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INDIAN INSTITUTE OF SCIENCE, BANGALORE

Electronic Modules for Industrial Applications using Op-Amps

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

(Refer Slide Time: 00:31)

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

LPF Design:

- Resistor Values: R1 = 670 kΩ, R2 = 670 kΩ
- Capacitor Values: C = 2.2 nF
- Gain: Av = 1
- $f_c = 1/(2\pi * 670\text{ k} * 2.2\text{ n}) = 107.9\text{ Hz} \approx 108\text{ Hz}$

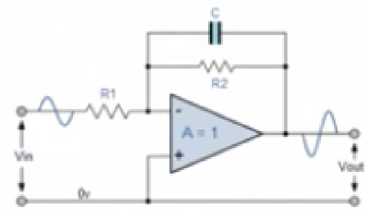

Figure 3

Experimental Procedure:

1. Apply a sinusoidal input signal of 1 V amplitude generated by the signal generator at 1 Hz into the integrator and observe both the input and the output on the oscilloscope. Calculate its gain
2. Starting with a frequency of 1 Hz, increase the signal frequency in steps of 20 Hz up to 200 Hz and record the output at each frequency
3. Observe the signal generator frequency for which the output is 0.707-times lower than the input signal. This is the −3 dB point or the high-corner frequency. Record this value
4. Verify the operation of a low-pass filter where the input frequency greater than the cut-off cannot pass

How do we do filtering circuit, right, as we have already seen on our previous modules, previous things, we know how to make use of an operational amplifiers and what are the advantages and disadvantages of going with an active filters when compared to the passive filters, and we have also discussed about the design.

Just recall what we have discussed and if I see here this is our active low-pass filter, right, so the combination of R and C tells our cutoff frequency, and the combination of R1 and R2 resistors tells us gain.
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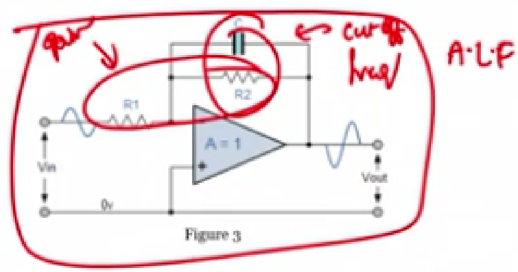

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Now what value, what value of cutoff frequency we require? We require a cutoff frequency of 100 hertz, since it is a low pass filter I don't want to see odd multiples of our power line interference that means 150 hertz, 300 hertz everything, so we will be using low-pass filter with a cut-off frequency of 100 hertz.

Now how do we know the cutoff frequency? So in this case we are considering a resistance as 670 kilo ohms, this is R1 670 as well as R2 also as 670 kilo ohms, we are taking 670 kilo, this is also as 670 kilo, and capacitors 2.2 nano farads.

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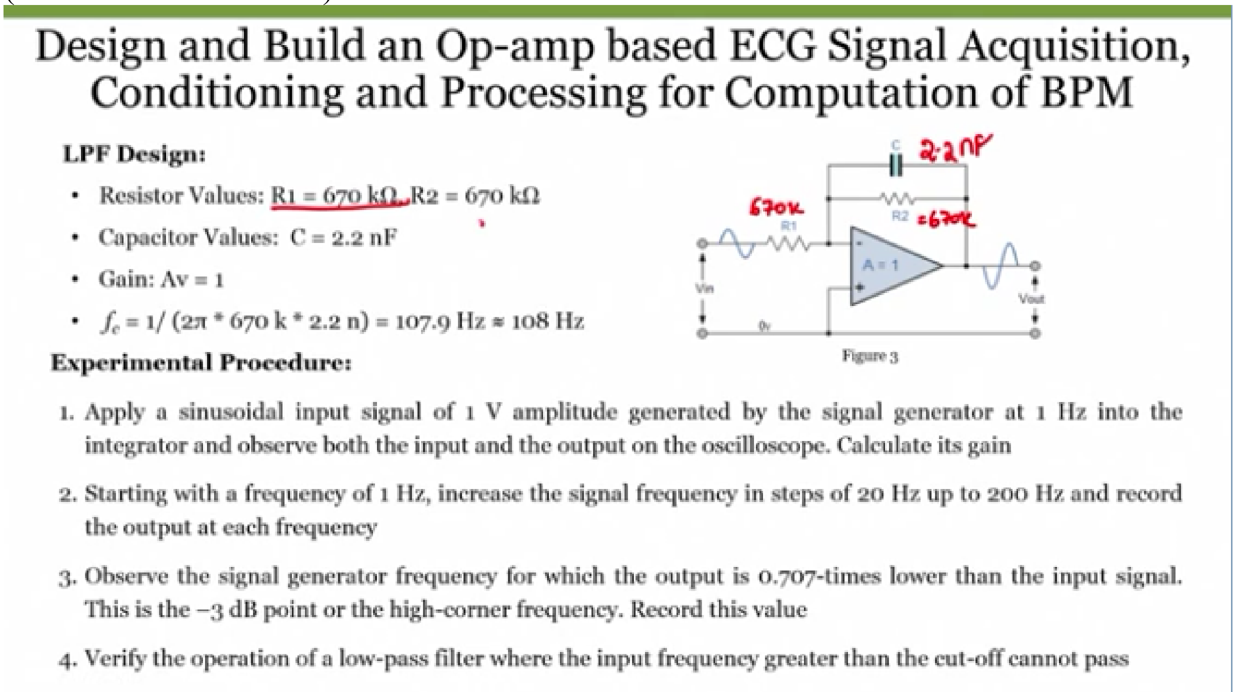

Now if I can compute the cutoff frequency, what is the formula? F = 1/2 pi RC right, so when we calculate everything we will get a cutoff frequency somewhere around close to 108 hertz. If I take 2 nano farads it will be even 120 hertz we can even get it, or if we take a smaller value it will be 100 hertz too, I mean if I take a larger value it will be either resistance R, and capacitors it will be even 100 hertz we can achieve, so in this case by considering the availability of resistance and capacitors we are designing a first order low-pass filter with a cutoff frequency of 108 hertz.

Then what about the gain of the system? Since R1 and R2 resistors are same, since it is an inverting amplifier the gain is R2/R1, so therefore the gain is 1 in this case, so what are the input we get? Without any amplification, with an amplification factor of 1 we will get the same output, but since it is an inverting we will get a negative, there will be an phase shift of 180 degree.

Now how do we know, since see if I want to understand the circuit I should look whether it is cutting off at that particularly frequency, I have to have a frequency spectrum, and now connecting it to a frequency spectrum it will be very expensive because the equipment itself is very expensive, so what we can do is that if you can visualize, if they can visualize whether the designed filter is cutting off at that particular frequency in a CRO itself we can even compute the same thing in our laboratory 2, how do we do that? So as we know that when we look into our frequency spectrum of low-pass filter and the gain is 1, so if we can calculate the 3DB line, right, this is nothing but our cutoff frequency.

Now when I represent the frequency form we are saying this value is 108H, but in CRO how do we found it?

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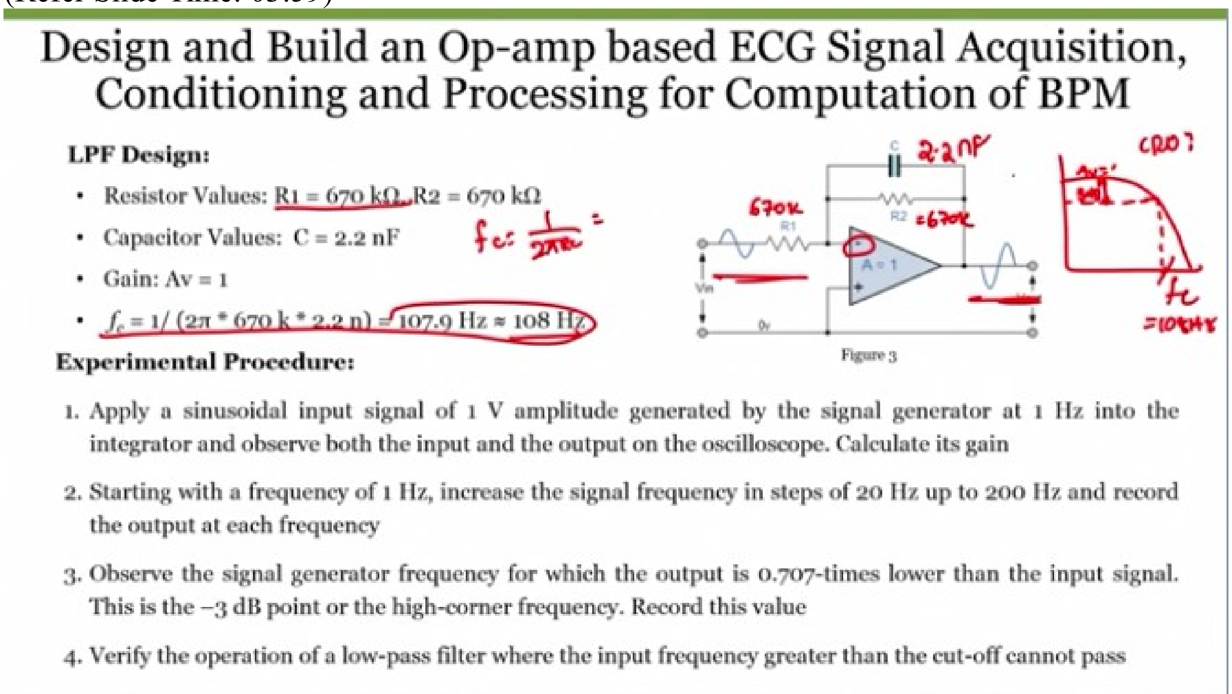

What we do is that we know the maximum voltage we get, right, so we will apply some, we'll take some functional generator we'll apply 1 volt as an input signal, so since it is also a gain of 1 we'll get an output as 1 volt.

Now we'll slowly increase the frequency, we'll slowly increase the frequency and we will observe what is the change in the amplitude, whenever we see 3DB line which is nothing but half input voltage or 0.70 times that of your input signal at that particular point that is nothing but our 3DB line, and from that point the output voltage will be keep on decreasing, keep on decreasing, so that frequency if I can calculate that is nothing but our cutoff frequency, but to give the frequency domain visualization what I will do is that in a simulation I'll show you the AC response as well as with a DC response and we can see the complete you know, the frequency domain value too.

But this is how the connection should be looks like, and we will be passing, we will be using a function generator to pass from 1H to somewhere around 200 hertz within steps of 20 hertz and we will record the output at each frequency, so we will observe this signal generator frequency for which the output is 0.707 times lower than the input signal, that point is nothing but 3DB point, so that point will consider as our cutoff frequency.

So in order to understand much more what we do is that, we'll go to multi sem, so as we have already seen how a multi sem looks like and everything in our previous module, but our intention here is to design a filter and we see the frequency response as well as whatever the intuitive that we have learned from the experiment, from the previous experiment as well as you know, in our procedure that we explained we'll try to put the same thing here and we will try to analyze even in the time domain too, and we will compare the frequency domain response with the time domain too, so in such case what I need now? First I have to take my operational amplifier, so I'll op-amp and I'll select an op-amp here, right.

