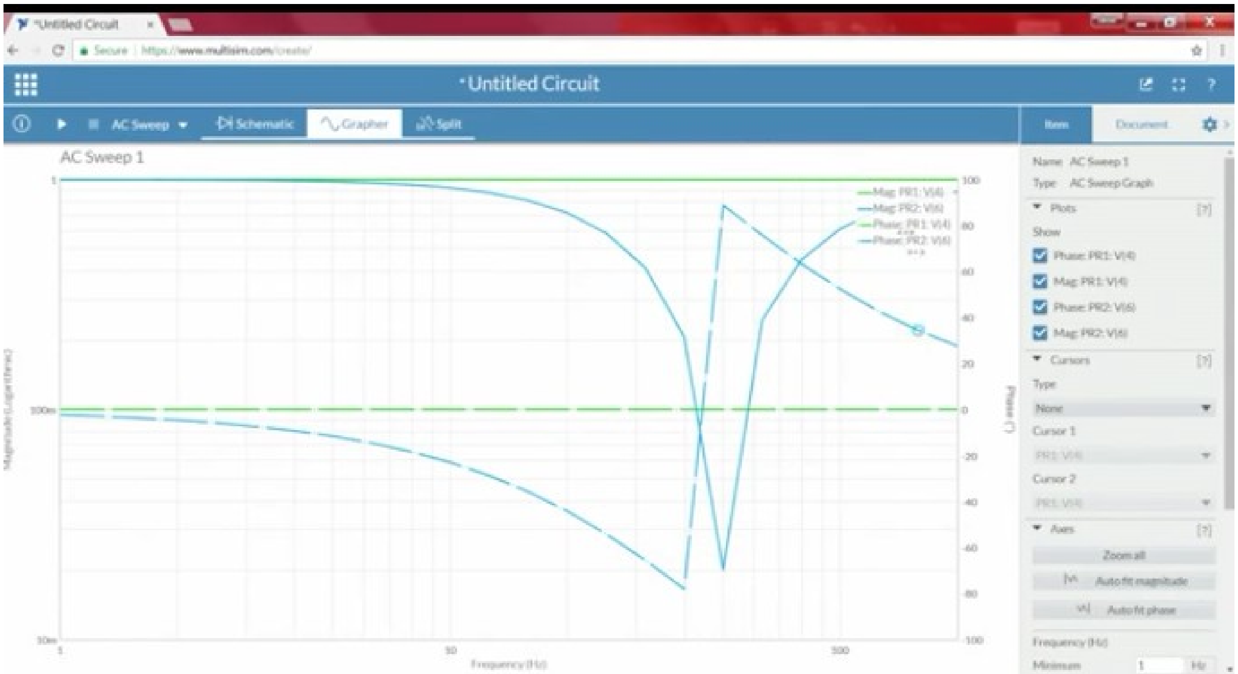

so it has two different frequencies, sorry, input phase as well as magnitude input, output phase as well as magnet since we are not interested in the phase too, we'll just look into the magnitude if you see that the output as well as input, right, output and input are you know having the maximum magnitude as 1, right, that means there is no gain acting in the system.

Now what we do is that we will see, we will try to increase the frequencies to somewhere around 1000 hertz so that even the output can go to the maximum right the gain,

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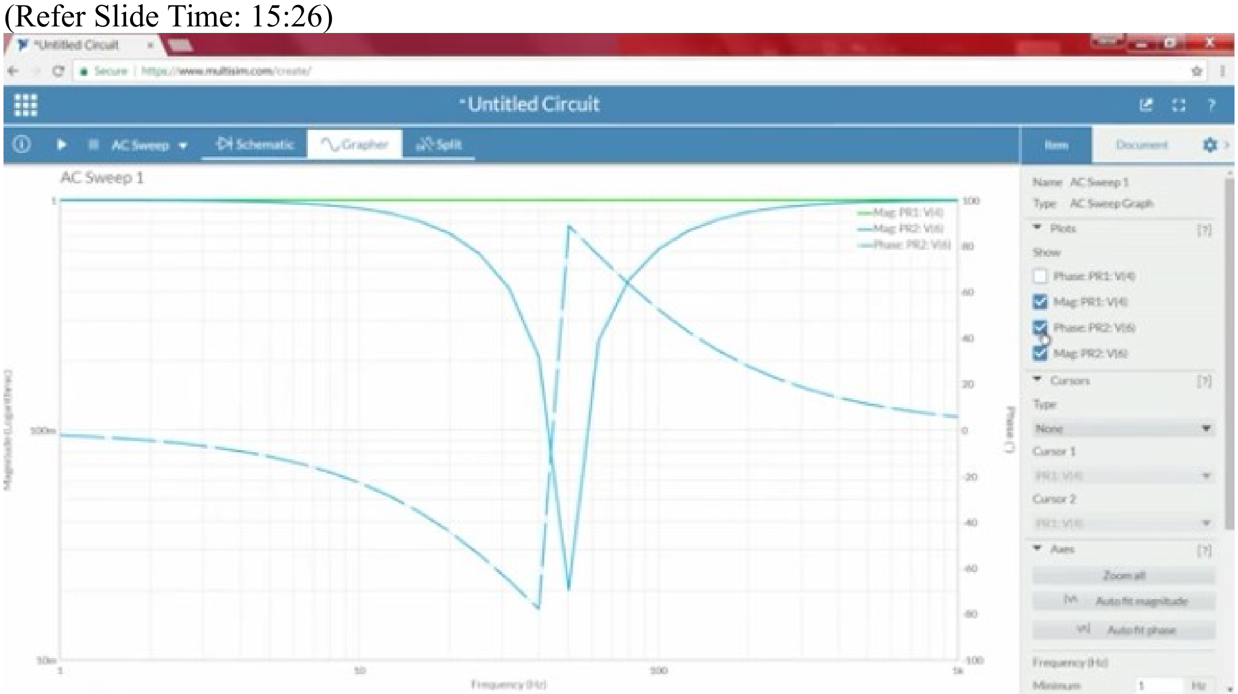

and let me remove the phase values, now if you clearly see that this is 10, it's in the frequency domain, so if you recall how do we measure in a frequency domain, so and that in the log scale

basically 10, 20, 30, 40 and 50, right, 60, 70, 80, 90, 100, now when we see that we need to know 3DB line, there is 1, 2, 3 this point, right.
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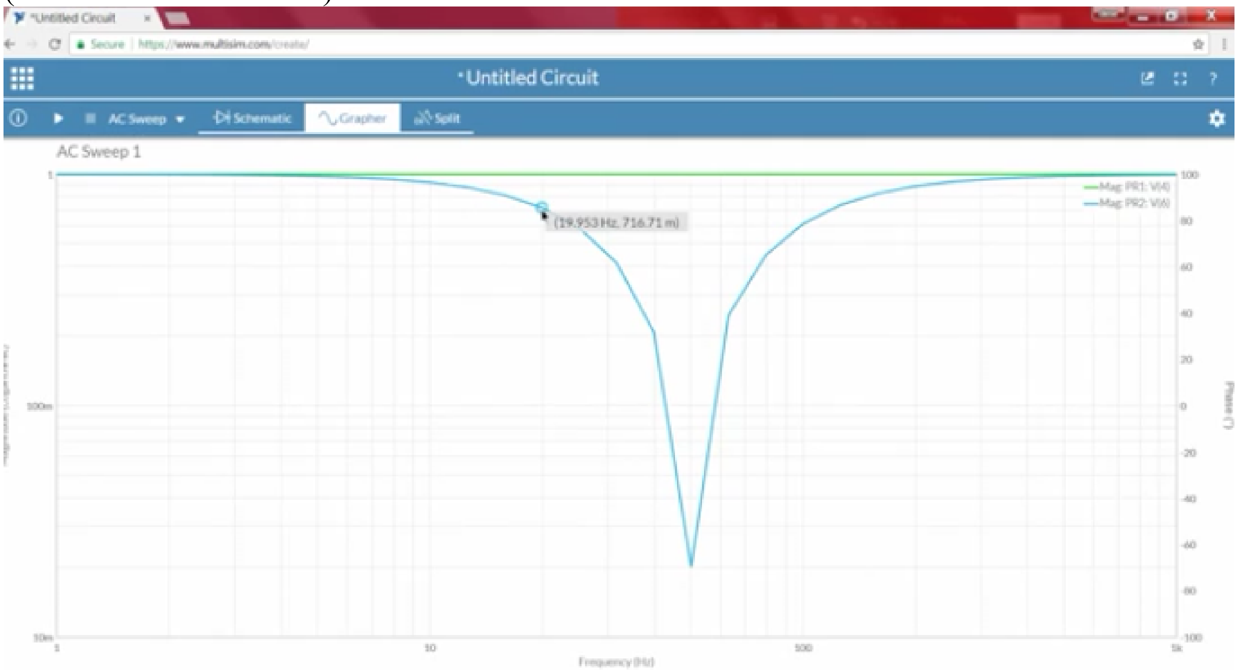

