Integrated Circuits, MOSFETs, OP-Amps and their Applications
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Lecture – 26
<u>Operational Amplifier as a Band Pass and band reject filter</u>

Welcome to this particular module, and this is the module for our lecture, but where we are looking at filters right. So, we have seen bend we have seen the filters that will pass a particular band and it will filter out particular band correct. So, we have seen low pass filter and high pass filter. Low pass filter we have seen passive filters and we have seen active filters same way in high pass filter we have seen passive filters and we have seen active filters.

Now, let us focus on low pass and high pass combination. So, what will happen it will be a band pass filter. So, how exactly band filter we can design using operation amplifier let us see it. So, we will see two kind of filters one is band pass filter and another one is band reject filters. And we will think some examples. So, we can understand how we can decide this circuits alright. So, if you come back to the screen and what you see here is a band pass filter correct band pass filter.

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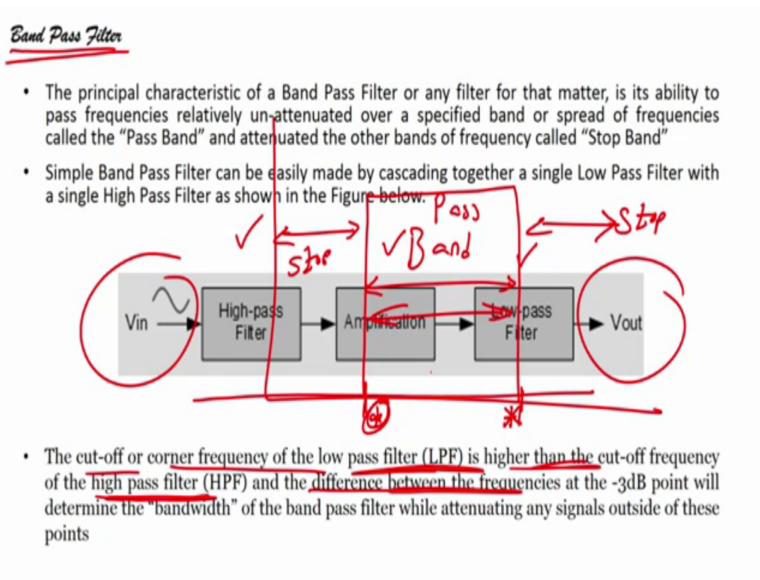

Now, the principle characteristic of band pass filter or any filter for that matter is it is ability to pass frequencies relatively, un attenuated relatively, un attenuated over a specific band or spread of frequency called pass band and attenuate the other band of frequency called stop band correct we are seen this. That when you design a filter a certain band of frequency is allowed to pass which are called pass band frequencies incident frequencies, that we do not want they are attenuated it is called the stop band frequency very simple right.

Now, a simple band pass filter can be easily made by cascading single low pass filter with a single high pass filter super easy right. If we knows how a low pass filter circuit is, if you know how high pass filter circuit is then by cascading low pass filter with a high pass filter, we can design a band pass filter.

So, if there is a block diagram it is a high pass filter at the starting of the block, this block diagram for the band pass filter alright this is our band pass filter, the first block is high pass filter, then we have to amplify then low pass filter alright. So, high pass and low pass combination of this cascading of this we will with we will result in a band pass filter; input peak to peak it is a term frequency we will see what is the output which frequency it can pass alright. So, the cutoff or corner frequency of the low pass filter is higher than the cutoff high pass filter and the difference between the frequency at minus 3 d B point we will determine the band width of the band pass filter alright. So, what does it mean? The cutoff or corner frequency of low filter right is higher than the cutoff frequency of high pass filter right and the difference between this frequency; that means, if I draw right the cutoff frequency of the low pass filter and the cutoff frequency of high pass filter write the difference between it; that means, this is the difference that is the band which will be allowed to pass. So, this is a pass band this is the pass band and this is the stop band right stop band, this is also stop band, this is what it means by this sentence ok.

The cutoff frequency or corner frequency of low pass filter is higher than the cutoff frequency of high pass filter right. So, if this is my cutoff frequency for low pass filter, this is higher than the cutoff frequency for my pass filter right and the difference between two that is this difference is my band of frequencies, that I want to and it is my band pass filter it is my band pass filter.

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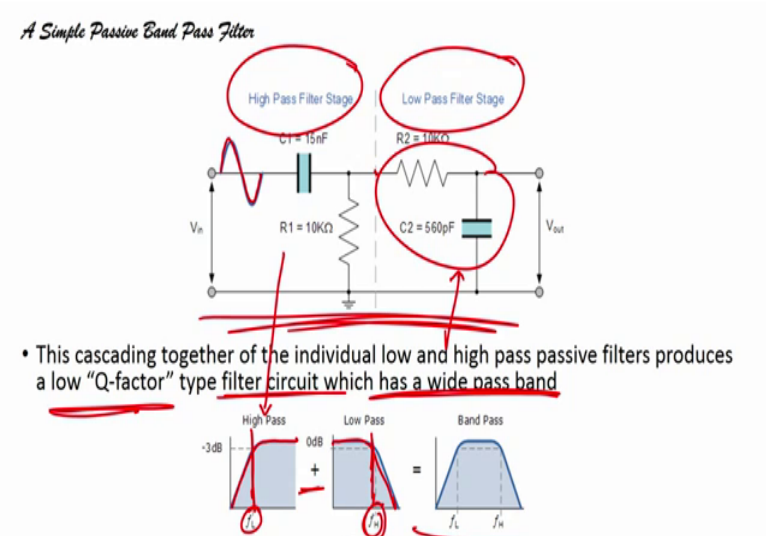

Figure 10

A simple band pass filter alright a simple band pass filter how we can design? We can use high pass filter stage,, we can use low pass filter stage, we can cascade both the stages. So, you see here we have capacitor and resistor this is our high pass stage. I apply a signal right to the capacitor and you know how the high pass filter works, this output of the high pass filter is fed to the low pass filter, and thus; in thus what will happened? In this particular case in high pass filter, you can have a band of frequencies that will pass above this f L right.