Then I have to take resistors in this case we have taken 670 ohms resistor, so I'm replacing with 670 kilo ohms sorry, 670 kilo ohms resistor and one more resistor that is also 670 kilo ohms, so that is a negative feedback to resistor, so I'll be connecting from here to here.
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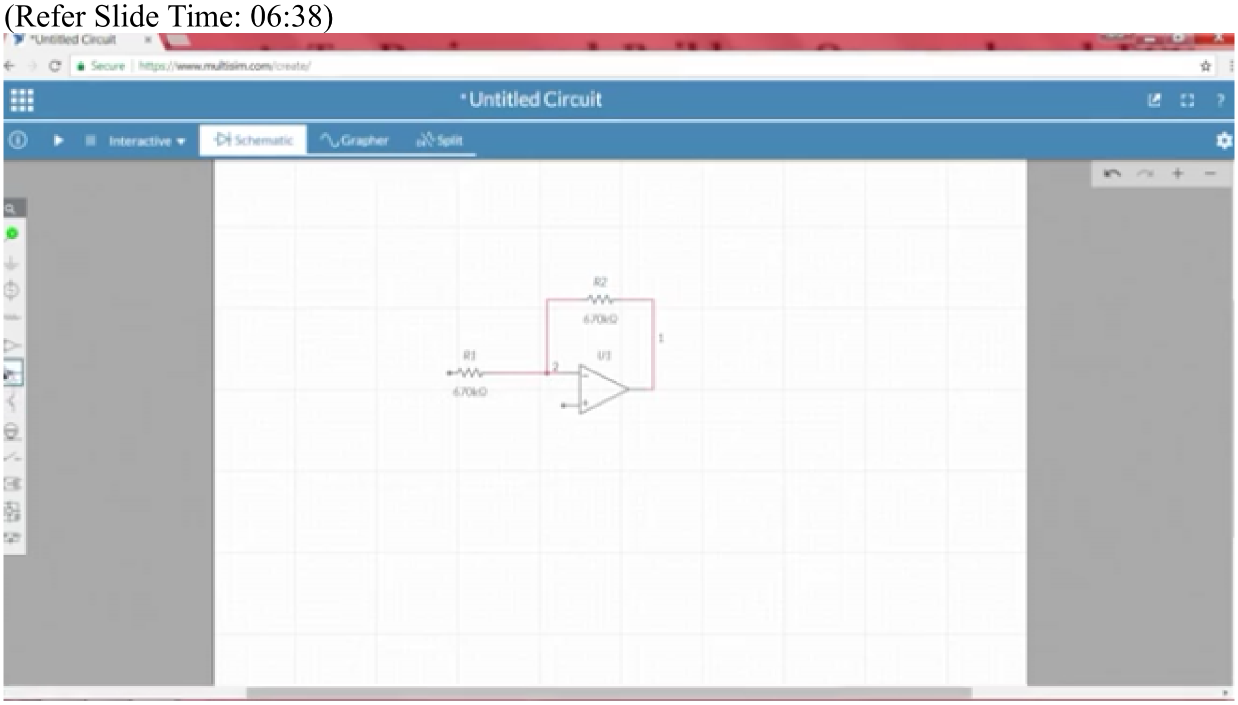

Then what is the other one? So we also have to connect a capacitor across R2, so what I'll do? I'll take a capacitor, what is a capacitor that we have used in our theoretical designs? We have used 2.2 nano farads, so I'll go with 2.2 nano farads,
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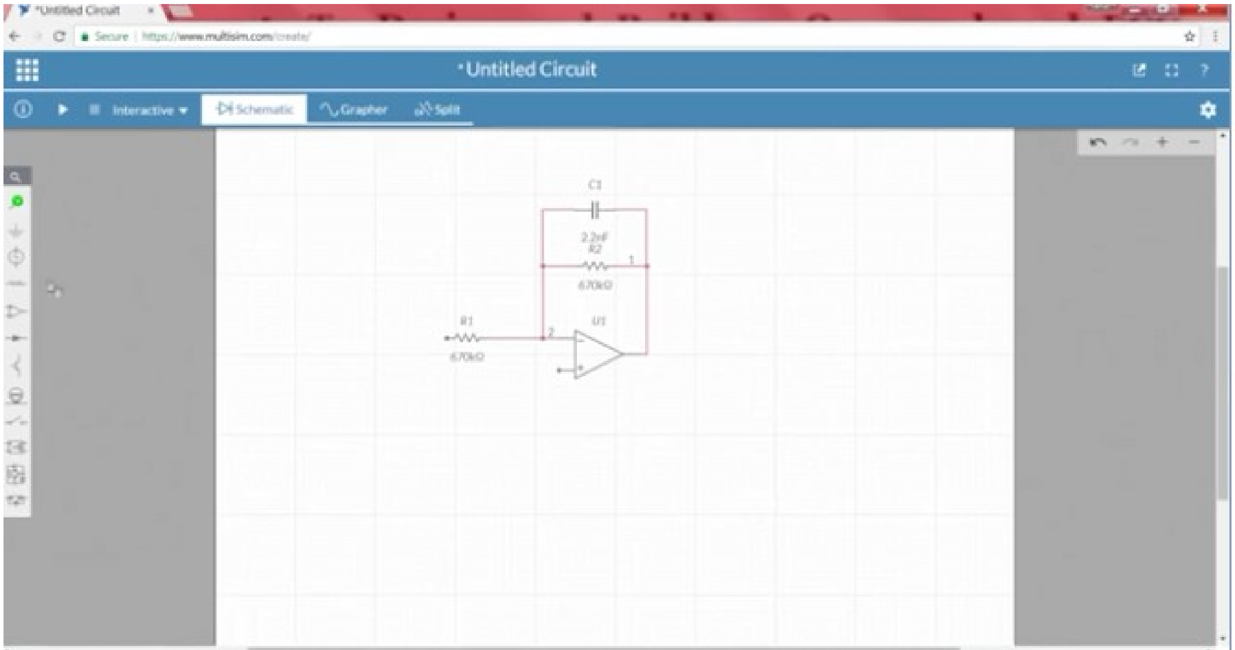

and 2.2 nano farads are available in the market too, right, then this particular value, the positive terminal should be connected to ground, so what I'll do is that rather and connecting to the ground in order to eliminate the effects due to the bias and offset currents, I'll use a resistance value 2 resistors in parallel which are nothing but 670 kilo ohms resistors itself, so that the effects due to the bias and offset resistance can be completely removed using this, right, that we have already studied in our previous modules, isn't it?

So I'm taking R1 and R2 resistor, and this two we are connecting it in parallel,
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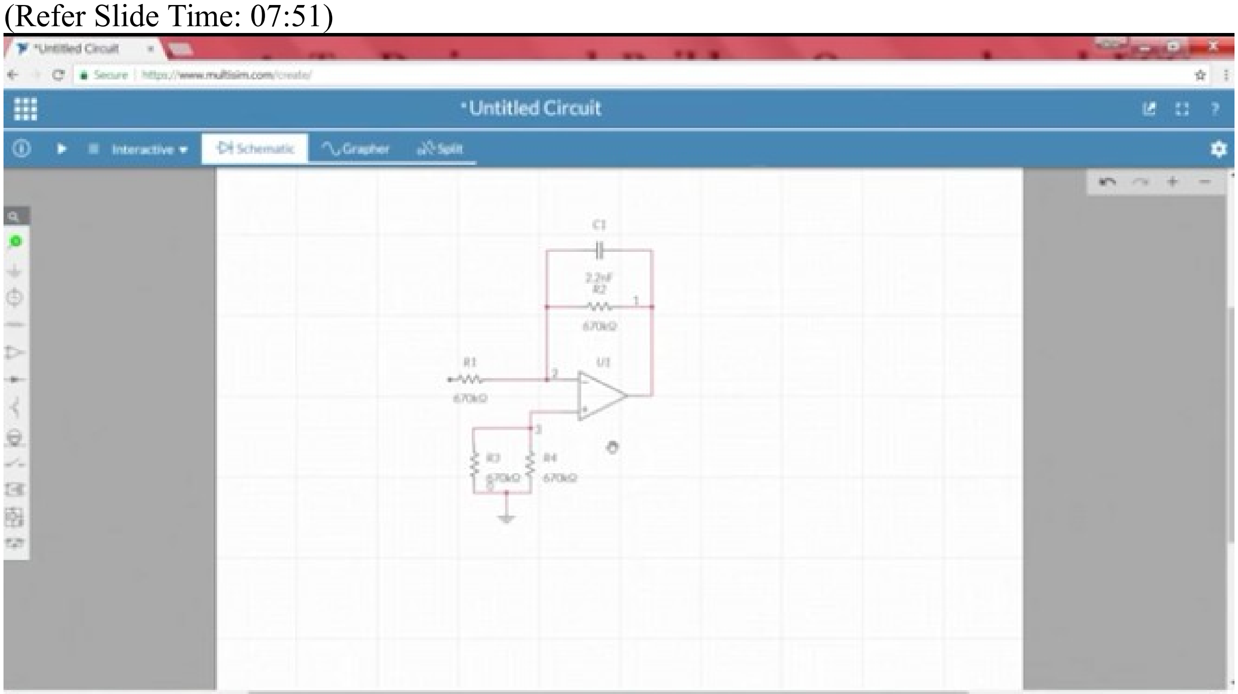

so that it will compensate for the effects due to the bias currents as well as basically for the bias currents, then I have to apply some AC voltage, right, and the other terminal should be connected to ground, I'll take it to ground, this is main input, so in order to visualize the system one I'll take here input, other one I'll take output.

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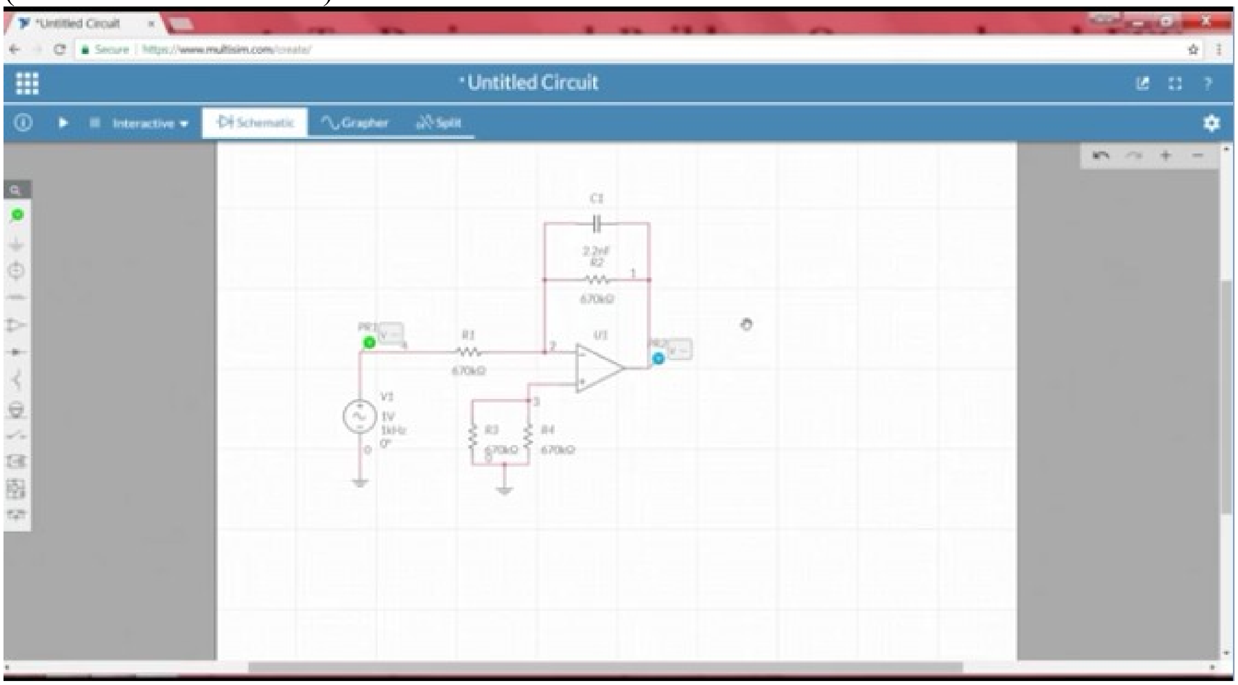

Now so in order to understand the cutoff frequency good way is to go with our AC sweep, so what I'll do is that in AC sweep I'll sweep the signal from, okay, let it simulate yeah, so here what I'll do is that the minimum hedge is of,

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one hedge I'm doing and the maximum you say I'll go with 200 hertz,

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right, then we may not require the peak values, sorry phase values, so I'll remove all the phase values, I only put magnitude values or even greater than minimum zero, and maximum somewhere around 1000 hertz I'll put or 1 hertz to 1,000 hertz, right, let me run once again AC sweep, okay, okay,

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phase I'm removing it, then till 1 mega I'll put 1 mega, so now we can see the signal, right.