This particular frequency, the frequency at this particular amplitude right is the cutoff frequencies generally we do, but now if you see at a frequency of somewhere around 50 hertz, right, the magnitude is completely very, very smaller, right and again suddenly after you know just above 50 hertz, just it started, it started raising, so when you see the valley it is just like a narrow, that's why this is called narrow band filter too.

So very narrowly we can sharp brown, we can cut down it too one particular frequency, the reason is that we are looking to eliminate or to remove only the 50 hertz noise, and other things we do not have to remove it, so that's a reason rather than going with a long range of notch filtering if we can go with a narrow band of narrow filtering, narrow band of our you know narrow filtering it would be really advantage so that it can only remove 50H frequency signal, so this looks similar to that of our narrow band frequency.

Now how do we understand? Since most of the cases we may not have a function, we may not have the frequency spectrum to visualize our filter, so what we can do is that we can EN analyze the cutoff frequency of the filter by looking into the time mind that is what we are even visualizing in our previous experiments too.

Now how do we do that? So rather than going to AC sweep, we'll go to interact to, and will go, we'll try to change the frequencies slowly from 1 hertz, 1 hertz to up to 100 hertz is more than enough, and we'll put it in the split mode, okay.

Now if we observe let me run, right now it's 1 volt, 1 hertz, let me change the settings of our time domain of our signal, right, so we have both the signals if you carefully observe, right,
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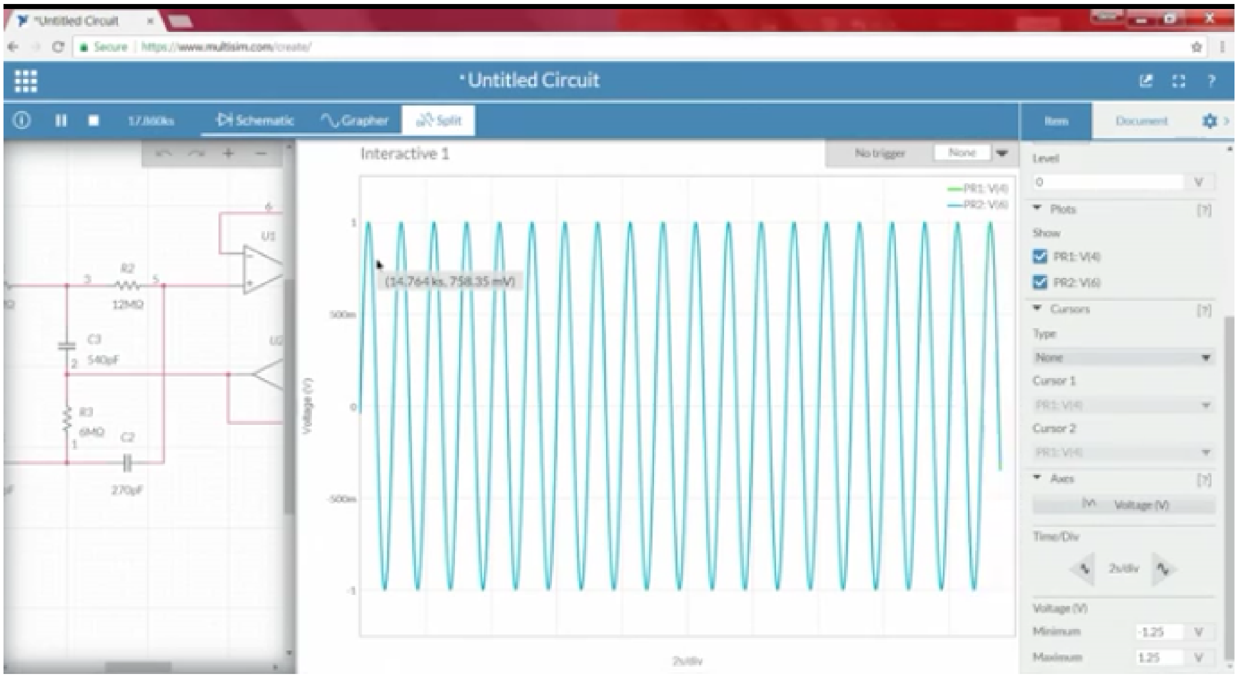

the reason why we are showing only one is because one is ahead of other, I mean the back, the green is on the background of the blue colour, okay, we slowly change our signal frequency at an intervals, at the steps of 10 hertz.

So now we'll go with the 10 hertz, now if you observe let me change our time divisions, right,
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here we can clearly see that this is our input green colour, and this is our output, now how do you understand this is the particular point that we have to consider it, so in order to make our self-easy let us, let me create a cursor for us, so the cursor point should be somewhere around 707 millivolts, so let me move very close if you observe here, at this point so I'll just keep the cursor at 707, so this is nothing but our 3DB line, what we do is that when our output voltage is lower than this particular 707 or at 707 that is nothing but our cutoff frequency under E consider in our frequency domain.