In case of low pass filter there will be band of frequencies that will pass below this f s that means, this one right this particular band alright. So, if I merge both if I cascade both what will I have? I have my band pass filter, with this cascading together of individual low pass and high pass filters produces a low Q-factor type filter circuit, which has a wide pass band which has a wide pass band. Very easy to understand band pass filter once you know how the low pass and high pass filter works.

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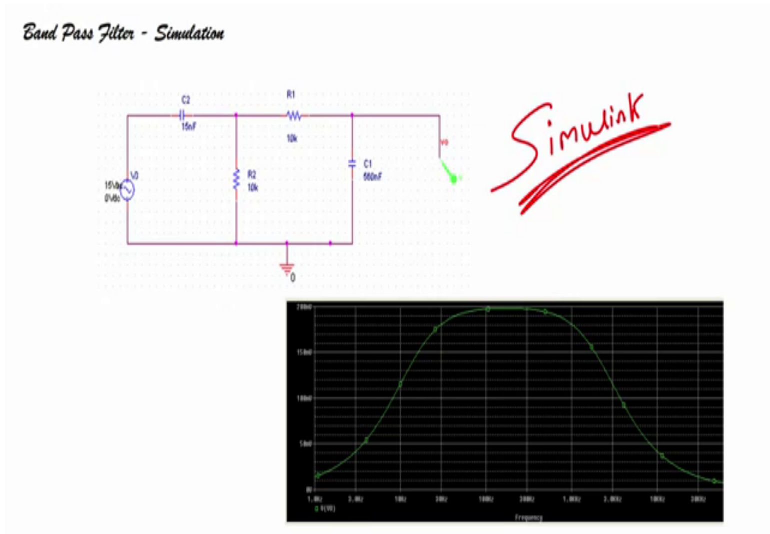

Figure 10 a

So, we will do this experiment also is called Simulink. We will perform a simulation with a software right and we will see how we can design the circuit using a Simulink and how we can obtain this point, obtain this plot for the band pass filter.

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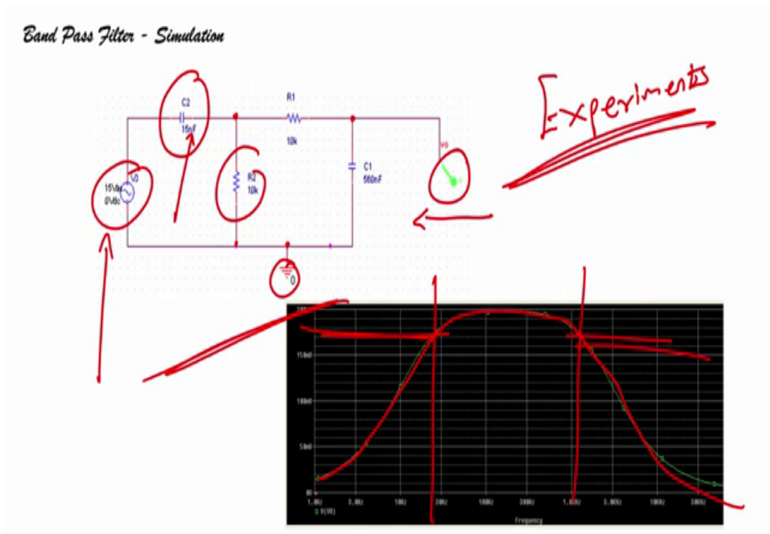

Figure 10 a

This will perform in the experimental portion, when we perform the experiments for designing the filters we will see how we can design a band pass filter. In general we will see how we can get the source from the library, how we can select the capacitor, how we can define deferent values of capacitor, how we can define and break the resistors, I have again connect this resistors, how we can connect this capacitors, how we can select the ground from the library, and how at what point we want to see the output voltage.

When we design this thing and we apply a fifteen volts peak to peak f is a sudden frequency right, that we have selected and we have to understand that what is the band of frequency that is around two pass, we will be able to see that whatever frequency we have selected that minus 3 dB that we were get minus 3 dB. So, it will be bend like this that is allowed to pass and that is why the band is not passed, thus there it is a band pass filter.

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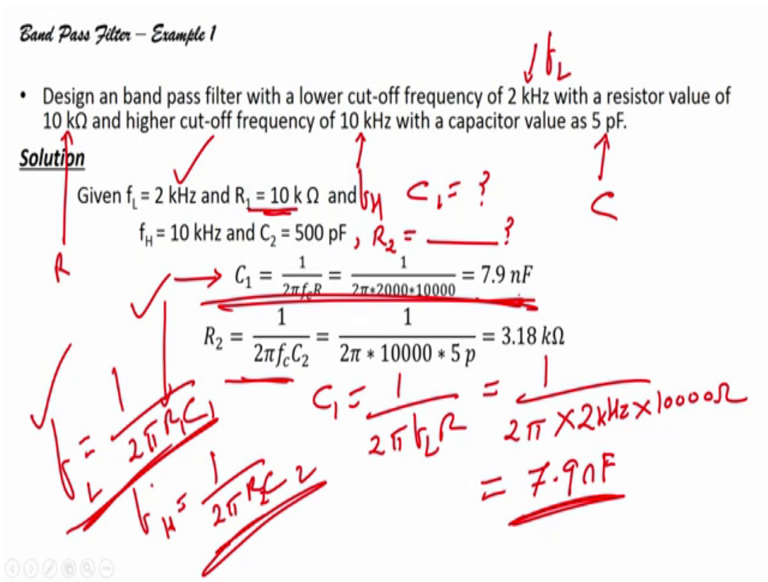

So, let us take an examples to make it easier design an band pass filter with a lower cutoff frequency of two kilo hertz, and beta resistor value of 10 kilo high cutoff frequency of 10 kilo hertz capacitor value of 5 Pico farad. So, what is given f L is given right f H is given. See f L is given right f L is given, f H is given. This is your f L this is your f H right. Now you are given R there is a resistor here, we were given c which is here right. So, we know that f equals to correct.