Now green represents what? When we look into our figure we can see here, green is nothing but my input and blue is nothing but output,

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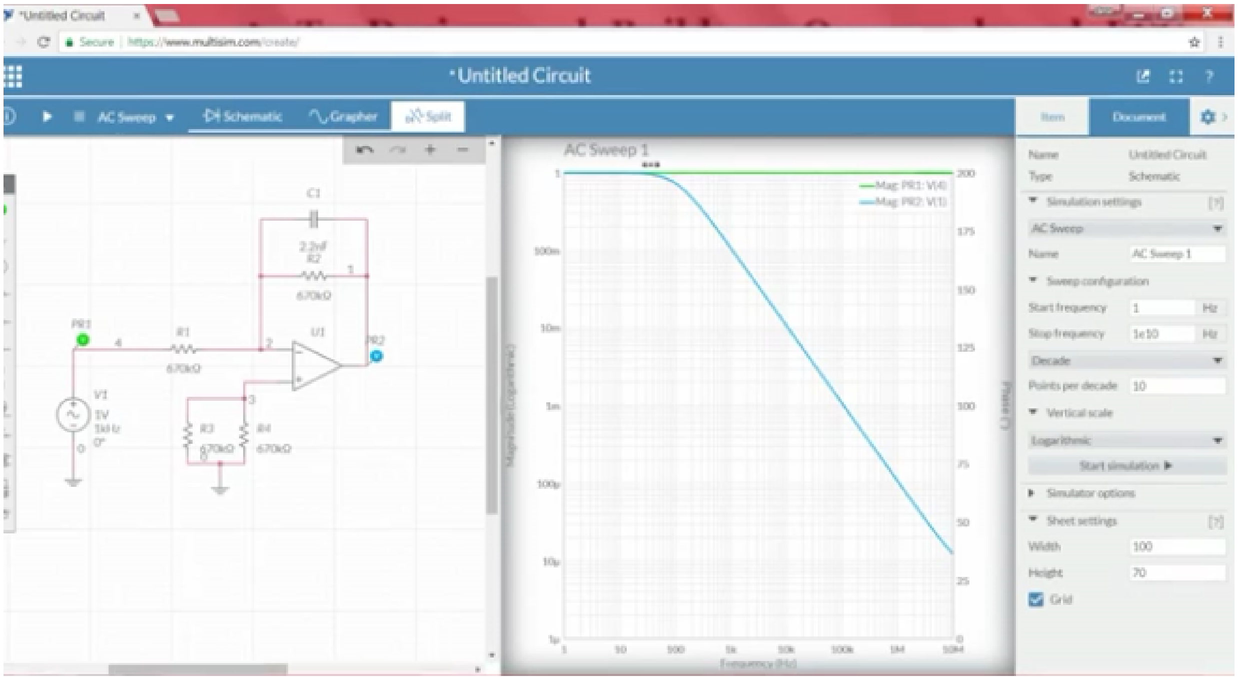

so one thing is clear that the input and output are having the same gain, right, amplitude of 1, right, magnitude of 1, so that means both are having the same gain, but after particularly frequency if I closely observe the output is attenuating, right, the magnitude is decreasing, right, but at what frequency?

How do we calculate our cutoff frequency? As we know that the 3DB line, we have to consider the 3DB line, since it is 1, 3DB line will be 3 magnitudes below to the 1, so in order to do that what I'll do is that I'll do, I'll zoom the frequency domain, so in order to zoom that I'll change this frequency values to somewhere around 1 kilo hertz, now this is 1DB, the below one is 1DB, this is other DB, this is this DB, so this frequency, right,
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somewhere around 700 right, this is 1 and this is 700, so approximately 3DB line, so when I see that what is the frequency at this point? We can see here 100 hertz, 733.68 milli DB, or if I put a cursor I'll put X axis cursor, so I'll be slowly varying observe the C2 cursor, I'll be varying it to 99,

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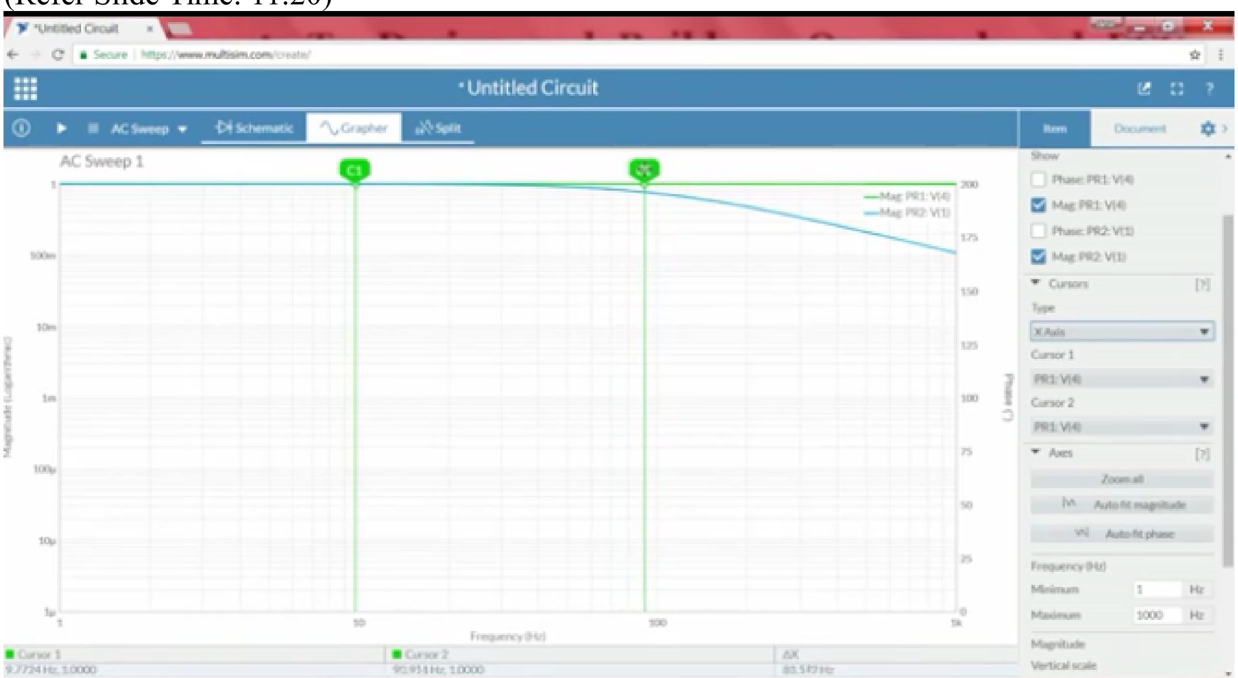

sorry, where is that? 3DB line, so the C2 value should be, so let us take somewhere around 100 hertz, then I'll take Y axis cursor, so because we require to take 700 milli magnitude, so slowly I'll increasing observe DY,

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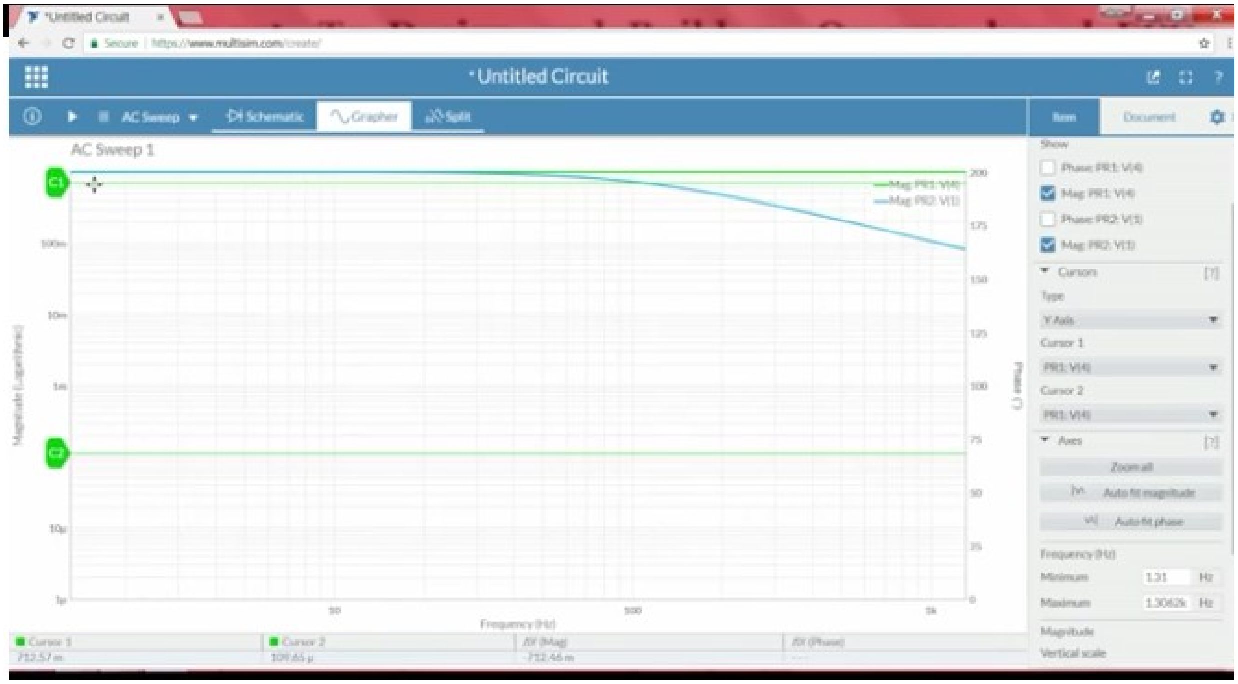

delta Y here so this particular value, right, so 750, 800 slowly decrease, 694, so this is nothing but my line, so this is my, if I observe this point,

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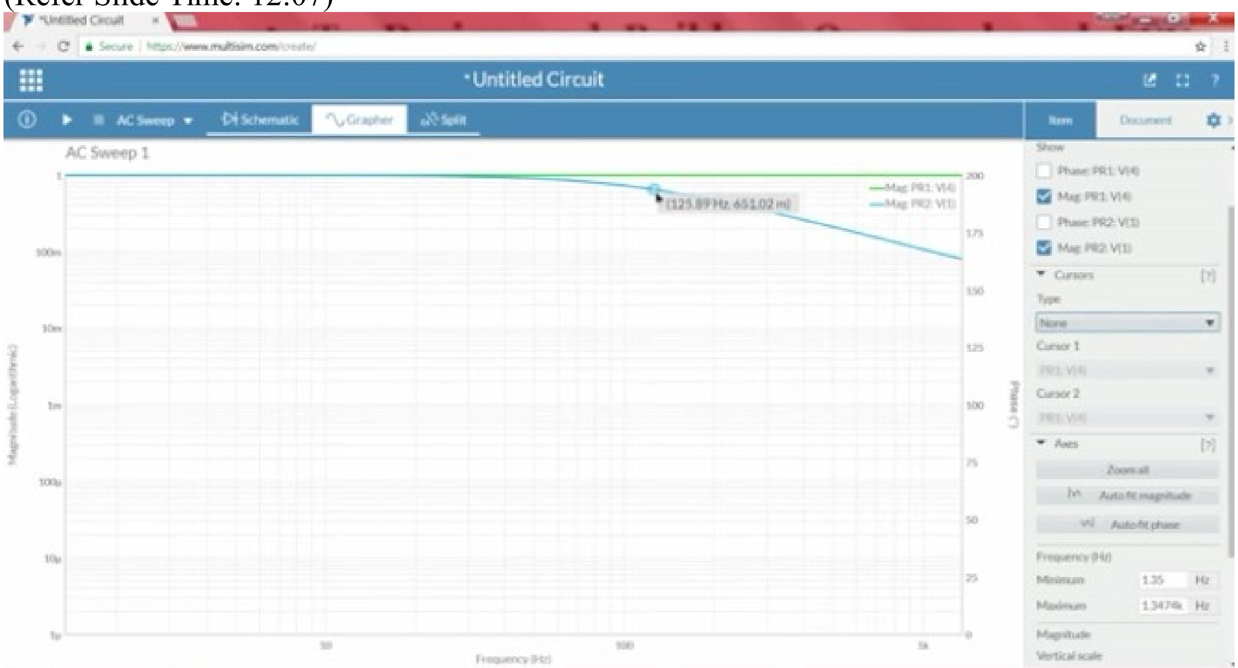

this particular point will be 700 milli, somewhere close to this, I won't be able to do that because of the resolution, okay, 1 kilo hertz because of the resolution I cannot see that or also I can little bit zoomed the vertical scale, so maximum, minimum I'll say somewhere around 1 milli, right.