Now the output is greater than that particular cursor point so that means this is not our cutoff frequency, let me increase to 20 hertz we increase almost close to, but not exactly, right,
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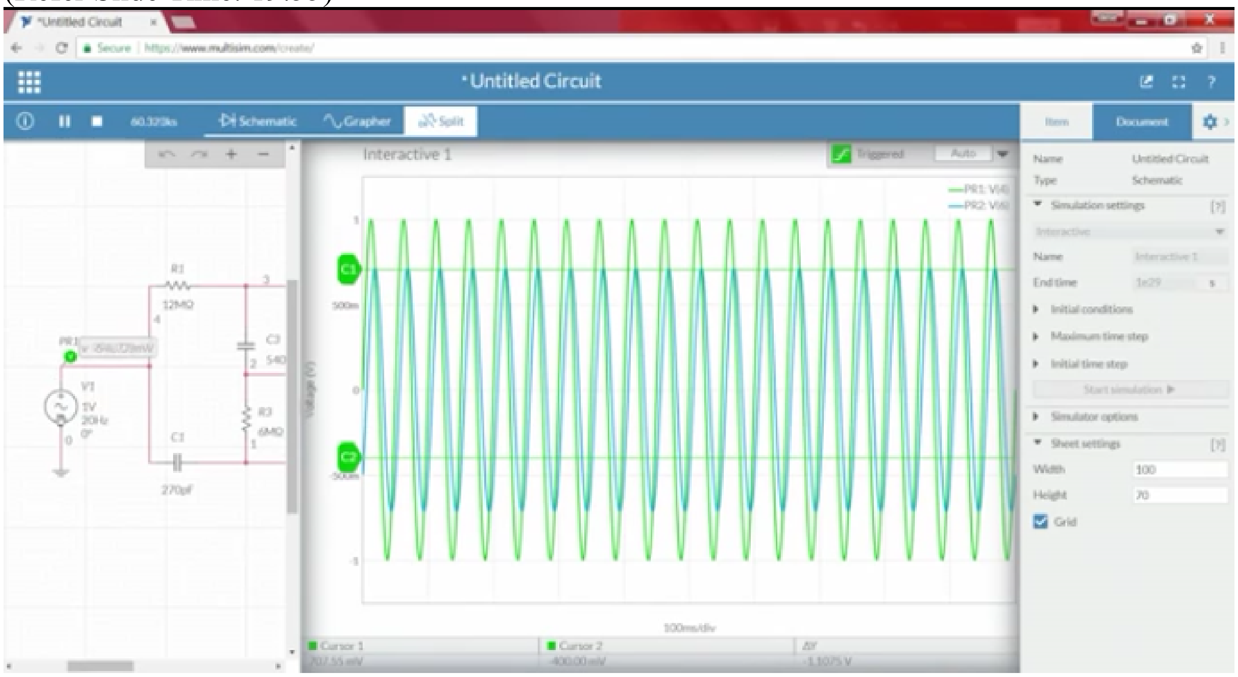

then 30hertz see below that, below that, 40 very, very small signal, 50 so that means if you observe that there is a drastic change for every 10hertz increment,
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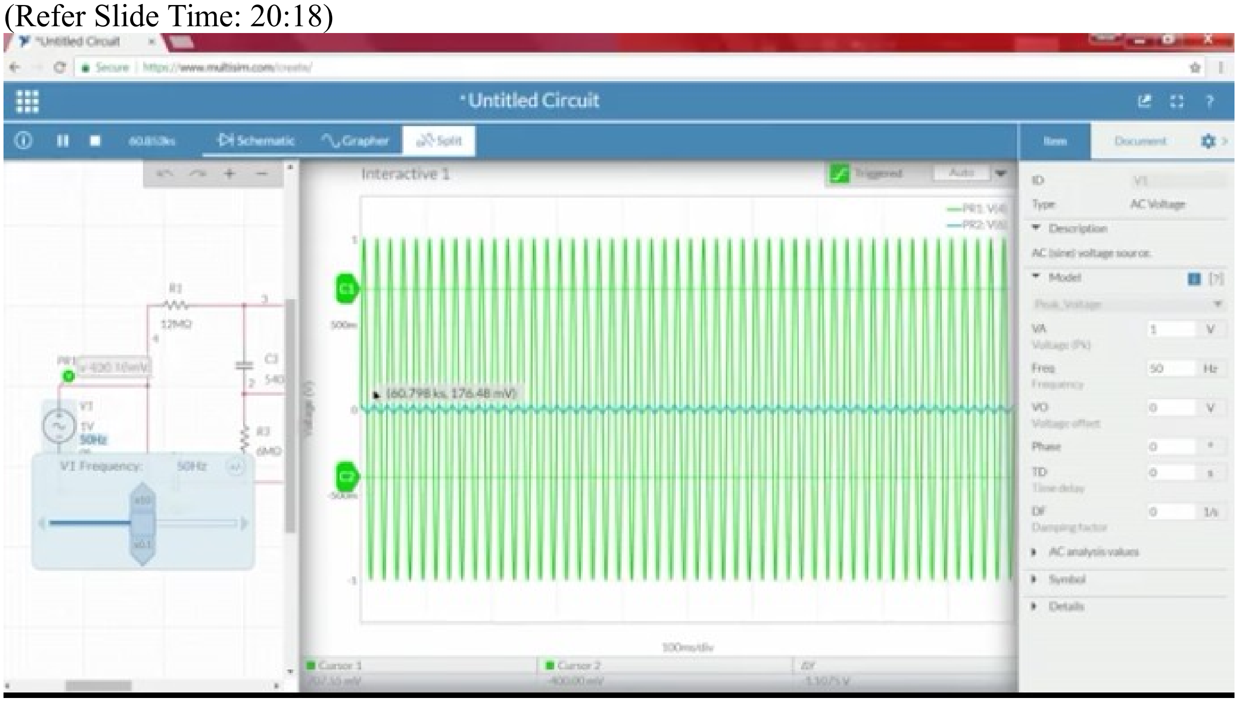

right, that's why this is called a narrow band, a very drastic change, right.

Now if I slowly increase the input frequency even we can observe the drastic change in our output signal too, right, now what is the purpose of the op-amp that we have seen here? If you observe, so what we do is that to understand that op-amp we'll keep to one particular value, yeah, we'll consider this one.

Now we'll change this particular resistance,
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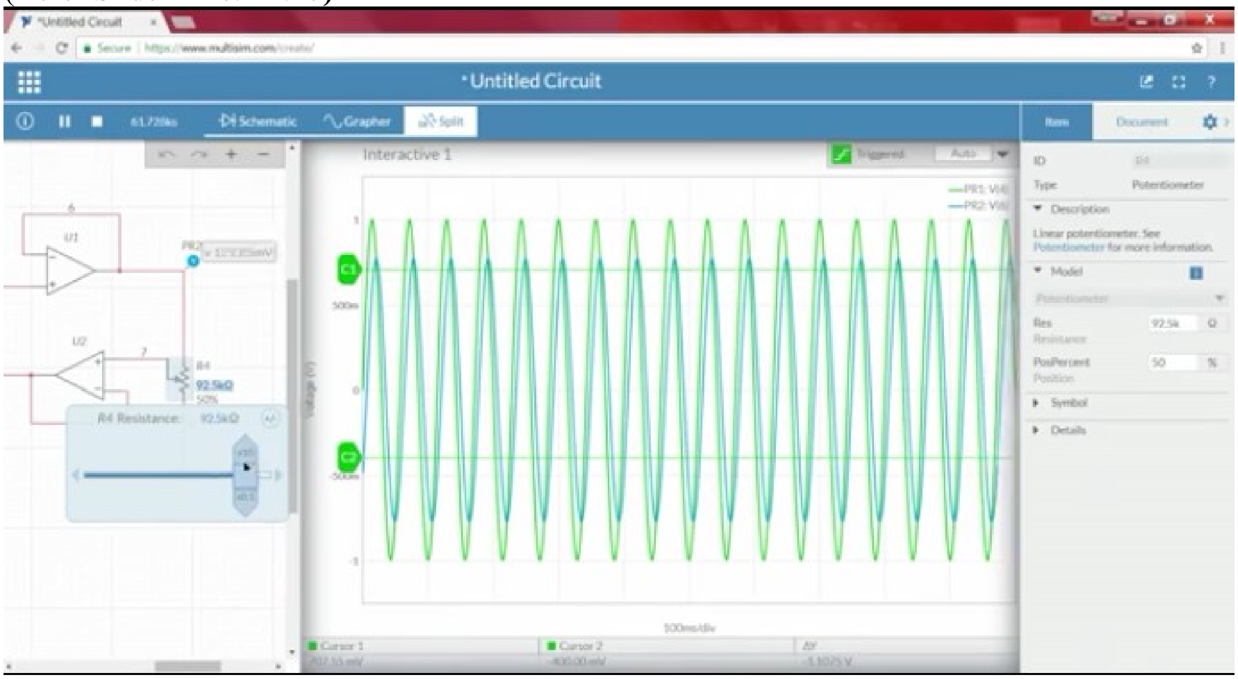