So, from here we can find c equals to 7.9 picofarad correct. Now we for second we know that this is for first one right. So, f again f equals to. So, f c 1, f c 2 we can say like this 1 by 2 pi right. So, this is this one we have calculated because we know value of R 1, but we do not know value of C 1 we do not know, here we know value of C 2, but we do not know value of R 2 right. So, first is the equation for f L, this is this is equation for f H right from here, from here, and from here we can find R 1 C 1 R 2 C 2.

So, here what is given? We are given value of f L then we have R 1 what we do not have C 1. So, C 1 would be equal to 1 upon 2 pi f L into R we can substitute value one upon two pi f L what is f L? F L is 2 kilo hertz into resistance, resistance is 10 kilo correct. So, we will get value of C 1 equals to 7.9 nanofarad, we get C 1 equals to seven point nine nanofarad beautiful very easy.

Now, let us see how we can find value of f H and using f H, how can find R 2 how we can find R 2. So, f H what we f H equals to?

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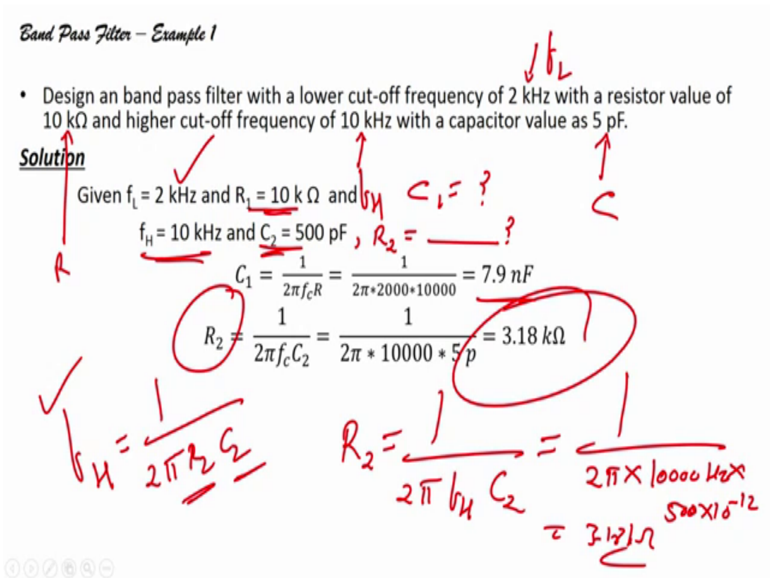

1 by 2 pi R 2 C 2 what we have we have f H, what we have we have C 2, what we do not have R 2. So, R 2 will be 1 divided by 2 pi f H C 2 right. So, this will be 1 divided by 2 pi f H what is f H? 10 kilo hertz right hertz into C 2 500 picofarad, 500 10 to the power minus 12 so, that will give us 3.18 kilo ohm, that you can see here 3.18 kilo ohm correct.

So, using the given values you can designed a band pass filter very easy right absolutely easy we have to just understand and remember one equation, and then you can easily design the circuit that is your band pass filter.

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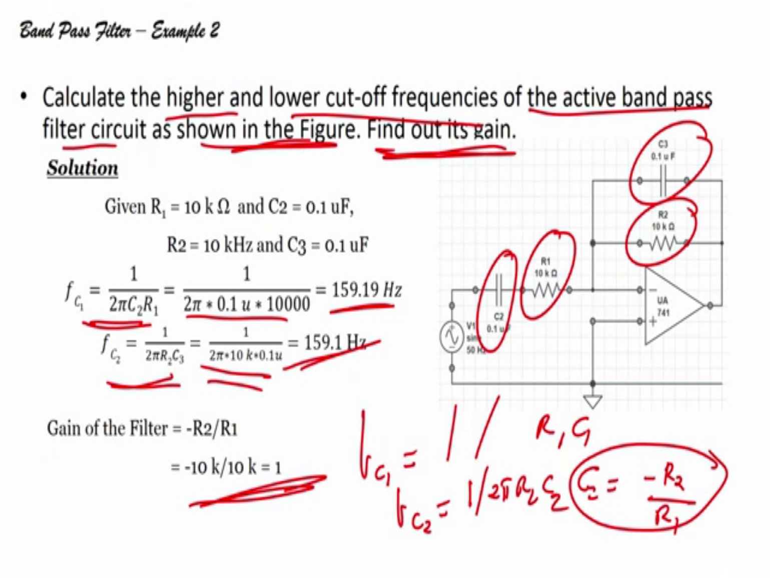

Now, if you are given a circuit right again this is a band pass filter and you are applying the signal to the inverting terminal. So, it is a inverting amplifier right inverting amplifier we understand. So, gain of inverting amplifier you already know minus R 2 by R 1 right frequency we know f equals to let us say we right f C 1 and f C 2 right because we have band pass. So, f C 1, f C 2 correct. So, we will write f C 1, f C 1 equal to 1 by 2 pi R 1, C 1; f C 2 1 by 2 pi R 2 C 2 correct and gain we know this formula right what is gain calculate the higher and lower cutoff frequency of active band pass filter as shown in figure find out it is gain.

So, let us find out it is gain first right gain first gain first. So, R 2 by R 1, 10 by 10, minus R 2 by R 1 minus 10 by 10 gain equals to 1 easy super easy right, now let us see the cutoff frequencies. So, f C 1; f C 1 equals to 1 upon 2 pi R 1 into C 2 right because C 2 is here R 1 is here right f C 2, 1 upon 2 pi R 2 C 3 right substitute the values. Substituting values what we get? We get the value of f C 1 and f C 2 easy very easy right super easy.