Now if I see 125, so we can understand that somewhere close to 100 hertz,

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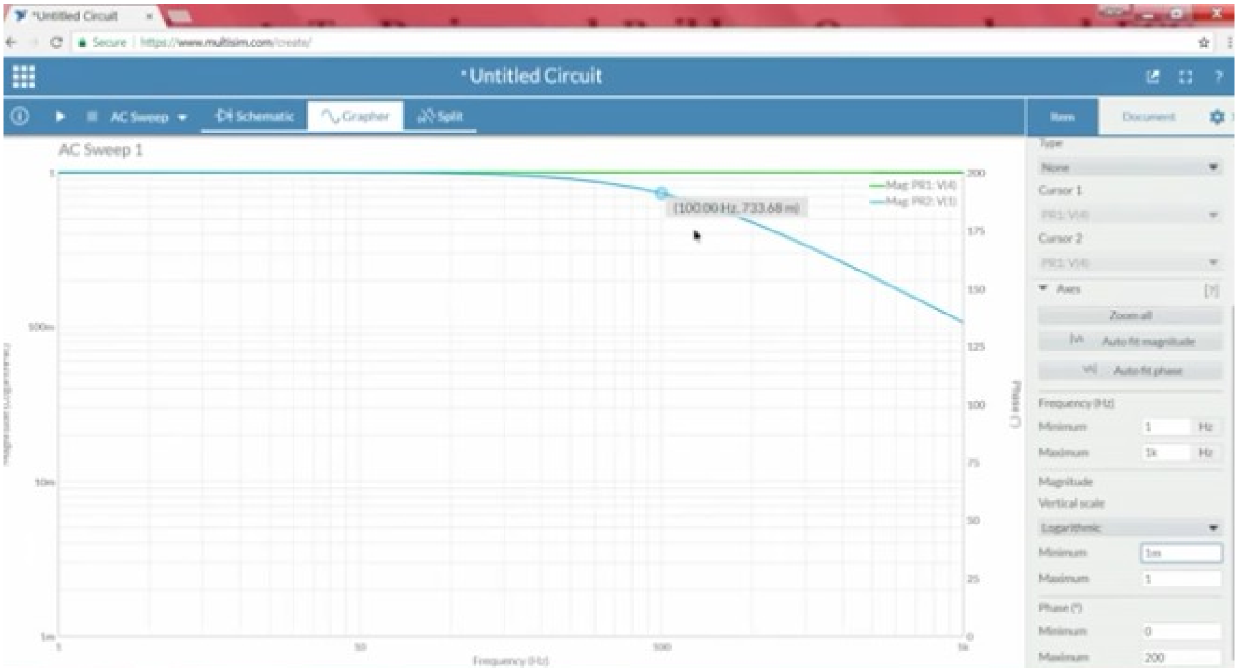

right, now how do we do the same thing, how do we understand when we look into, when we are looking into the CRO, so in order to understand what we do is that, rather than going with AC sweep I'll go with interactive, so here starting from 1 hertz will change,

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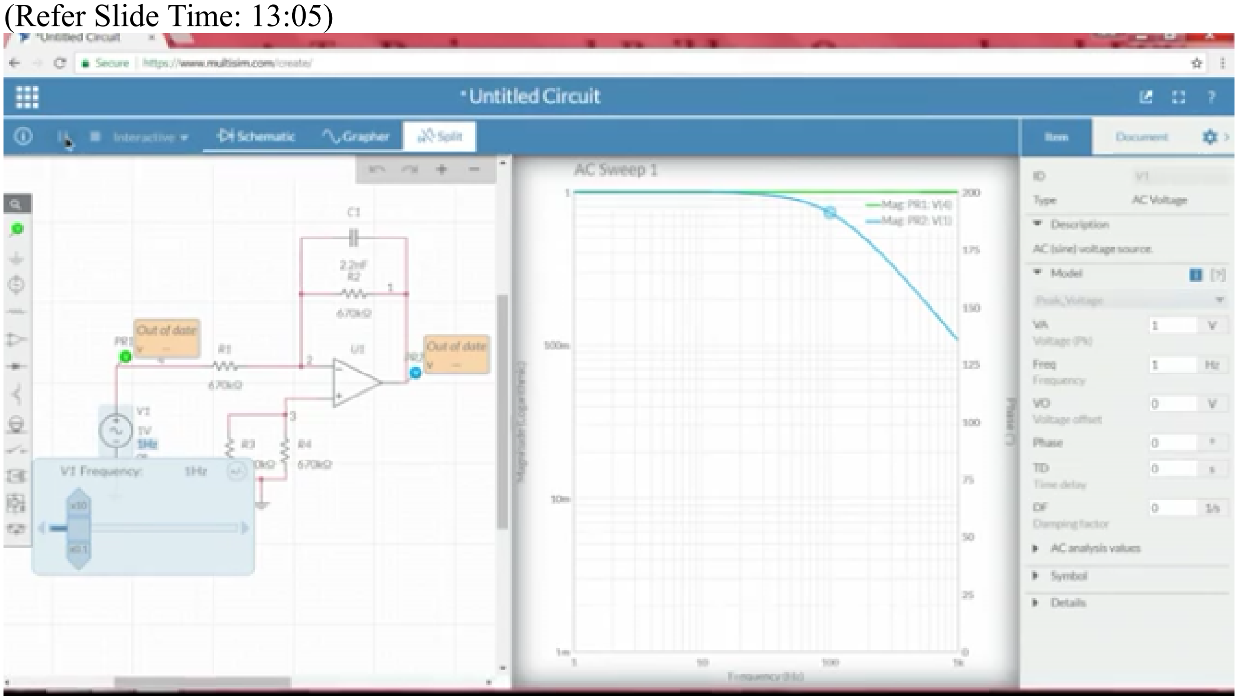

and we will observe the input and output frequencies, so I'll increase the time division,

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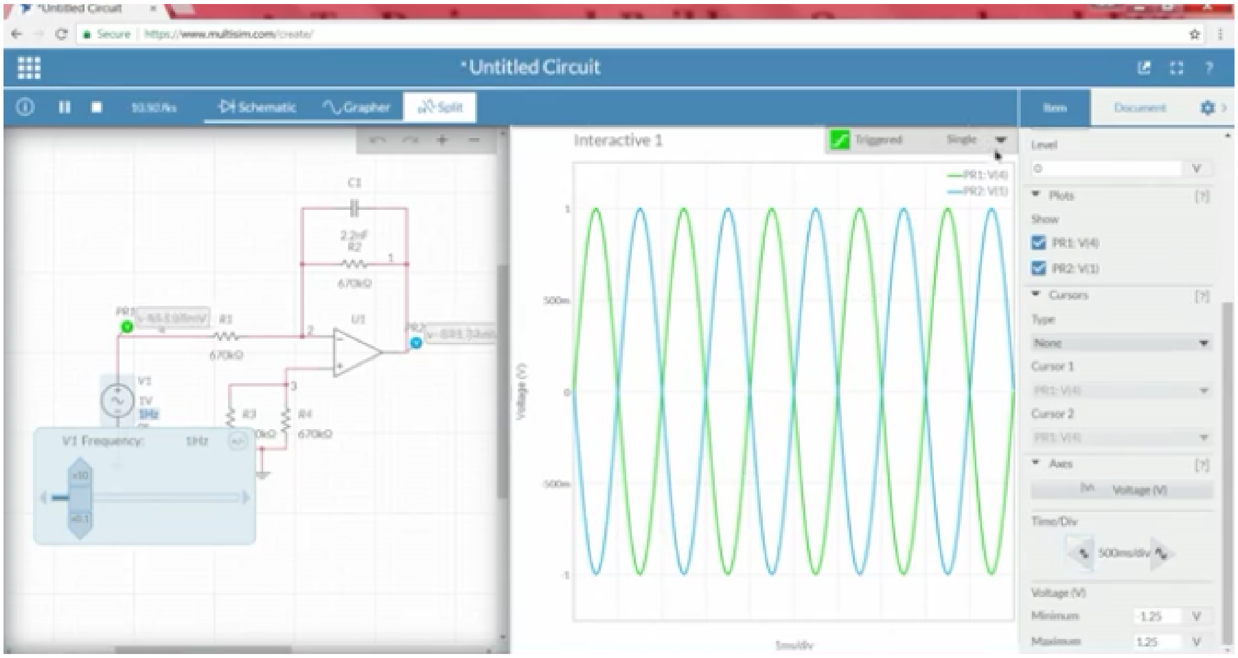

so we can see that we can easily observe the phase difference so I'll make it auto, we can see the phase difference this is R input the green colour one, the blue colour one is nothing but R output, because of we are using inverting there is a phase difference and the amplitude wise it is one and the same.

Now I'll slowly increase the frequency, there is no change in our gain, so with a rate of 20 hertz, so I'll go with a 20, I'll make it as single or auto,