already it should be 10 kilo, and let me change this value, we observe right, now how much band, how much narrow band that we require? We can select by using this particular part, now we'll slowly change once again, 17, 25, 26, 30, 33 right, at this particular frequency somewhere around 34,
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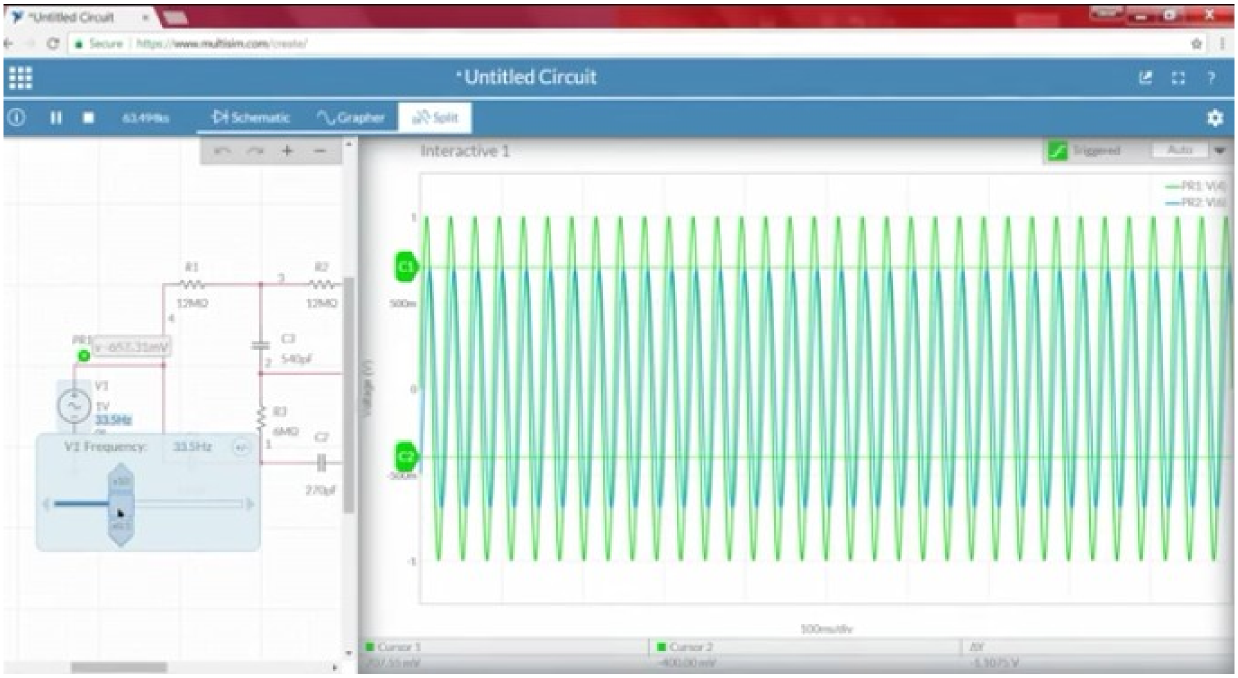

right, somewhere around 33.5 if you observe here it is very close, very close to RC1.

So what if I increase it? Okay, so if I see that till that particular frequency 39, now it has increase to 39, so that means we can see at what frequency that we require to have you know the proper cutoff, right, now if I slowly increase, right, 45 let me take 45, okay, see there is a drastic change from 44.5 to 45 itself,

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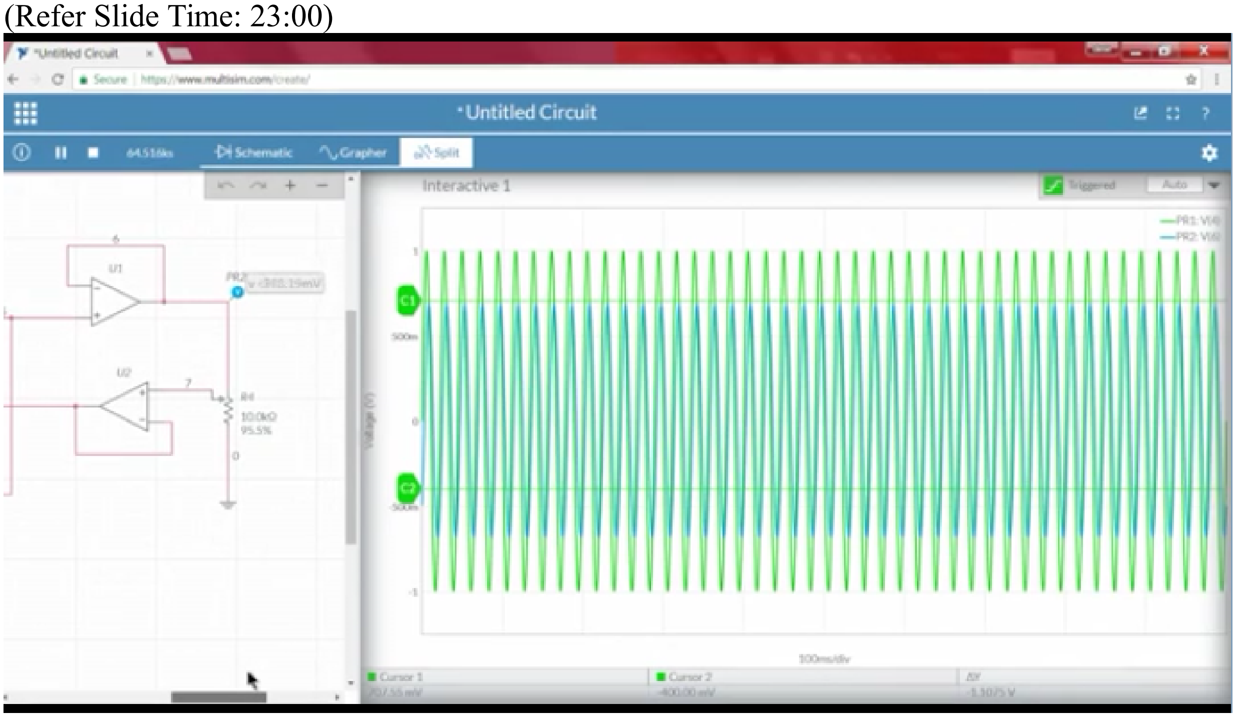

and since our interest was somewhere around 50 hertz within the range of +R -5 hertz frequency, so from 45 hertz to 55 hertz frequency I'm completely eliminating, MN if it is not even required what we can do is that even we can change this R4 resistance to some other

value, so we can see a very drastic change, narrow banding of the frequency everything, but the problem with this thing is that we can, when we closely look into the grapher, there is some shift, there is some shift in our output signal too, so to understand let me zoom little bit right,
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so as long as if we keep on change our, now the potential meter value it causes to create some kind of shift in our output signal, so if that is okay that's fine, if not try to set our you know op-amp, the resistor to one particular value and change our resistance values, so but if we are really you know interested in narrow band of frequencies, one good way is changing the resistance value and we can observe that what's this drastic change from 44 hertz to 45 hertz itself, and below that particular value it's completely, it'll be completely below the setoff.