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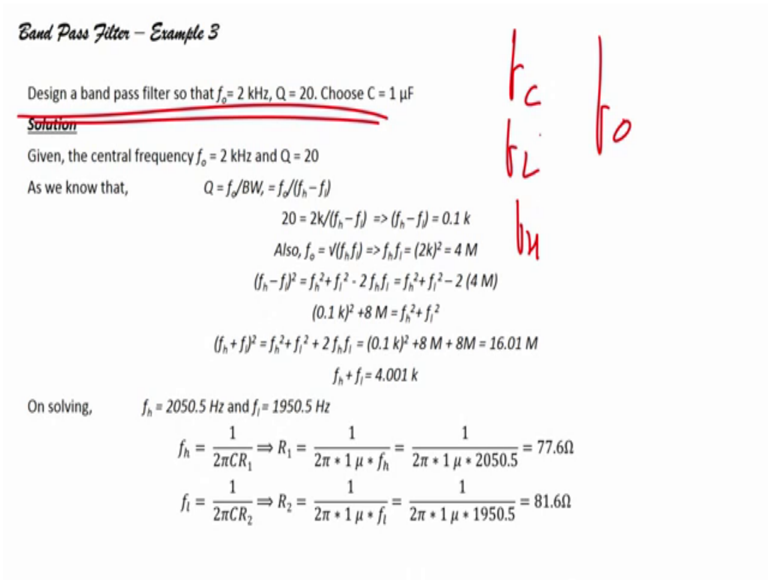

Then let us do one more problem let us solve one more problem, design a band pass filter show that f o equals to 2 kilo hertz using different way of putting the things, some people say f c some say f L, f H some say f o right does not matter. Do not worry about it never get confused with this kind of terms right. So, we f o 2 kilo hertz quality factor 20 c equals to 1 microfarad in this case central frequency f o. So, what is f o?

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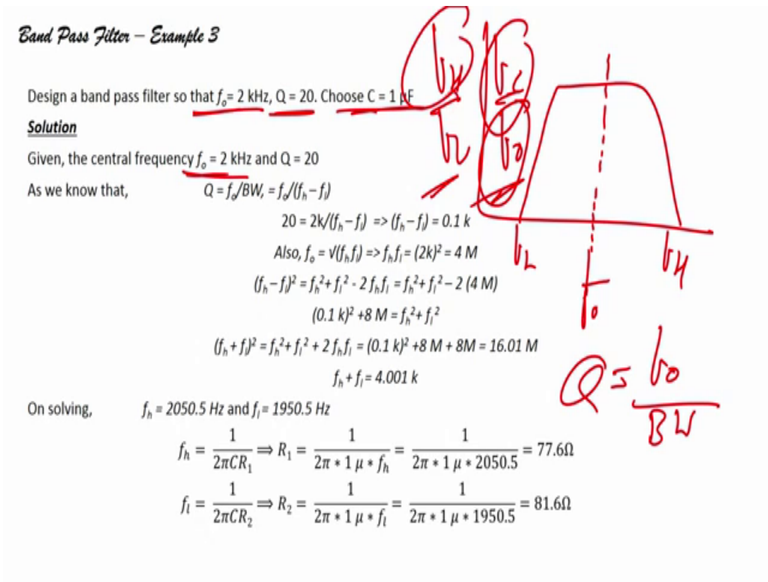

See central frequency. So, you have this right f L f H right and this will be center frequency. So, f o right and quality factor can be f o divided by band width quality factor can be f o divided by bandwidth. So, when I say we have people say f H people say f L people say f c people say f o this is term for everything, that does not mean that everything is same.

This is critical frequency this is central frequency this is higher cutoff this is lower cutoff. So, you have to understand what are the terms, but point is do not get confuse if you see a suddenly new term do not get confused the central frequency is given by f o we have seen here right for this.

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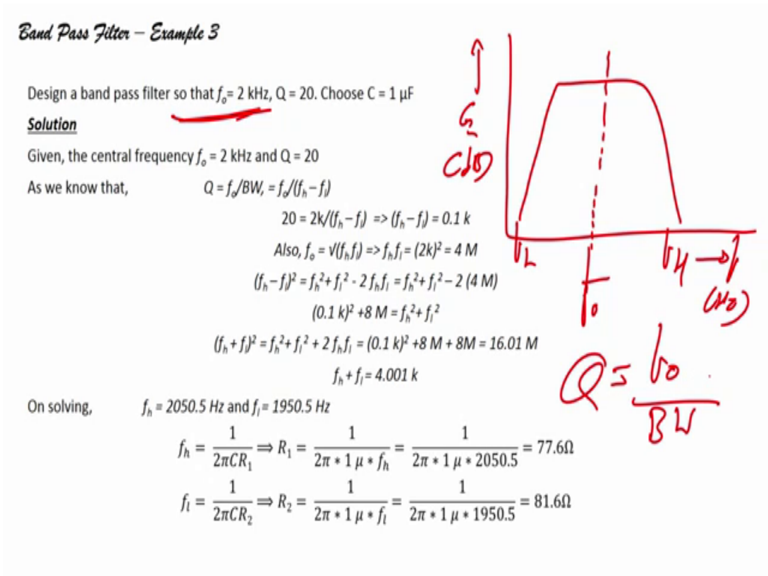

Particular plot this is again your gain, gain decibels this is your frequency in hertz correct then Q equals to f o by bandwidth what is bandwidth? Bandwidth is nothing, but lower frequency minus up upper frequency right f L minus f H or higher frequency minus lower frequency.

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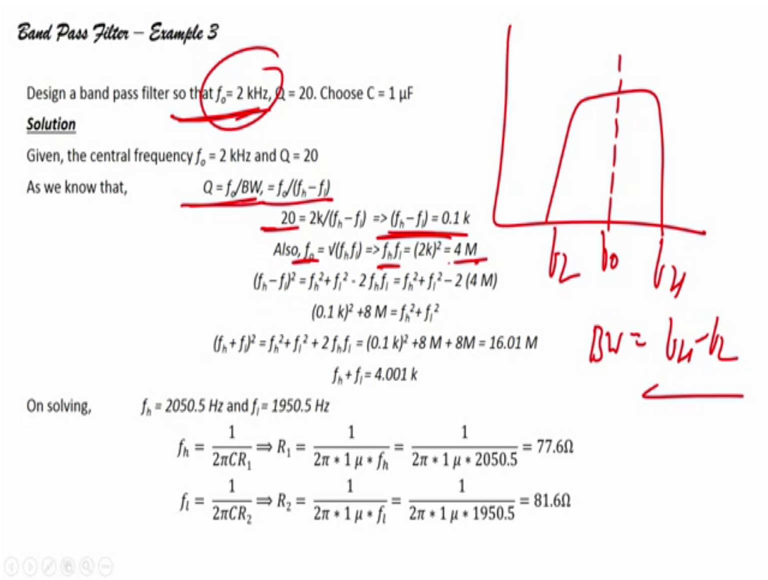

So, in terms if positive, if you have this f H f L right f o bandwidth, f H minus f L right. So, we have written Q equals to f o divided by bandwidth f o divided by f H minus f L substitute value q equals to twenty right then f o is 2 kilo hertz right divided by f H minus f l. So, f H minus f L would be 0.1 k.

