**Electronic Systems for Cancer Diagnosis**
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# Lecture - 33
# Basic building blocks of Electronics System: Filters (contd.)

Welcome to this particular module. And this is the, module for our lecture; where we are looking at Filters right. So, we have seen band, 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, we have seen 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; it will be a band pass filter. So, how exactly band pass filter we can design, using operational amplifier, let us see it ok. So, we will see two kind of filters; one is band pass filter and another one is band reject filters. And we will take some examples, so, you can understand how we can design these circuits, all right.

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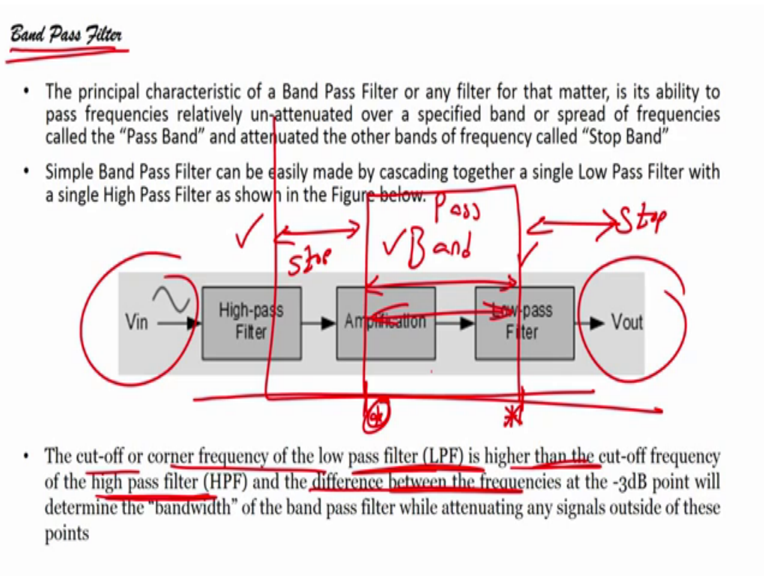


So, if you come back to the screen and what you see here is a band pass filter right band pass filter. Now the principle characteristic of a band pass filter or any filter for that matter its ability to pass frequencies, relatively un attenuated relatively, un attenuated over a specific band or spread of frequency called pass band, and attenuate the other band of frequency called stop band, correct. We have seen this, that when you design a filter, a certain band of frequency is allowed to pass which are called pass band frequencies. And certain frequencies that we do not what, there attenuated it is called the stop band frequency; it is called the stop band frequency, very simple right, it is very simple.

Now, a simple band pass filter, can be easily made; can be easily made; by cascading a single low pass filter with a single high pass filter super easy right. If we knows, how low pass filter circuit is, if we 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; 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 band pass filter all right. This is the band pass filter, the first block is, high pass filter. Then we have to amplify, then low pass filter all right. So, high pass and low pass combination of this cascading of this. We will result with; we will result in a band pass filter. Input peak to peak with certain frequency, we will see what is the output, which frequency it can pass? All right.

So, the cut off or corner frequency of the low pass filter is higher than the cut off high pass filter. And the difference between the frequencies at minus 3 d B point, we will determine the band width of the band pass filter, all right. So, what does it mean? The cut off or corner frequency of low pass filter, right is higher than the cut off frequency of high pass filter, right. And the difference between this frequency that means, if I draw right, the cut off frequency of the low pass filter and the cut off frequency of high pass filter right; the difference between it; that means, this is the difference that is the band, which will be allowed to pass.

So, this is the pass band; this is the pass band and this is the stop band, right stop band, this is also stop band; stop band right. This is what it means by the sentence ok. The cut off frequency or corner frequency, of low pass filter is higher than the cut off frequency of high pass filter, right. So, if this is my cut off frequency for low pass filter, this is higher than the cut off frequency for my high pass filter, right. And the difference between two; difference between two, that is this difference is my band of frequencies that i want to pass and it is my band pass filter; it is my band pass filter.