And if you see even that go to split and if I slowly increase input frequency 45.5, right, at 49 hertz almost nothing,
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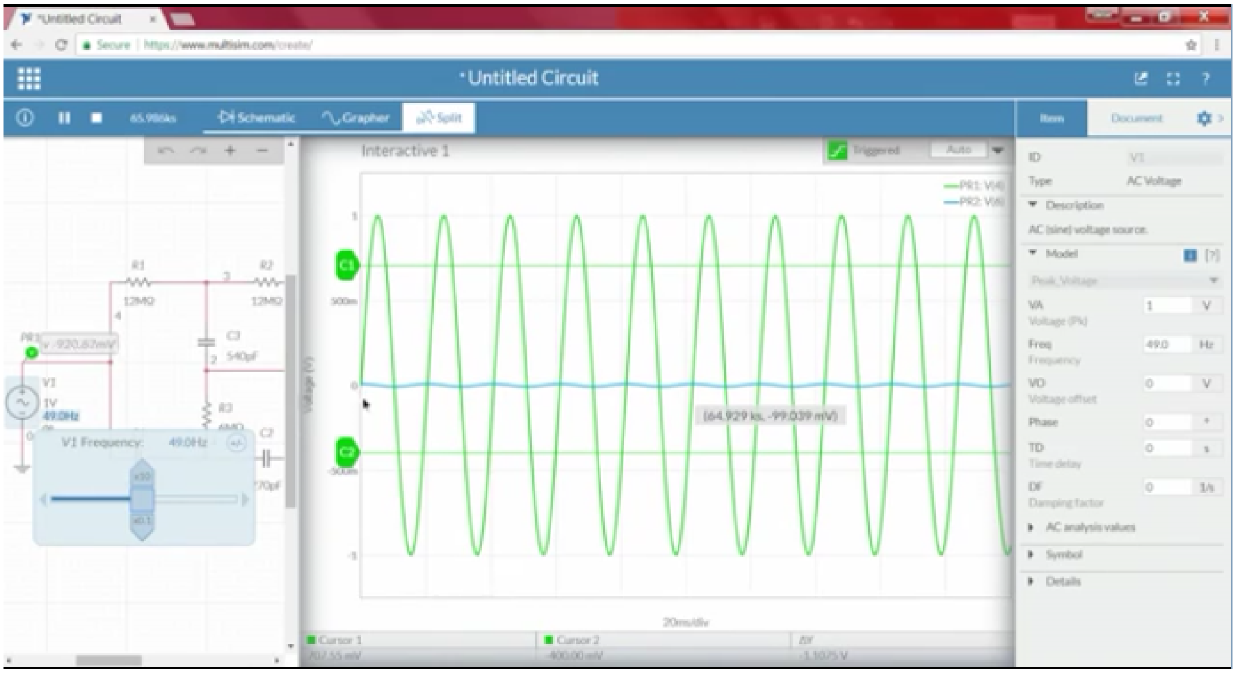

if it is 50 again start an increasing, forget about C2, right, but as a frequency is you know greater than the value again it follows the input, right, so this we can clearly understand whether whatever the filter that we have designed can cutoff very close to the 50 hertz frequency or not, right.

Now how do we perform an experimental thing? When we look into our board,
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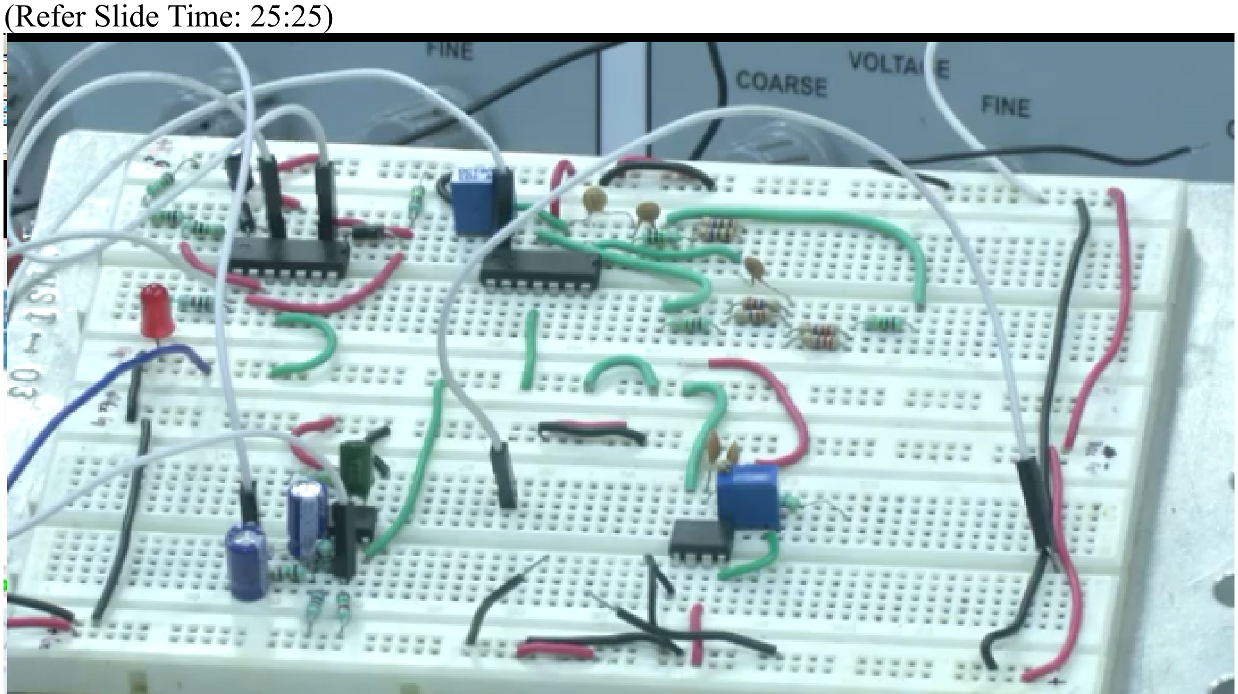

if you recall this particular portion, this particular portion we have used for both low-pass and high-pass filtering, right, so this portion is for low-pass filtering, right, and this portion is for high-pass filtering that we have used.

Now the other part that we are using is notch filtering, and that too 50 hertz notch filtering, so if you recall our resistance value that we have used that time,
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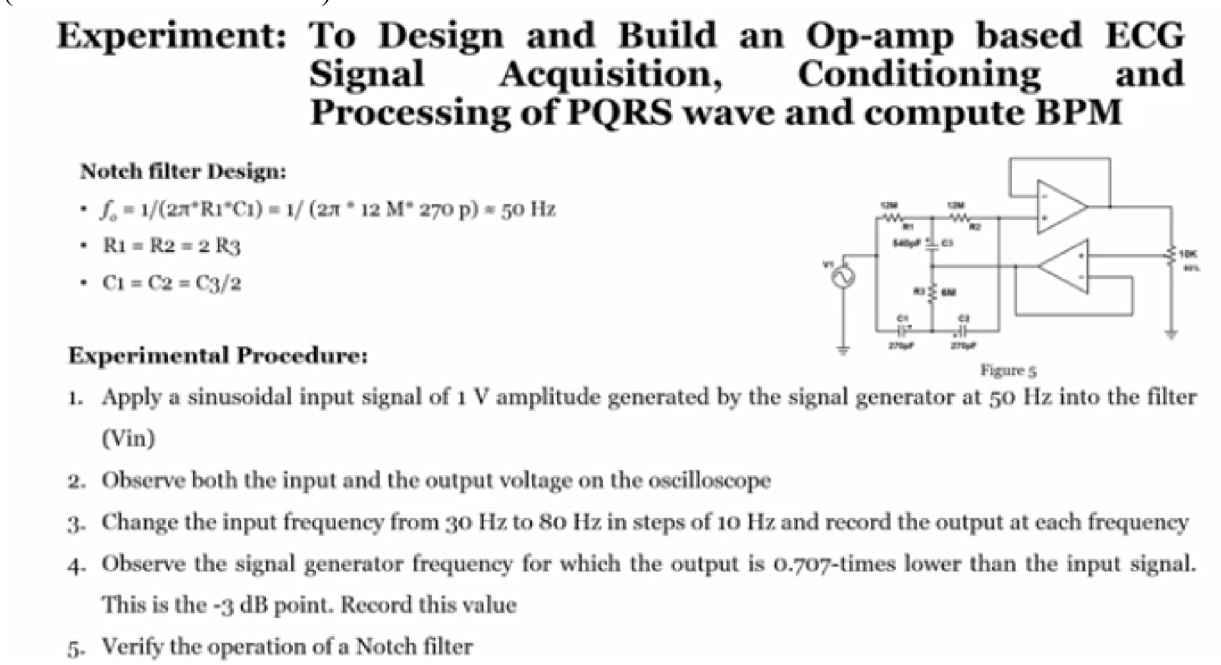