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and in order to visualize I'll decrease the time division, right, then again I'll go with the 40, right, so in order to understand that let me put a cursors, so what I'll do is I'll go with the cursors and make it as an Y axis cursor, so at what point we have to see? We have to see a point

at 0.707, so I'll put the cursor one at 707 millivolts, so we can see the right now the cursor yes, so cursor one is at 70,
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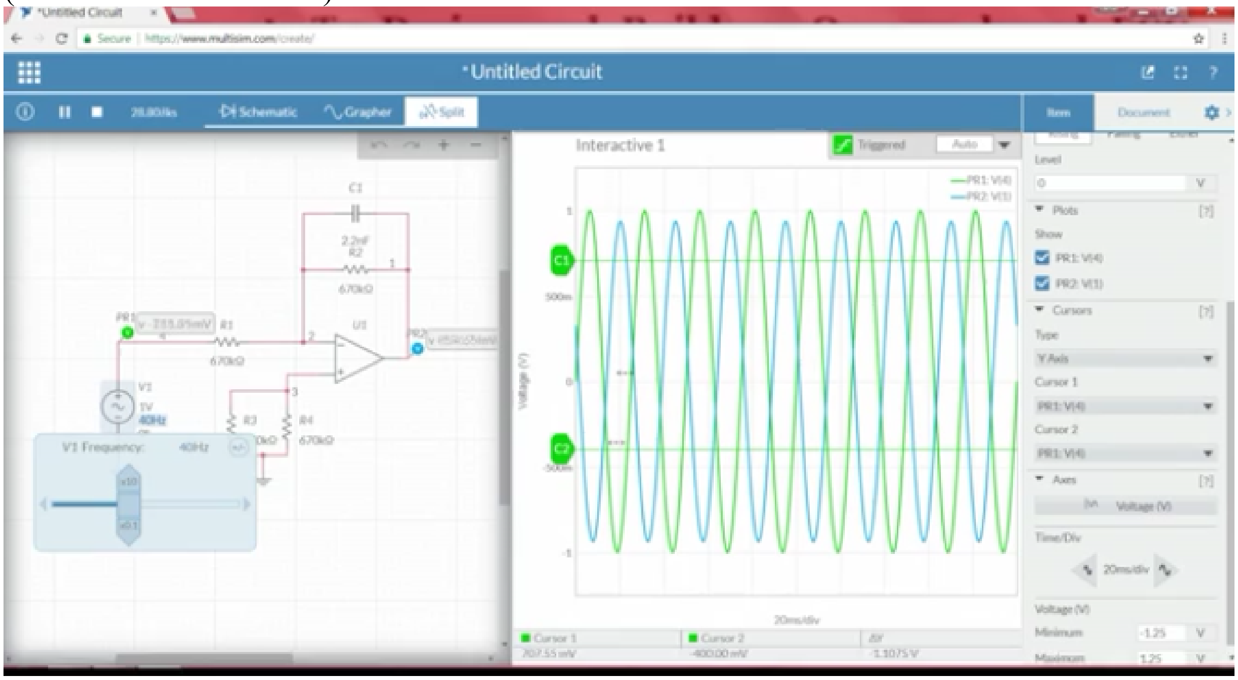

whenever this blue colour line is below the 707 that frequency is nothing but our cutoff frequency, right, so I'll increase, so I'll increase to 50, now decrease yet, so I'll go with 60 no change, not lesser than 707 millivolts, 80 not even, so I'm going with 100, right, almost close.
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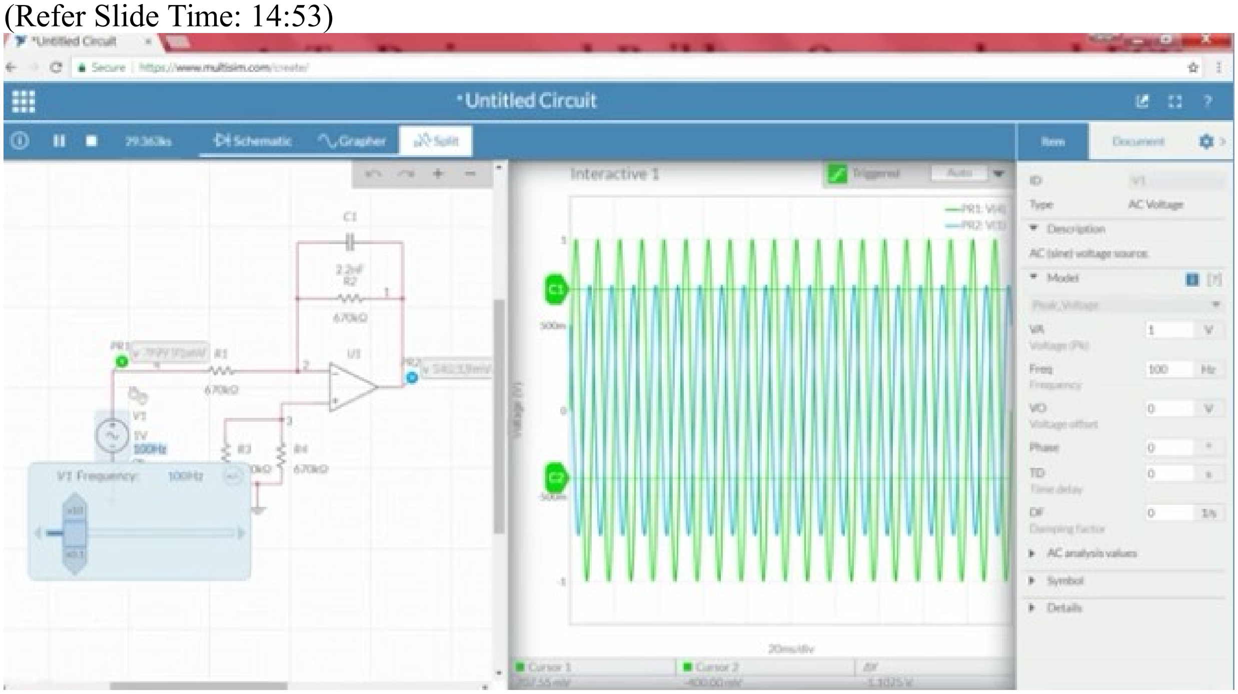

Now we'll increase one by one, so before going that what I'll do is that little bit time divisions I'll increase it so that easy to view, increase right, somewhere around close to 105 almost coming close, now I’ll increase to 107, right, even little bit higher so I’ll go with 108, right if I see that if the input is at 108 hertz the output voltage is 707.55 millivolt,

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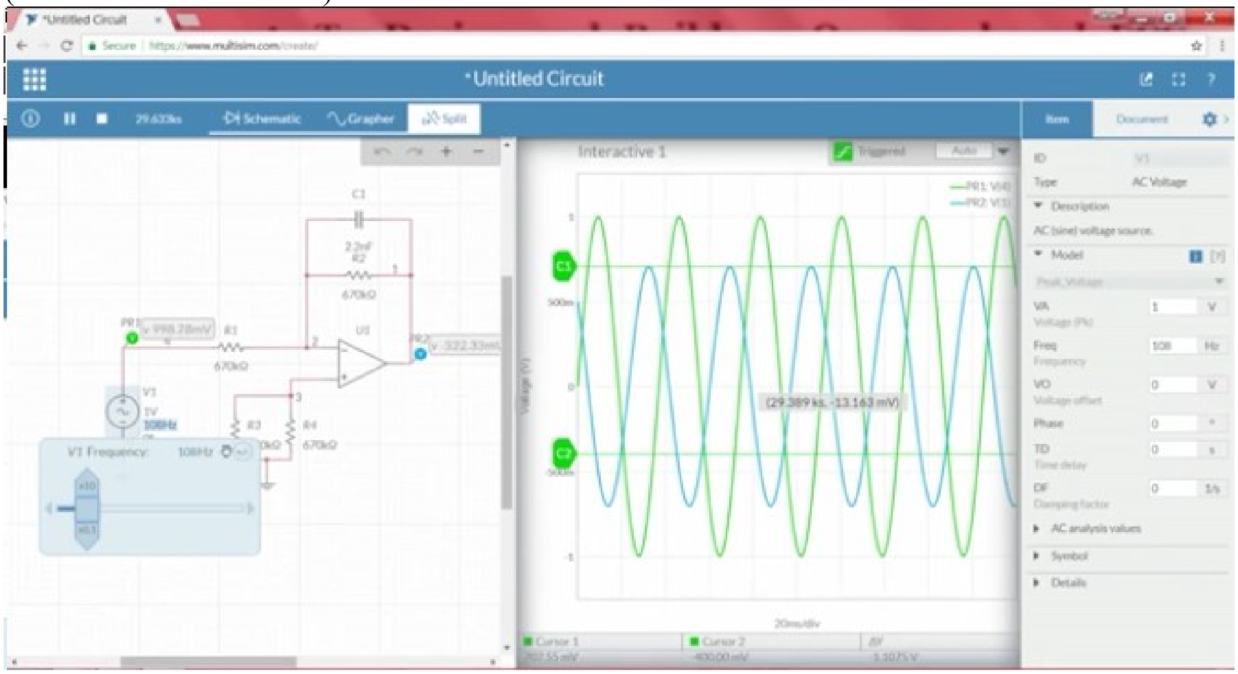

even if I increase it 109 right, 110 started slowly decreasing it, 120 decreased, so that particular value is nothing but our cutoff frequency, so in order to visualize by using a time domain signal by looking into CRO one way to do is slowly increase your input frequency whenever it goes to the 3DB line which is nothing but 0.707 volts to that of your 70% is of your maximum voltage, that is nothing but 707 millivolts, whenever the input voltage is lower than 707 or just at that point of 707 millivolts that frequency is nothing but our cutoff frequency, so we have seen that it is nothing but somewhere around 108 hertz, right.

But even though if I increase the frequency it is not suddenly attenuating the two even below then 500 milli, the reason is the rolling factor, the role of factor of first order filter is 20DB per decade because of very smaller rolling factor it will also allow particular band of frequency to pass through, but we require a cutoff, we don’t have to pass a frequency at 150 that is what our power line odd multiple frequency, but since role of factor can be you know, if I observe at 150 hertz we can see that right, only it is even much more below than our cutoff frequency, so we don’t have any problem.

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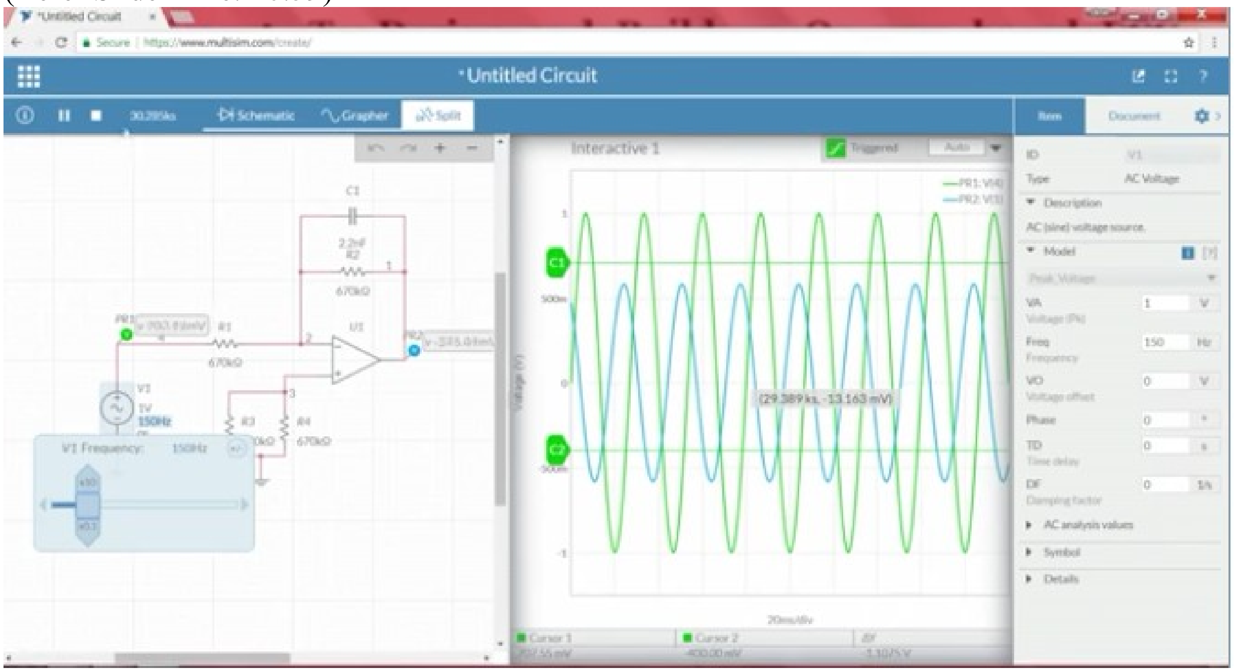

Now we'll simulate, we've done the simulation, we will do experimentally the same thing, since we do not have a frequency spectrum we will show you how to do the same analysis in our using breadboard and use a function generator, as well as an oscilloscope and we visualize the same thing and we will observe it what particular frequency it is reaching to 707 milli volts.