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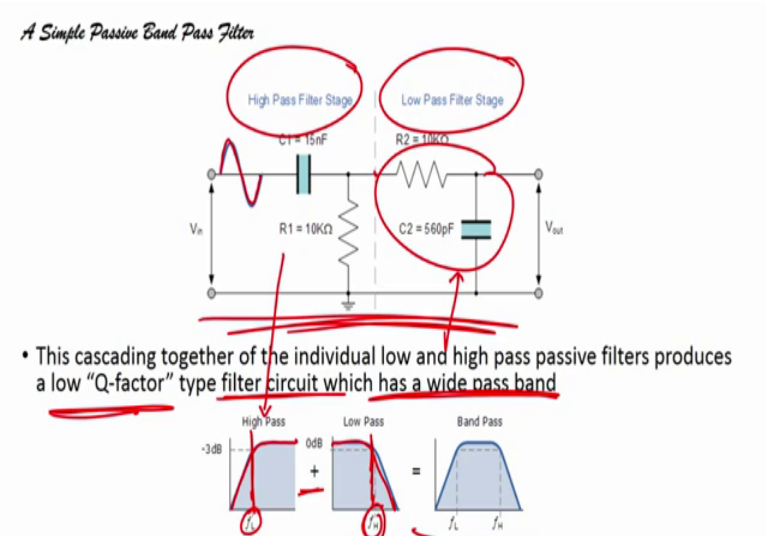

Figure 10

A simple band pass filter, all right. A simple band pass filter, how you can design? We can use high pass filter stage, we can use low pass filter stage, we can cascade both the stages; we can cascade both the stages right. So, you see here; we have capacitor and resistor this is our high pass stage I apply a signal; 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 what will happen? In this particular case, in high pass filter you can have a band of frequencies; that will pass above this f L; above this f L, right. In case of low pass filter, there will be band of frequencies that will pass below this f H; below this f H; that means, this one right, this particular band correct.

So, if I merge both, if I cascade both, what will I have? I have my band pass filter. So, this cascading to whether 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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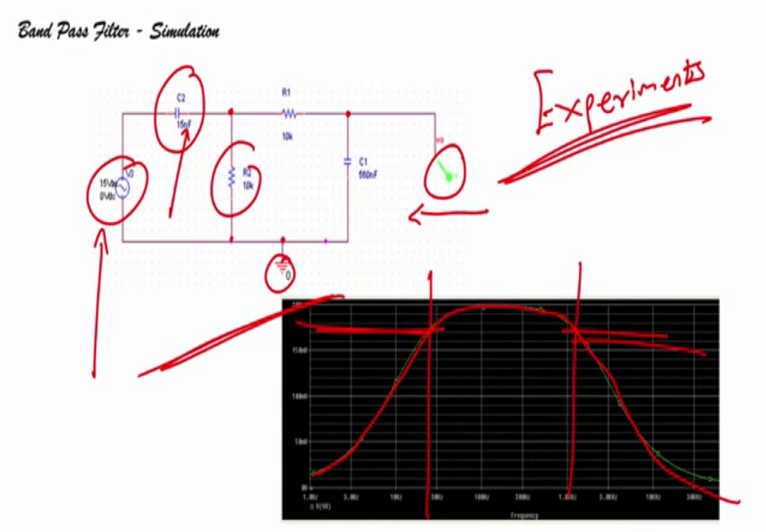


Figure 10 a

So, we will do this experiment also, is called Simulink ok. 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. 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?

In general, we will see how we can get the source on the library, how we can see the capacitor, how we can define different values of capacitor, how we can define and drag the resistors, how we can 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 15 volts peak to peak. And if the certain frequency right, that we have selected. And we have to understand that, what is the band of frequency? That is allowed to pass, we will be able to see that, whatever frequency we are selected minus 3 d B that we are calculating minus 3d B. So, it will be band like this that is allowed to pass and rest of the band is not passed, thus there is a band pass filter; its a band pass filter.