so somewhere around 12 mega and 6 mega resistor, 270 picofarad, and 540 picofarad, right, so since 12 mega, getting a 12 mega resistor is really hard, in the market so but we can get 10 mega resistances, so either you can go with a 10 mega + 2 mega, so that is the one way or you can use some other combinations in order to get 10 mega value, sorry 12 mega value, so in this case we have used somewhere around 20 mega, and 20 mega connected in parallel and we have connected it, and 6 mega also so we have adjusted the resistance value such a way that to get the 6 mega resistance and apart from this everything as per the circuit, so that if you observe at this point we have a different resistors connected in parallel, right, and connected in series, right.

Series, parallel, again parallel and series and the capacitor, right, and both the op-amps we are using from TL084, so TL084 is a cord op-amp, so it has a 4 op-amp this side, so we are using only 2 op-amp in this point, and this is another port where we have seen even in the simulation where we are changing the shifting our you know the phase value or shifting the narrow band and everything here, right.

So now let me implement the circuit so that we'll see how exactly it is working, so input at this point is the junction of both 12 mega and capacitor, so when we see that so this particular point is the input to our system and the output is the 7th pin,
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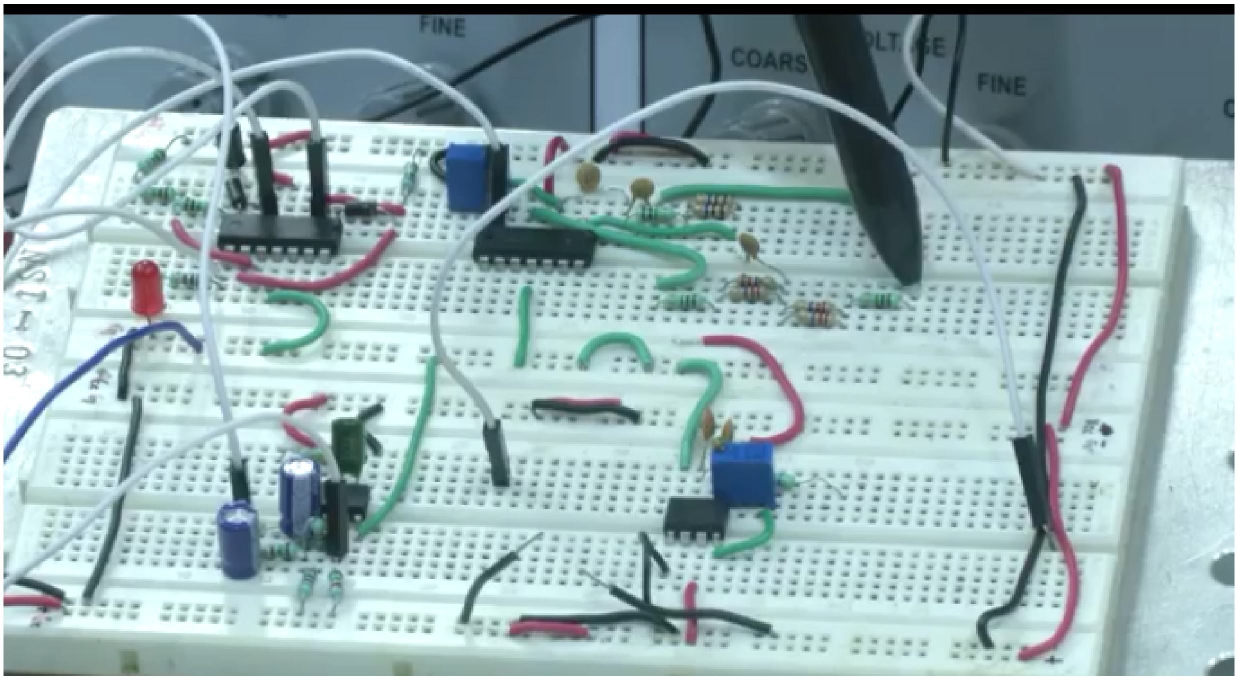

this pin is the output for us, okay.

Now what I'll do is that, I'll take CRO, I'll take function generator, I'll connect input from the function generator right, if you remember we are going to use a function generator starting from frequency of 1 hertz to a frequency value of 100 hertz, if you slowly increase, increase our frequency at one particular point we can see 707 decrease in our lesser than 707 millivolt output voltage that frequency, at that frequency it is nothing but a 3DB line, so I'm connecting the input here, and changing the input frequency to somewhere around 1 hertz and so I'll take CRO, so one terminal connecting it to the ground, other terminal I'll be connecting at the same input point so that we can see what input that we are connecting it to the system, right.

So I've taken CRO, one CRO probe, connected at the same point, right, another CRO probe let me connect it to the output, so this should be our ground, this is the ground and this should be our output, the seventh pin is our output I'm connecting it to the output, right, so let me switch on the circuit, let me switch on the input signal too, auto-set it, so when we look into the CRO, right,

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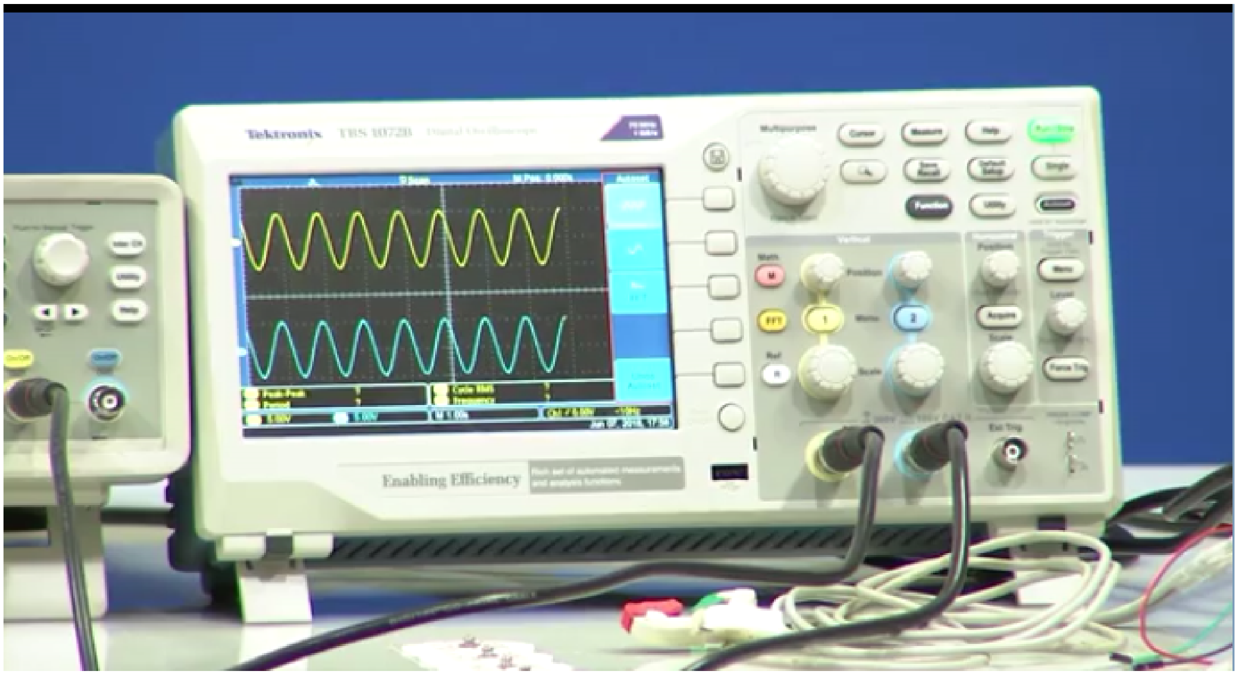