Now, f o equals to underfoot of f H into f L that also we know right which is nothing, but f H f L equal to 2 k whole square equals to 4 m right. Now f H minus f L whole square is what it is like similar right this is very easy you see mathematics. So, easy math basic mathematics.

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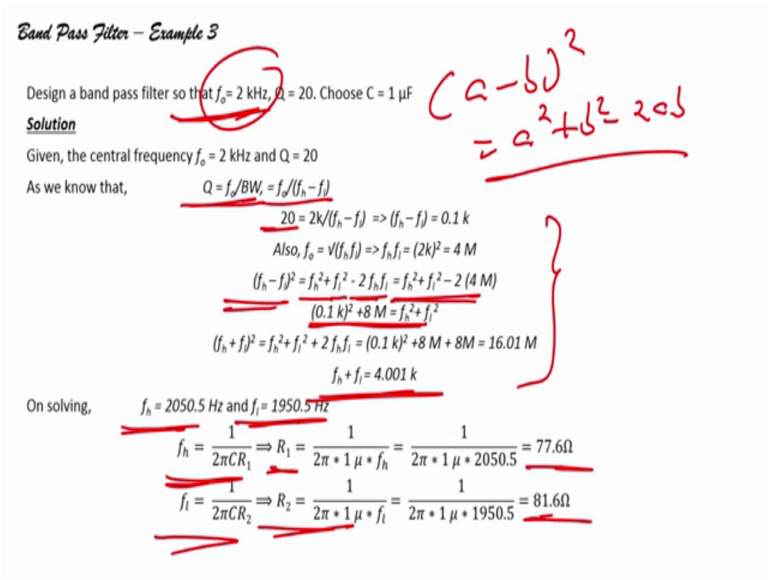

what is this a minus p whole square equals to a square plus b square minus 2 a b right this is what is written f L square plus f L square minus 2 f H into f L, this is nothing, but f H square plus f I square minus 2 types 4 M. So, when we substitute the value we will get this finally, we can use a when you solve this equation, when you solve this ah equation you will get f H plus f L is 4.001 K.

On solving f H equals to this one and f L equals to this one. So, f H equals to 1 by 2 pi R c R 1 equals to this f l equals to 1 by 2 pi R c, R 2 will be this value correct. So, this is how we can design the band pass filter.

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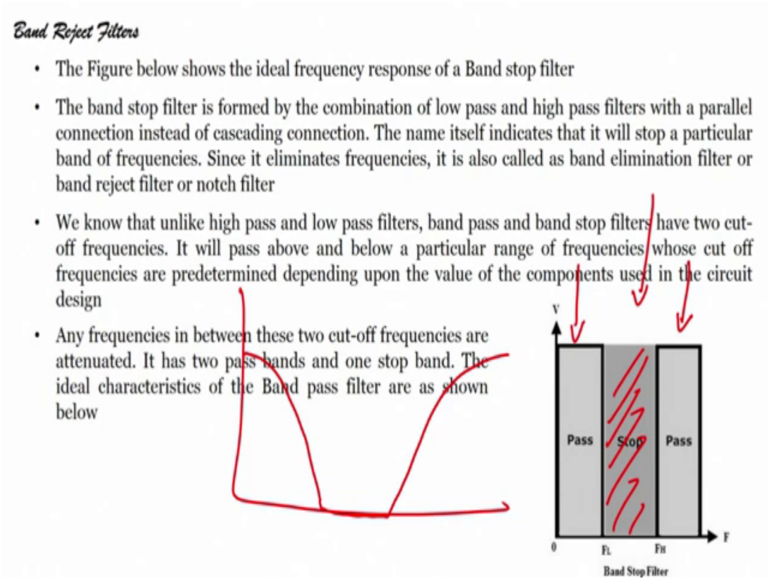

Now, once we have seen how the band pass filter can be designed, let us see how band stop filter can be designed, and what are band stop filters, what are band reject filters right. So, you see here the plot if you see the plot what you see is this, is the band which is top band, this is the pass band, this is the pass band right. So, this is ideal in actual you will get something like this alright.

This is the plot for response plot for band stop filter; that means, a particular frequency that we do not require particular band of frequency, that we require we can stop it by designing a filter using a pressure amplifier right. The figure shows ideal frequency response of band stop filter, with a band stop filter is formed by combination of low pass and high pass filters.

So, band stop filters can be again design or can be formed by using low pass and high pass filter. In case of the band pass filter, it was high pass and low pass in case band stop low pass and high pass with a parallel connection instead of cascading connection you see. So, in case of band pass filter we were cascading low pass filter and high pass filter. In case of band stop filter, we are connecting low pass filter and high pass filter, but in the parallel connection ok.

So, you remember that when you have to design a band band reject filter or band stop filter you have to connect low pass and high pass in a parallel connection. The name itself indicates it will stop a particular band of frequencies since it eliminates frequencies, it is also called band elimination filter or band reject filter or noise filter you see. So, it has lot of names what are the names let us write down.