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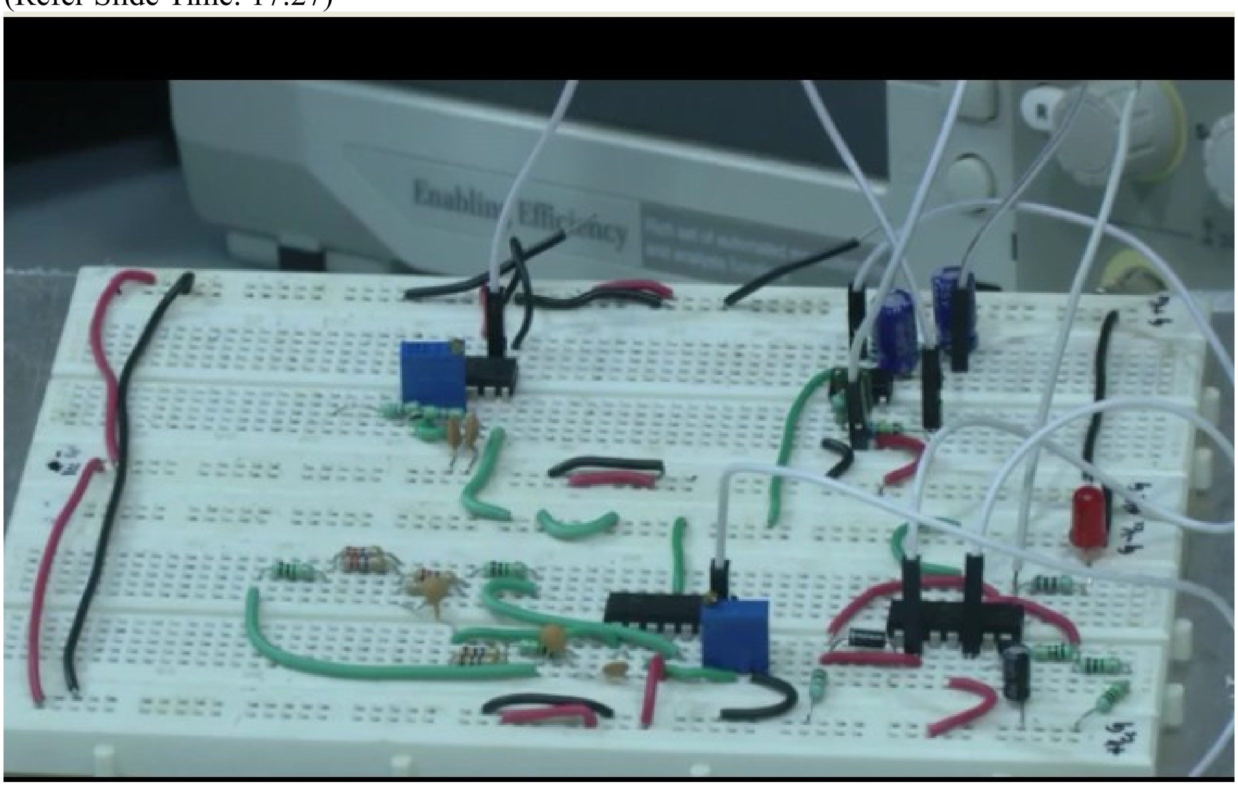

When we look into our breadboard this is the complete signal conditioning as well as a processing circuit, that we are going to use in this particular case study, so if we observe here this part is our instrumentational amplifier part, this part contains low-pass filter, if I see I'm using 2 nano farad, this is our 2 nano farad that green colour wire, here we can see, sorry this green colour, this capacitor is our 2.2 nano farad capacitor and this are our 2 resistors, one is here and other one is here 670 kilo ohms, right, this is TL0A2IC so it has a dual op-amp, one side of op-amp we are using low-pass filtering.

Now we will see this low-pass filtering circuit how it works, right, and the connections I have already discuss in the simulation as well as even our power point too, so the same circuit I have made it on the breadboard, and we'll apply input from the function generator, right, and we will observe the output in our oscilloscope, so how do we do that? So first thing since it is active filter we have to power it, so we'll take a voltage source, we take a voltage source we'll connect +15 and -15 to our breadboard.

So now what we are doing is onto this particular part wherever we have designed a filter low-pass filter which is similar to that R, the experiment that connection that we have seen in our simulation as well as our you know presentation we can see one set of an operational amplifier is a low-pass filter, so now by using a function generator, so function generator it is being connected to the input resistor, so here we can see this input resistor we have connector, this white colour wire, right, so from one side of you know CRO oscilloscope we use a wires and we'll connect it to the same point so that we can see the input signal too, so here I'm connecting it to oscilloscope too, this is the input to oscilloscope, input signal is connected as a input to the oscilloscope and ground to ground.

Then what is other one? We also have to see the output, so another probe we are taking another probe of oscilloscope and connecting it to the output, so output here is 7th pin, right, so 7th pin is this one, and this is to ground, so what we have done here? So from our voltage supply we have connected +15 and -15 to their respective inputs provided on the breadboard so that here by using wires we have already connected to all the IC's, so whenever I switch on all the IC's whichever used on the breadboard will be a port with a +15 and -15, okay.

Then from the function generator, using a function generate we will generate different frequency, input sinusoidal frequency signals starting from 1 hertz up to more than 100 hertz so that we can observe at what frequency the input is becoming 707 millivolts, right, so 0.707 volts, so that is being connected as an input to the system, to the low-pass filter, so at the point of input resistance which is nothing but R1 resistance, and output is taking at 7th pin of op-amp, this is sinusoidal to TL082 so we are using the second op-amp of the TL082 so the output is at the 7th pin, so we have connected to the 7th pin.

Now I'll switch on the power supply,
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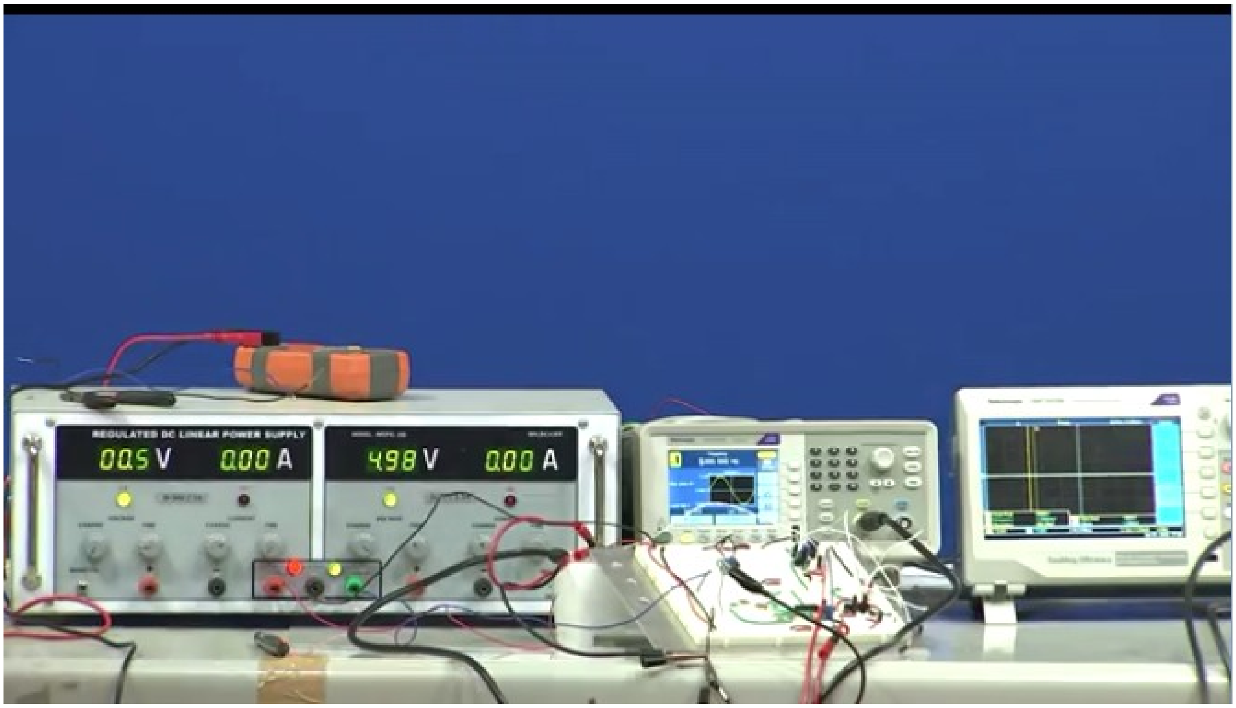

okay, we switch on the power supply and make it as auto-scale, switch on function generator, increase the scale, so the input voltage applied is, so here we have to change the input voltage, so the amplitude, I'm going to the amplitude setting it as 1 volt, and offset I'll make it as 0, offset as 0 volts, right, so we can see,

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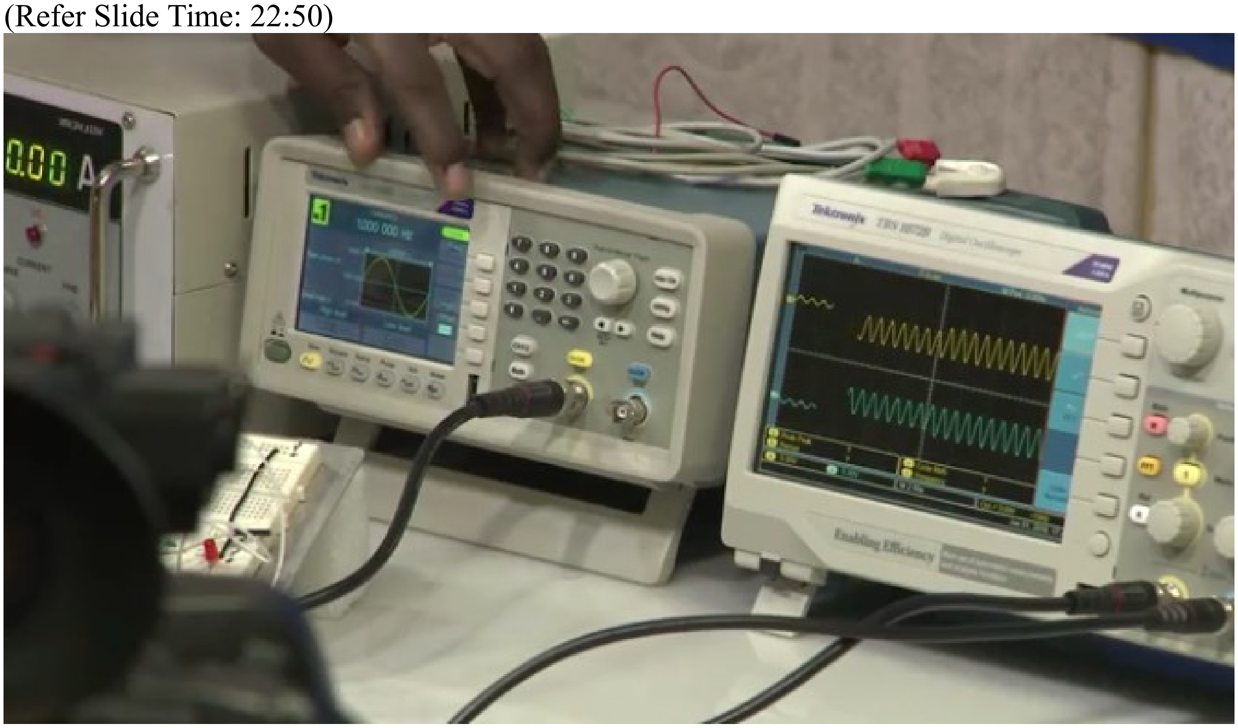

so rather than taking this what I'll do is that 2 volts peak to peak we'll apply, so we'll go to high, sorry amplitude to 2 volts peak to peak, so we can see 1 volt input as well as 1 volt output, now to visualize the signal so I'll just increase the scale, scale to 1 volt both the input as well as an output, and make it a single point so I'm shifting both signals to one point, that is zero position, so yes zero division and we have an offset of 500 milli, even I have to renew the offset here, so I'll go to offset and make it 0 volts, now there is no offset we can see that.