so this is nothing but our input the yellow colour line and the blue colour line is our output, so just to understand what I'll do is that I'll keep both the signals to the same point at this particular point, so that it is easy for us to compare, okay.

Now, so let me change my amplitude to 1 volt, so I'm setting the amplitude to 2 volts peak to peak so that is nothing but 1 volt peak, now I'll assume this particular,

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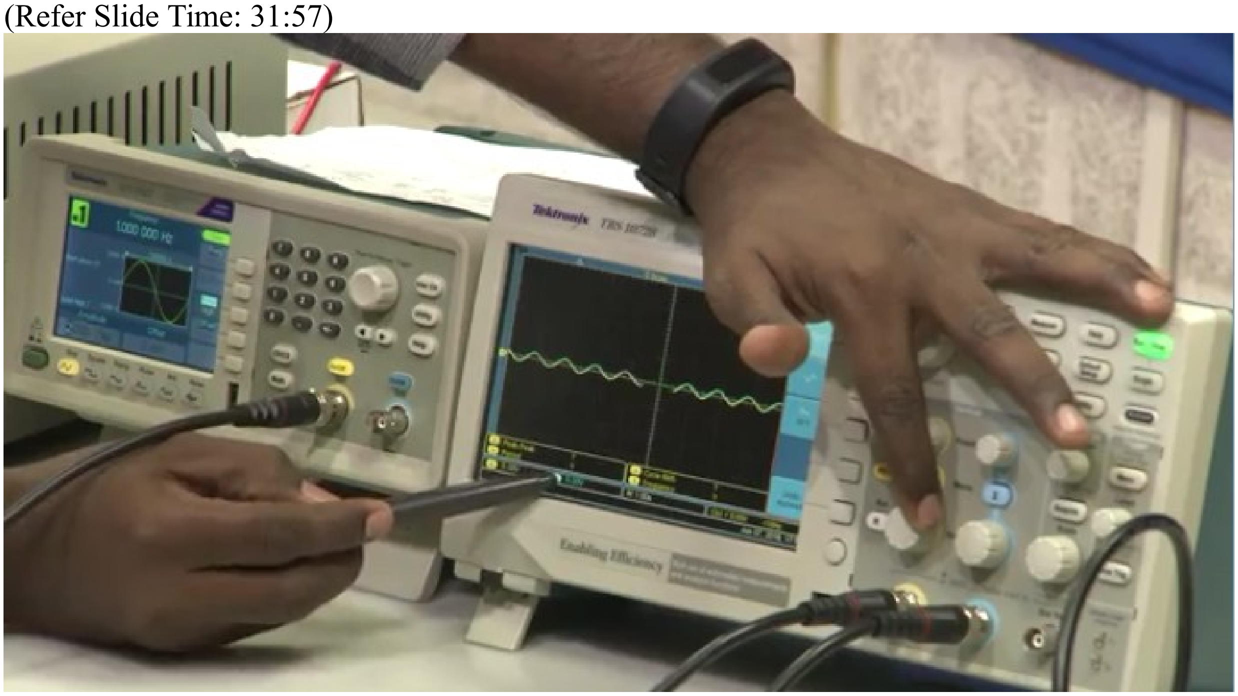

so if you see one box in this case represents 5 volts, right, even in this case one box represents 5 volts, so let me increase the value 1 box to 1 volt and even here, okay,

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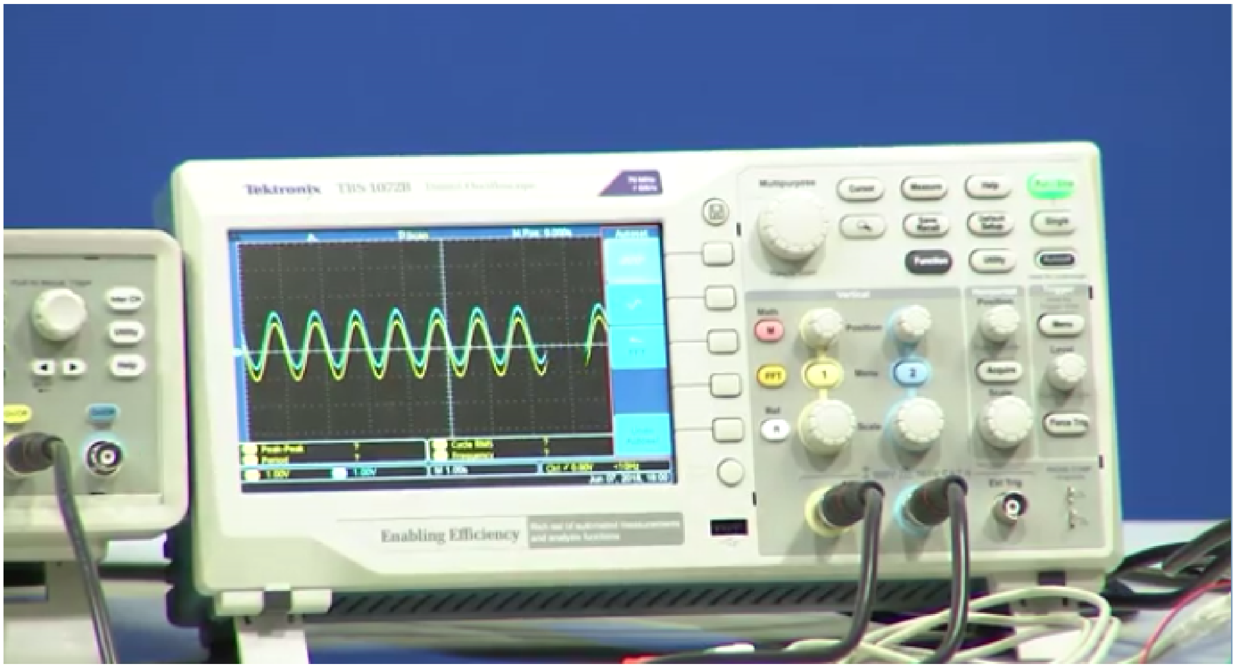

so there is slightly shift of our output, so that we can adjust by using by changing the port, right, so let me change the port value, when we look into CRO we can see we are getting both input and output signal.