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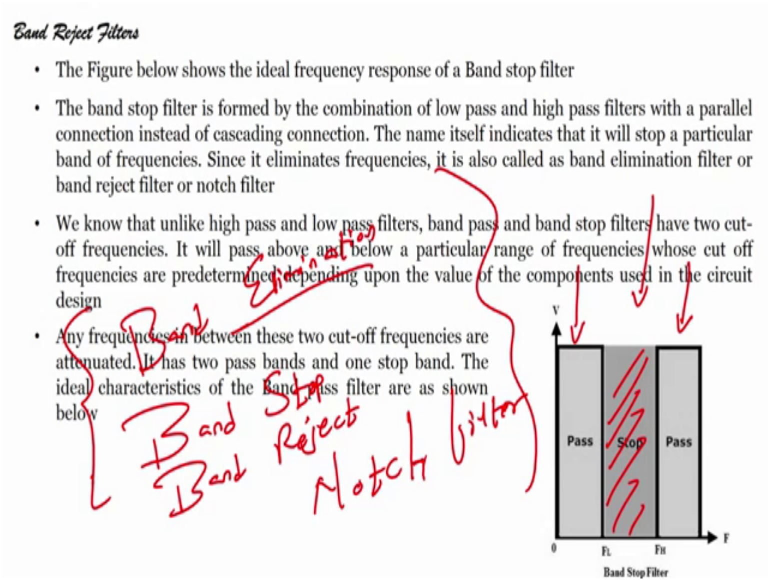

Band stop filter, band reject filter, band elimination filter also called notch filter you see four different names for band reject filter, band stop, band reject, band elimination, band notch filter alright.

So, any equation comes to your exam or any equation comes in your interview, then you can answer, that yes we know all this filter because all this filters are same filter, which is my band reject filter. So, it is called by many names, it is called by many names very easy right very easy to understand op amps and it is application is not it.

So, the band stop filter is formed by combination of low pass and high pass in a parallel connection right second is it will stop band of frequencies is also called band reject notch or band elimination, we know that unlike high pass and low pass filter band pass and band stop filters have two cutoff frequencies right see here 1, here 2 same way in band pass filter.

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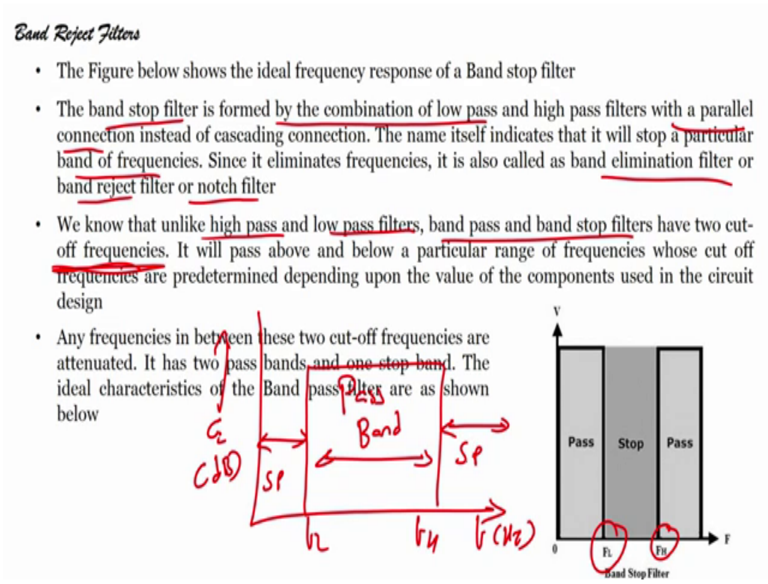

We have we had 1 and we had 2 and this was stop band, this was stop band this was pass band right you do not you do not have to write PBS SP S P you have to write stop band, you have to write pass band, you have to write gain, it is very important what you write on the axis. Even you know it is obvious that is the frequencies still you have mention when you are plotting a graph, what is your y axis, what is your x axis you have to write full form pass band, you have to write full form stop band ok.

So, whenever you show in exam or in your class or in your interview, if you are ask please plot everything correctly. Now it has two cutoff frequency, when we have band pass and band reject filter. You will pass above and below a particular range of frequency whose cutoff frequencies are predetermined depending on the value of components in the circuit design. So, what does that mean that? Here in this particular case it will pass all the frequencies below F L and all the frequencies above F H it will only stop the frequencies between F L and f H; that means, this band of frequencies it will not allow to pass right.

Now, any frequencies in between these two cutoff frequency are attenuated that means, they are stopped. It has two pass bands and one stop band the ideal characteristics of band pass filter are shown below. So, it is are actually may not band pass, but band reject filter ah shown in this particular figure.

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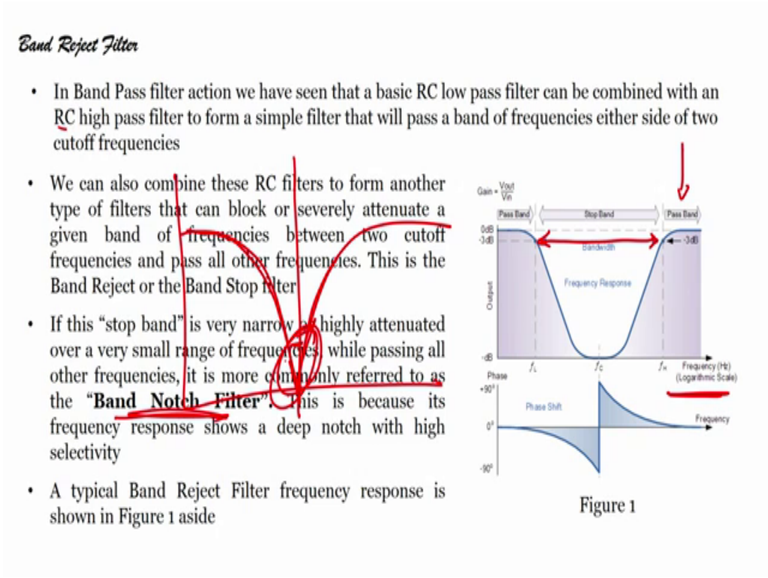

So, band reject filter; in band reject filter in band pass filter what we have seen? We have seen a basic R c low pass filter combined with RC high pass filter to form a simple filter that will pass a band of frequencies either side of two cutoff frequencies. These figures in the case of band pass filter right. We can also combine these RC filter to form another type of filter that can block or severely attenuate a given band frequencies between two cutoff frequencies, and this is called your band reject or band stop.