Now slightly change, increase the scale right, so yellow represents our input signal, right, and the blue one, the second one is our output signal, when we observe there is an phase difference between the input and output, this is because of our inverting amplifier, so we know that inverting amplifier will have a 180 degree phase shift because of that, now but what about the amplitude? We have to look about the amplitude now, isn't it? So what is the voltage below which we have to consider, what is the voltage that we have to consider to calculate our cutoff frequency, 707 millivolts, so what I do is that in order to understand I'll create a cursor, and I'll create amplitude cursor, right, so I'll put the cursor at 707 milli, so since we have even more you know range, what I'll do is that I'll increase, I'll decrease the width of it, so I'm making it as 500 milli as 1 block, even for the negative to 500 milli.

Now by using a, okay, sorry, I'll change the division 0, so 1 division now it is equal to 500 millivolts for both input as well as output too, I'll go with the cursor, I'll put it at 707 millivolts, so I'll go to cursor 1, right now it is at 180 milli, I'll go, slowly I'll go till 707 millivolt, 520, 580, yes 700 millivolts, so I'll observe by changing the frequency, input frequency we'll see at what particular frequency the output voltage is below that particular

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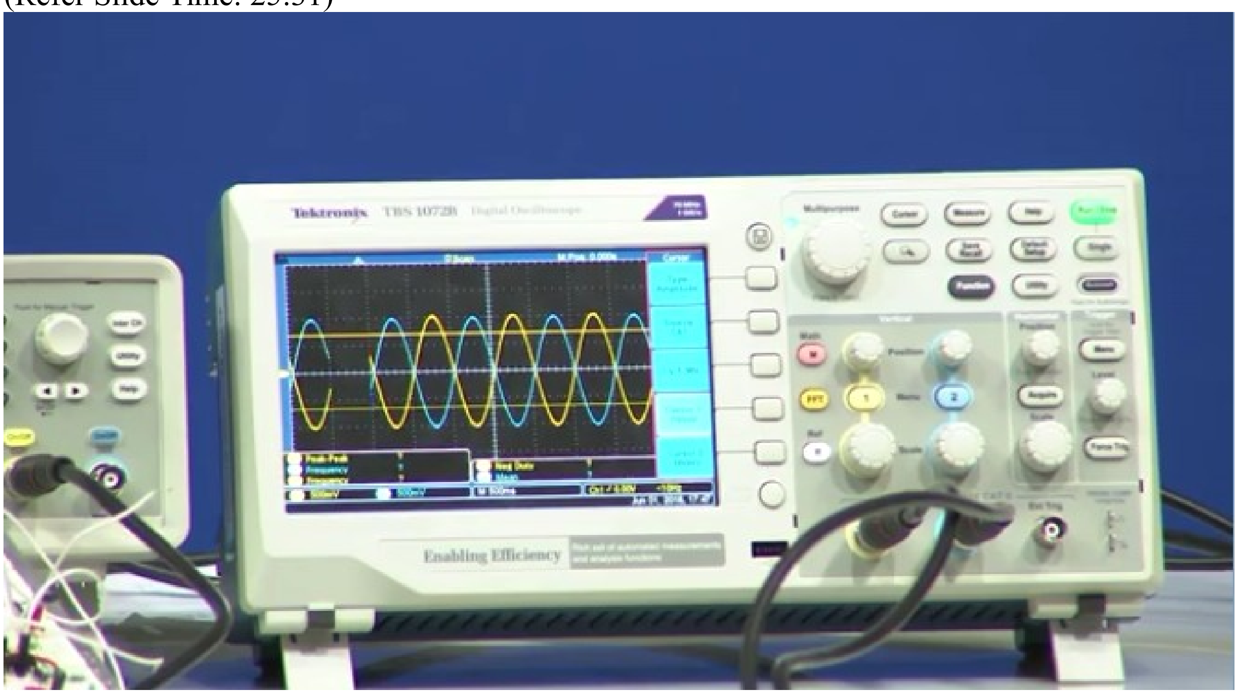

threshold that we have set, right, the threshold is 707, now we'll slowly change the frequency at an interval of 20 hertz, so when we look into the function generator, right, when we look into the function generator I'll go to the frequency,

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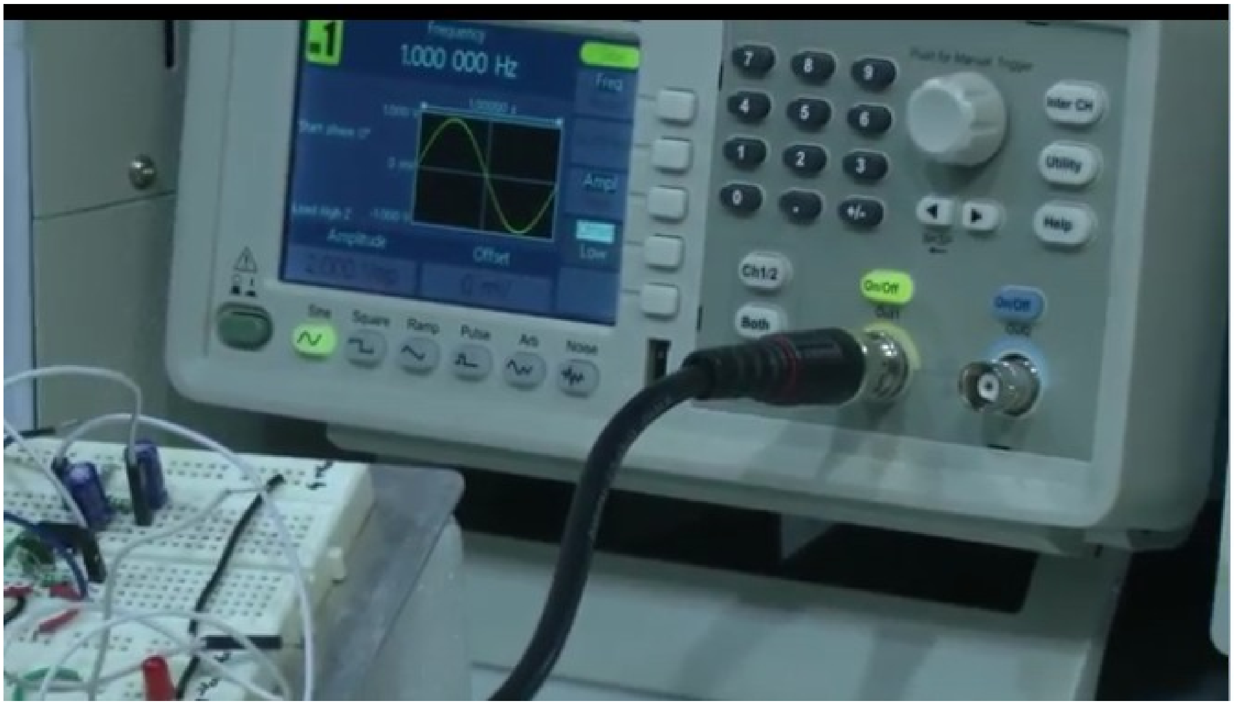

and I’ll change it to 20 hertz, right now it is at 10 hertz, observe the input and output I’m changing the nob there, now when I see the output still the amplitude is still following, right, it is even greater than the line, that means this is not our cutoff frequency.

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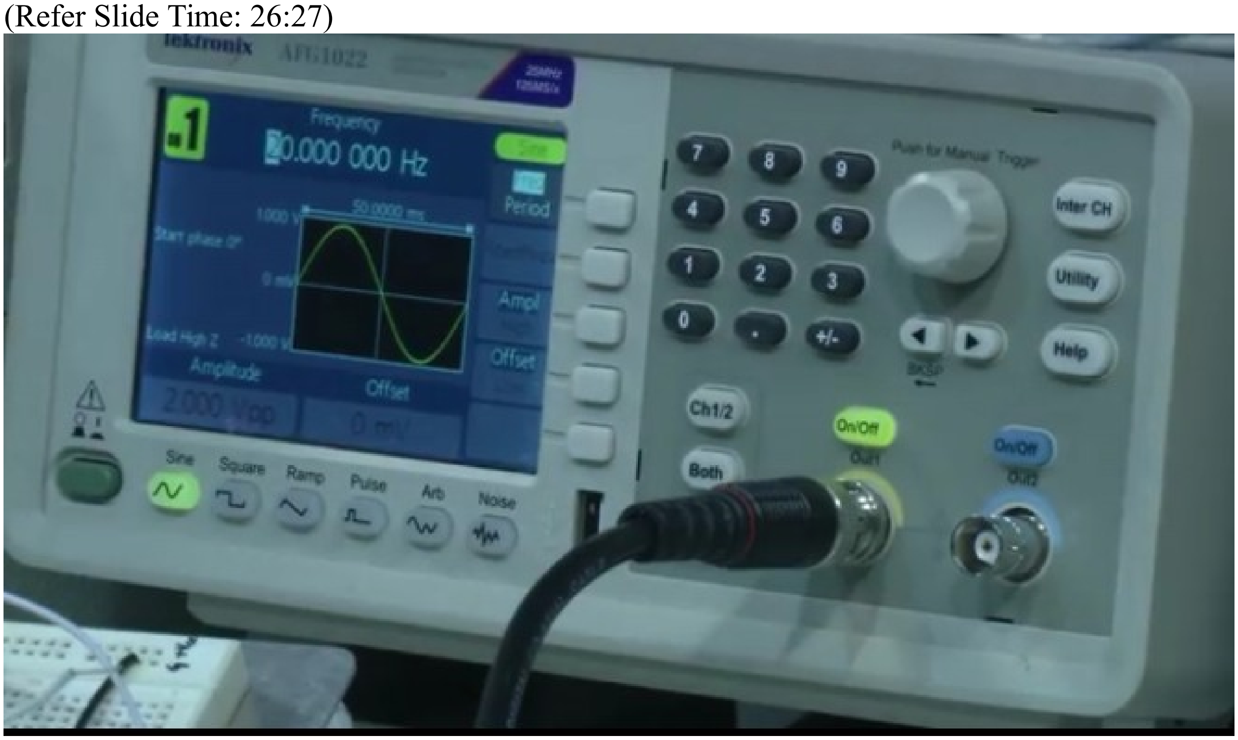

Now I’ll change it to 20, going here, going it to 20 what is a frequency we are getting? Right, observe the frequency,