Now what we have to do? We have to see whether this but this particular circuit is filtering out the 50 hertz component and other frequencies are passing or not, so for that we have to change our input frequency, and we have to see at what particular frequency the output is below 707 millivolt, so in order to set 707 millivolt I'll use the cursor, so I'll go with the cursor, and I'll make it as an amplitude cursor for channel 2, so I'll go for channel 2, and sorry, okay, so I'll change the cursor 1 value to, so the peak value when I take, so this is the value, and another channel I'm moving it somewhere below, so the peak to peak value when I see delta V it is 2 volt that is cool, so this is our ground terminal, and this is 720 milli, so right,

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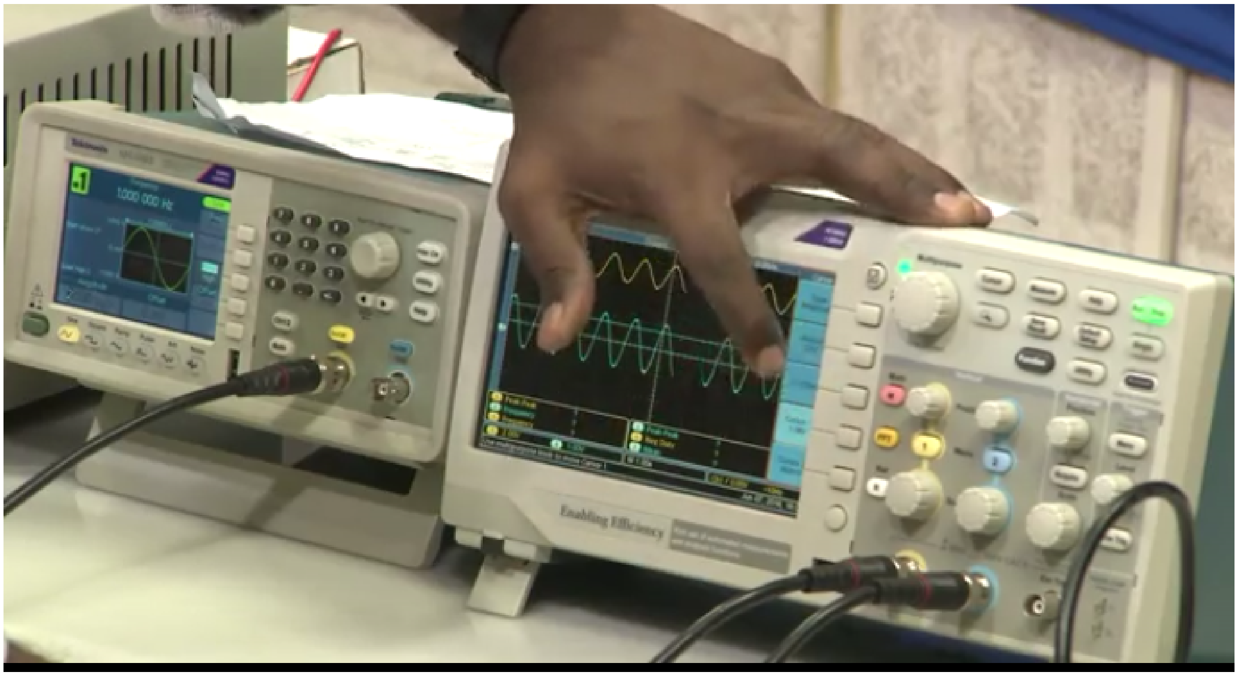

cursor 1 is the difference between both the cursor 1 and cursor 2 is somewhere around 720 millivolts.

So now what I'll do is that when we look into the function generator, I'll slowly change at a frequency of 20 hertz, so now it is at 1 hertz frequency, I'll change it 20, okay, so to 10 first, to 10 hertz, now when we see, right, so I don't see any difference in below that particular value, so let me change to 20 hertz even the result at the same, 30 even higher than that of the cursor value, 40 slightly higher than that, from here I'll slowly increase, 41, 42, 3, 4, 5 right 6, 7, 8, 48, 49 right when we observe that somewhere near to 49, somewhere near to 50 hertz,

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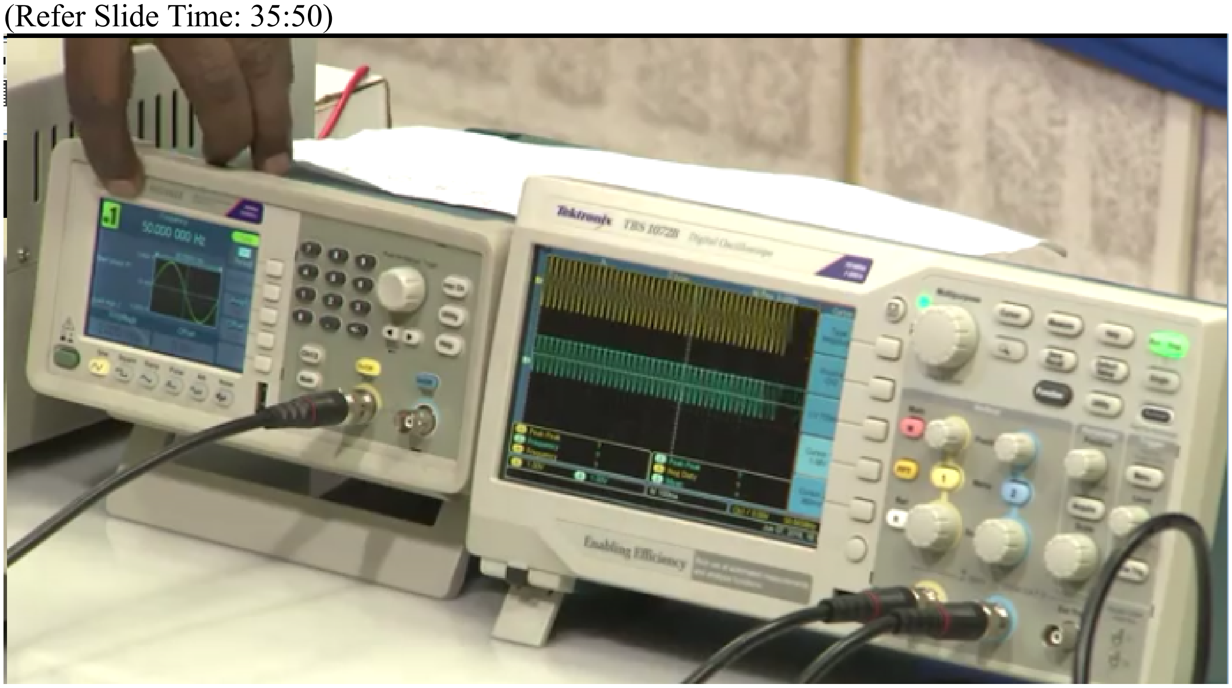

so when we see this CRO value 50 hertz that is the output is almost below the cursor value, right, when I slowly increase hereunder the amplitude will be the peak to peak amplitude we can see its completely decreasing it, right, and if it is increasing again the peak to peak amplitude if you observe starts increasing.

Now okay, so in order to make it narrow band or something what we have to do?
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We also have to change the resistance value, so I slightly change the resistance value to, because we need narrow band, so that's the reason by adjusting your resistance value we can easily see whether it is creating a narrow or little wider band, right, so that's a reason I change the resistance value, I'm decreasing somewhere to 53, 52 hertz, 50 hertz, and 49, it is higher so there was no much impact.

Now so if you recall our the port resistance value that we have chosen, so if that same resistance value if I measure and select it, right, we can see so I'm adjusting the resistor, so we can see it has come down, right,
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whereas if I change the resistance value the port the peak to peak voltage value will change it, we can easily see the CRO, right, so depends upon whether we require narrow or wide band, so this port, the port that we are using decides it, right, so this way we can even you know change the notch filtering to be narrow band absolute little wider band and everything.