Then have you see here you see pass band, pass band, stop band gain is given by V out and V in we have in decibels we have frequency, if it is logarithm logarithmic scale logarithmic scale then we have to write down it is log right if it is not, it will write down it is in hertz right frequency now bandwidth. Bandwidth is f H minus f L this is your central frequency. So, if this stop band is very narrow or highly attenuated over a very small range of frequency while passing all the other bands, it is more referred to as band notch filter what does that mean? It means that if instead of having this this bandwidth, if I have like this very narrow band using very narrow band right.

Then it is called band notch filter, this is because it is frequency response was a deep notch deep notch you see deep notch right here with high selectivity. Only that particular small band of frequencies are stopped right and it looks like a deep notch that is why it is called so called band notch filter, same filter band reject filter is also called band.

A typical band reject filter response is shown here alright this shown in this figure.

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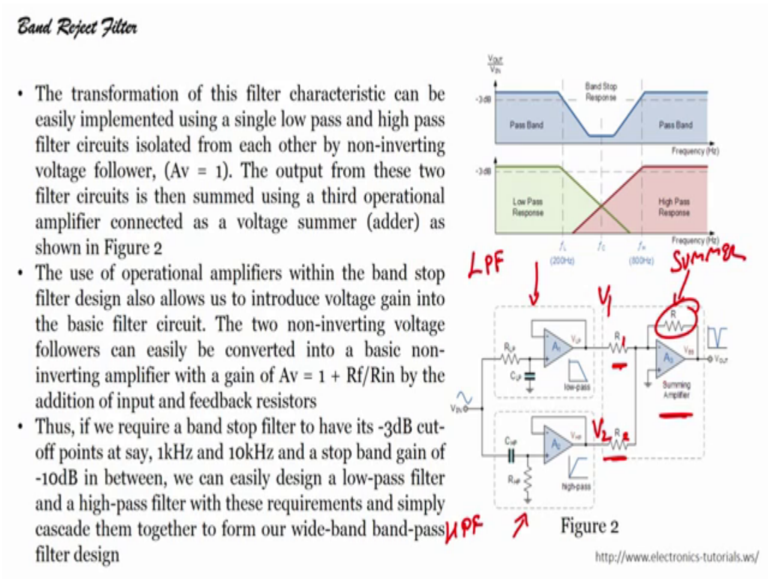

Now, let us see further. The transformation of this filter characteristics can be easily implemented as we can see here right. So, we see this is the band pass, pass band pass band, band stop response low pass response, high pass response and here this is center frequency, this will be the band which is rejected this is a band which is rejected. So, if I want to draw this I can draw this very easily right.

I have a low pass filter a low pass active filter let me just clear this point. I have this low pass active filter, I have high pass active filter, I have a summer summing amplifier is not it we have seen summing amplifier we have seen op amp as a summing amplifier you see R output voltage fed here, that is like V 1, R 1, V 2, R 2 right this output will be RF into V minus RF into RF is this one RF into V 1 by R 1 plus V 2 by R 2 right this is what we have seen into V in. So, that will be my V out.

So, we have seen summer we have seen the low pass and a high pass active filter, when I connect the low pass and high pass active filters in parallel connection as you can see with a summer which you can see here and you have a input voltage with peak to peak voltage this to this right and with a particular frequency, and we can design a notch filter or band reject filter by selecting different values of resistors.

So, resistance and capacitance of course, transformation of this filter characteristics can be implemented a single using a single low pass and high pass filter circuit by non inverting voltage follower, the output from these two filter circuit is summed using a third operational amplifier called a voltage summer, which you can see here right. The use of operational amplifier within the band stop filter design, also allows us to introduce voltage gain right. So, because we have used now the amplifier, we can also amplify the signal and we can also improve or gain the voltage, we can also introduce the voltage gain. The two in non inverting voltage followers, can be easily converted to into a basic inverting amplifier with the gain of A f equals to 1 plus.

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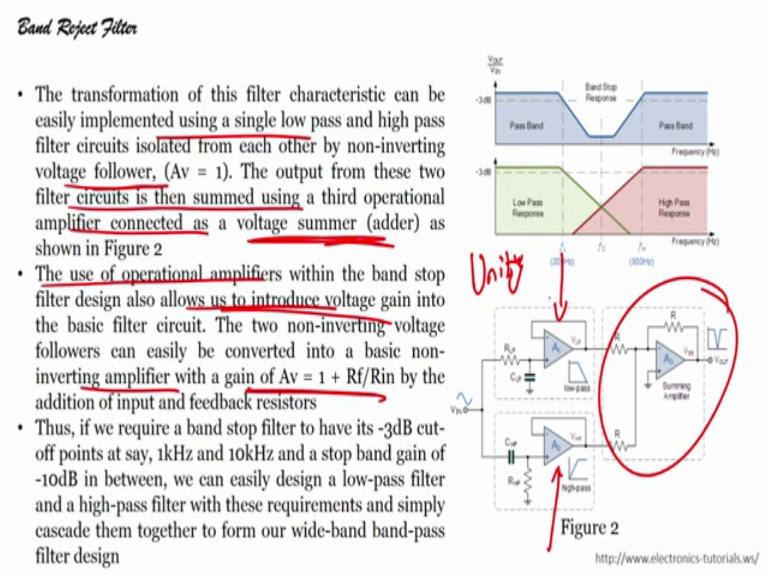

So, you see this is a amplifier this is amplifier, it is nothing, but unity gain amplifier right unity gain amplifier. This unity gain amplifier we can convert into a non inverting amplifier right and we can introduce a voltage gain right now this both are (Refer Time: 27:38) amplifier or a voltage follower right. This is my low pass filter, this is my high pass filter right, but these are just voltage follower instead of voltage follower, if I use a non inverting amplifier or if use a inverting amplifier, they can I can easily tuned by gain. Thus we require a band stop filter to have it is minus 3 dB cutoff frequency say 1 kilo hertz and 10 kilo hertz a stop band gain of minus 10 d B, in between, you can easily design a low pass filter and a high pass filter, with this frequency requirements, and simply cascade them together to form a wide band pass filter design.