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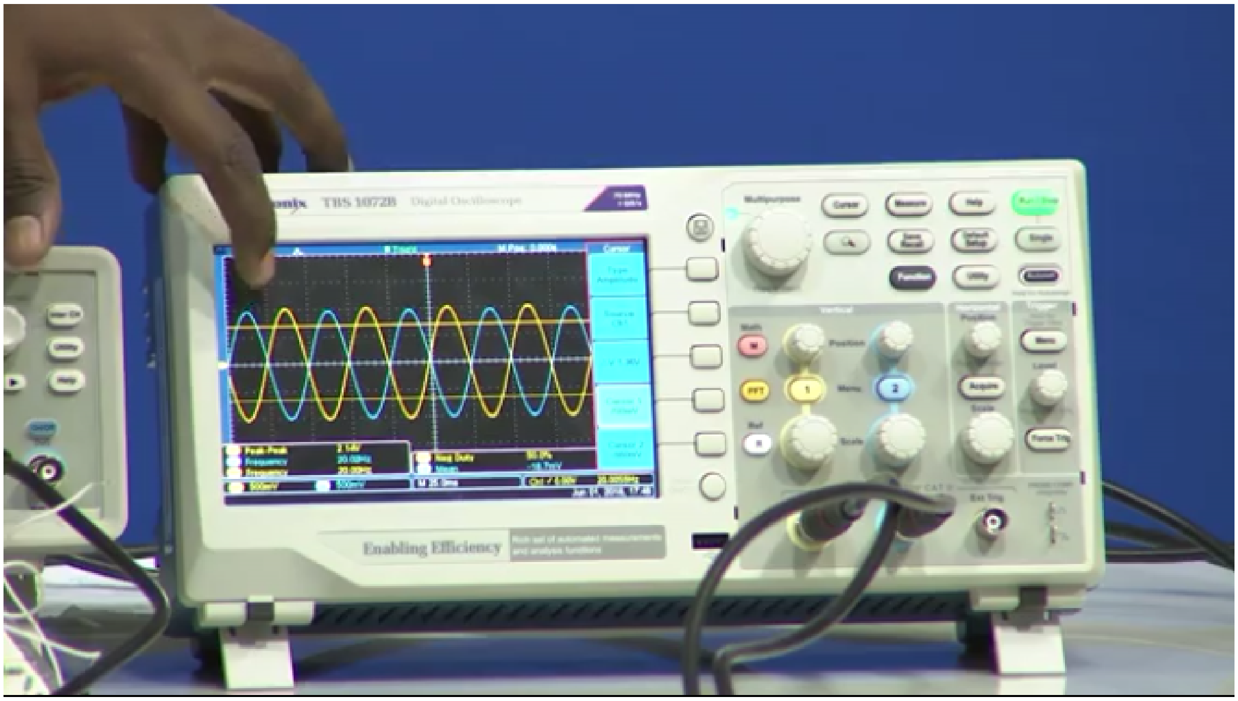

frequency is same, amplitude even above the threshold value, so that means even this is not. I'll increase to 30, 40 in this case, I'll go to 40, observe the output, right, even more, even more right, now go to 60, 40, 50 and 60 observe, same, so even that is not our cutoff frequency, then 80, even observe it is even greater than the threshold value, so the threshold is at 700 milli right, then again I'm going to 100, right, when I look into the oscilloscope I can see that very close to the cutoff,

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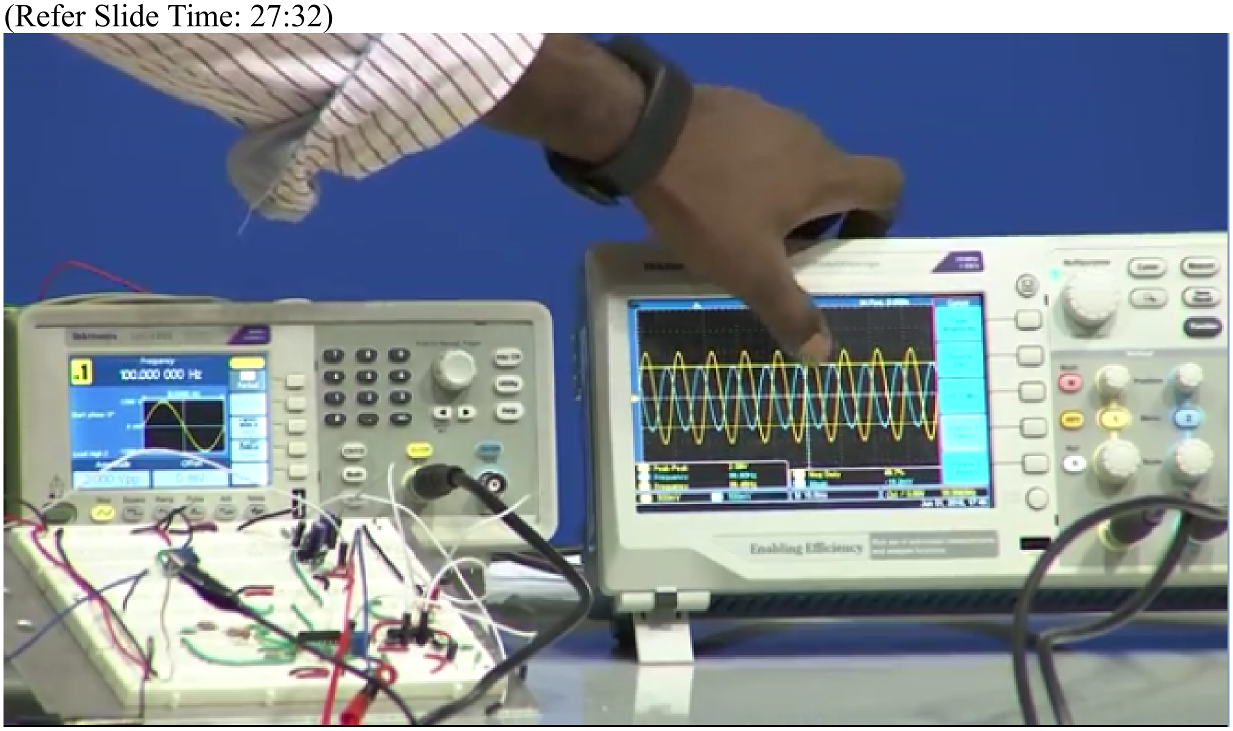

very close to our 3DB line, right, very close to the 3DB line which means that this is our almost near to our 3DB line.

So I'll slowly increase, I'll slowly increase the input frequency and we will see at what point it is started decreasing it, so to visualize it I'll increase, I'll change the scale, so you can see 102, 103, 4, 5, 6, 7, 8, now if I clearly observe here, when we zoom into this particular point, at this point it is slightly below than that of our threshold value, this threshold is 700 millivolts, right,
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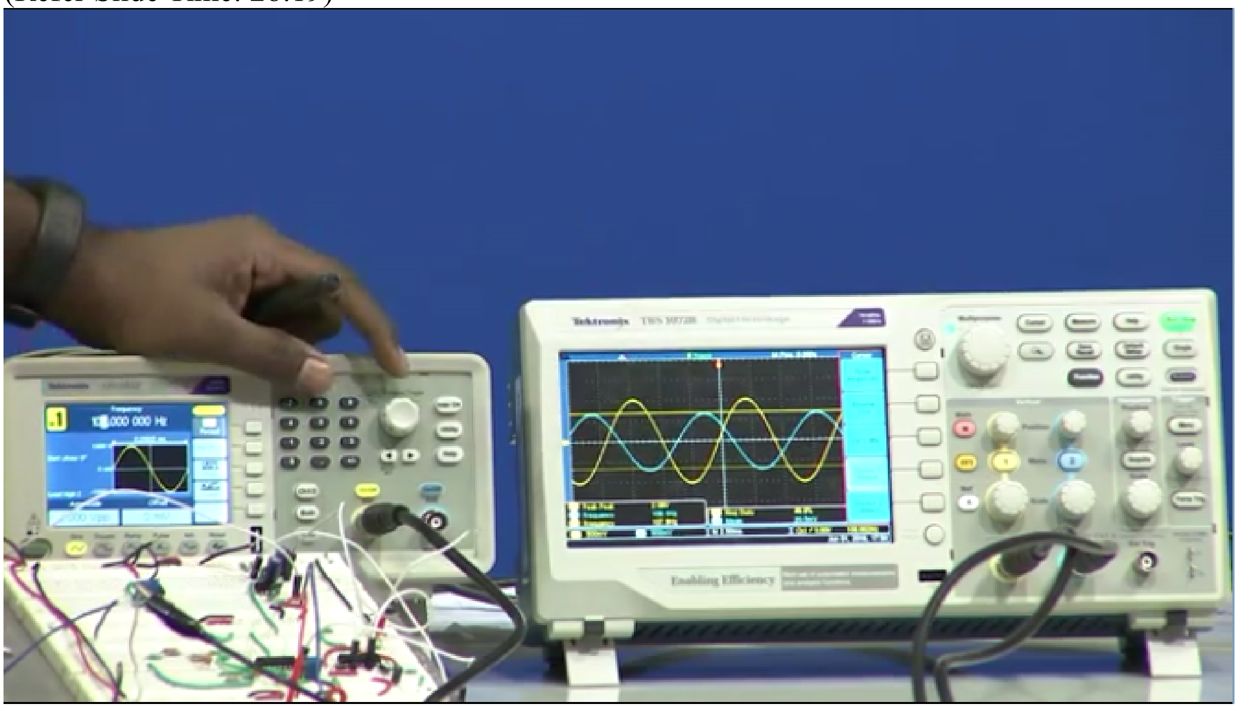

so but if it is greater than this value, you can see the value is slowly decreasing that means the output is attenuating, right we can observe that values slowly decreasing, the amplitude, the output see we can observe that only the output amplitude is decreasing, now when we re-colour our filters we know that the output will not remove, the output will be attenuated, for a low-pass filter above the threshold frequency, sorry about the cutoff frequency the output will not be removed, it will be attenuated, so here we can see higher the frequency the amplitude of the output is slowly decreasing.

So from this experiment we can conclude that the cutoff frequency after filter is somewhere close to 108 hertz, right, even with our theoretical design we got 108 hertz, even with our simulation design we got 108 hertz, so this particular filter, this particular operational amplifier, this particular circuit we will use this for our low-pass filter circuit, so that the power line interference due to odd multiples will be completely removed by using this low-pass filter.

Now what next? We also required to have a notch filter as well as high-pass filter.
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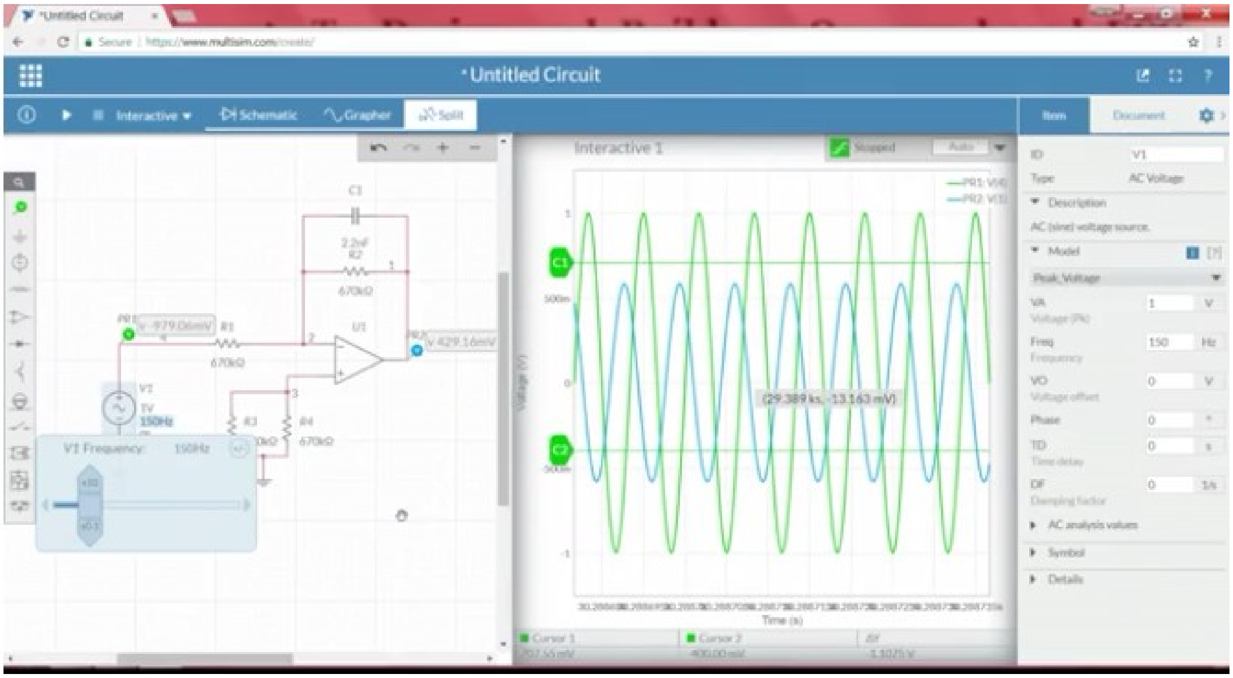

Now we’ll look into the high pass filter circuit, right, we’ll look into the high pass filter, so when we go to the presentation….