Same way if I cascade them in a parallel form, I can form the band reject design.

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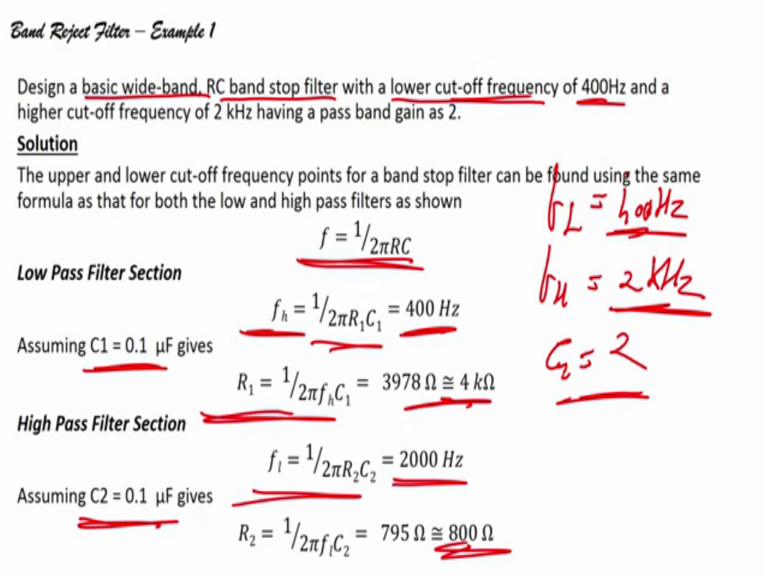

So, let us now design a basic wide band RC band stop filter with a lower cutoff frequency of 400 hertz right. So, f L equals to 400 hertz, f H 2 kilo hertz, gain 2 right have you know this formula. So, f H equals to 1 upon 2 pi R 1 C 1. So, we will get 400 hertz we have 400 hertz already right we have 400 hertz already. So, R 1 will be nothing, but 4 kilo ohms right very easy. Now same way f L equals to 1 by 2 pi R 2 C 2. So, we already know f L is equal to 2 kilo hertz or 2000 hertz. So, R 2 would be nothing, but 800 ohms. So, we have found the value of R 1 we have found the value of R 2, we have already know value of C 1, we already know value of C 2 do you know it yes you know it C 1 C 2.

Then then you see if I keep value of C 1 and C 2, I know now I can finally, of R 1 and R 2 and you know f H and f L the n I can design the band stop filter.

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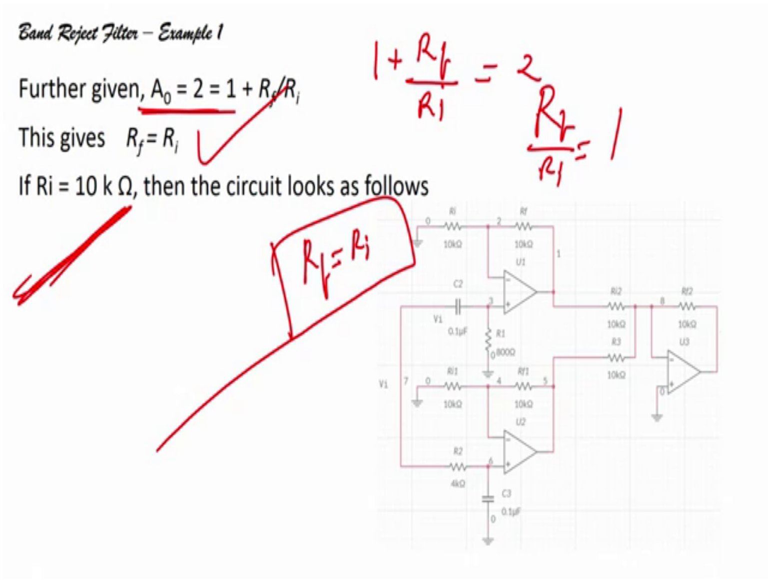

So, now further what is given? Further is given that gain is 2 right. So, let me design band reject filter with a non inverting amplifier. So, gain will be 1 plus R f by R i right R f by R i equal to 2. So, R f by R i equal to 1 or R f equal to R I, R f equals R i, R i equals to 10 kilo ohm right. If R i equals to 10 kilo ohm right and R f is also equal to 10 kilo ohm, then my circuit will look like the one I have shown on the screen, is not it.

So, I have R f I have R i, I can put a value of R i substitute the value of R i, I have found C 1, I have found C 2, I have found R 1 I have found R, R I; I know R f I know R i 2, I know R 3 I know R f. So, I can easily design my band reject filter alright. So, this is how I can design my band reject filter.

So, now what we see is using the operational amplifier we can design a band pass filter, we can design a band reject filter, we can design high pass filter, we can design a low pass filter. Now once you know low pass filter your life become super easy, because using the low pass and high pass in different combination, we will give us the band pass filter or we will give us the band reject filter right give us the band pass filter or will give us the band reject filter correct. So, now, we have also seen how we can design the circuit for band pass, we have seen the circuit for band reject, we have solved some problems for band pass and solved some problem for band reject.

Similarly, in the previous module you have solved some problems for high pass we have solved some problem for low pass. So, now, it will be little bit easier for you to understand how the filter would work, how the filters would work. So, just go through all the modules for this particular lecture and I am hoping that you will understand better about how the filters would work and how we can design a filter using operational amplifier alright.

So, the next class what we will see, we will see the design of the oscillators. Very important topic and it will have several modules to help you out how we can design oscillators using operational amplifiers. What are oscillators, what are kind of oscillators, what are the problem arises with oscillators, and how we can design oscillators alright.

So, till then what you do is, you just look at this lecture understand how these filters are designed and if you have any kind of problem in understanding, you can definitely ask me through the forum and I will try to get back to you at my earliest. So, you take care read this and have fun bye.