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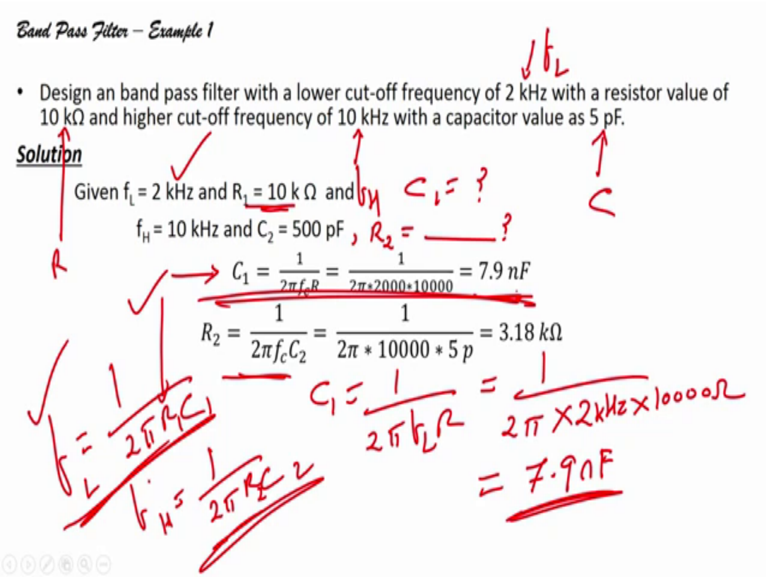


So, let us take an example, to make it easier; let us take an example to make it easier; design an band pass filter with a low cut off frequency of 2 kilo volts, 2 kilo hertz and with a resistor value of 10 kilo ohm. High cut off frequency of 10 kilo hertz, capacitor value of 5 pico farad. So, what is given f L is given right, f H is given. See f L is given correct; f L is given, f H is given; this is your f L, this is your f H right. Now you are given R, you are given R where is the resistor here, you are 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 pico farad correct.

Now, we for second one; we know that this is for first one right, so, f again f equals to 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 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 the equation for f H right. From here; from here and from here, we can find so, 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 1 upon 2 pi f L. What is f L? F L is 2 kilo hertz into resistance; resistance is 10 kilo ohm correct.

So, we will get value of C 1 equals to 7.9 nano farad, we get C 1 equals to 7.9 nano farad beautiful very easy. Now let us see, how we can find value of; how we can find value of f H and using f H, how can find R 2; how we can find R 2.

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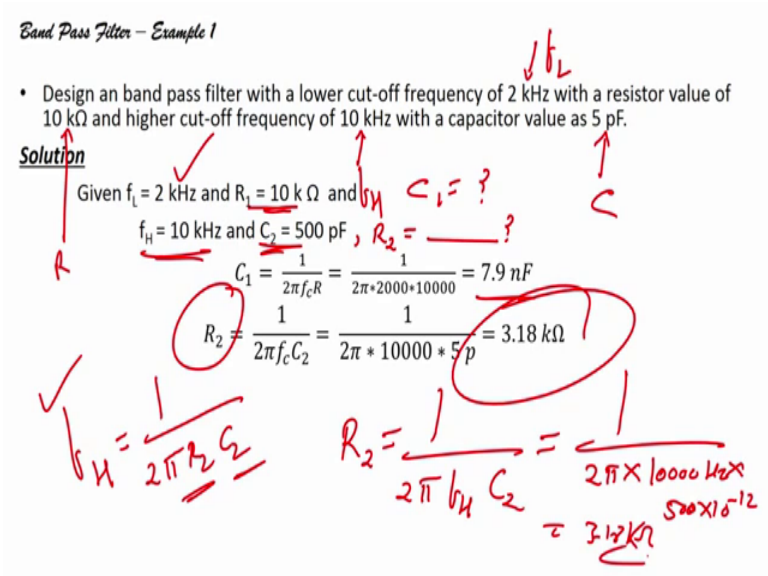


So, f H, what we written f H equals to 1 by 2 pi R 2 C 2. What we have? We have f H? What we have? We have C 2. What we do not have R 2. So, R 2 will be 1 divided by 2 pi f H C 2 right. So, this will be 1divided by 2 pi f H. What is f H? 10 kilo hertz right, hertz into C 2 500 pico farad 500, 10 to the 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 design a; you can design a band pass filter; you can design a band pass filter; very easy right. Absolutely easy, you have to just understand and remember one equation. And then you can easily design the circuit; you can easily design circuit that is your; that is your band pass filter.

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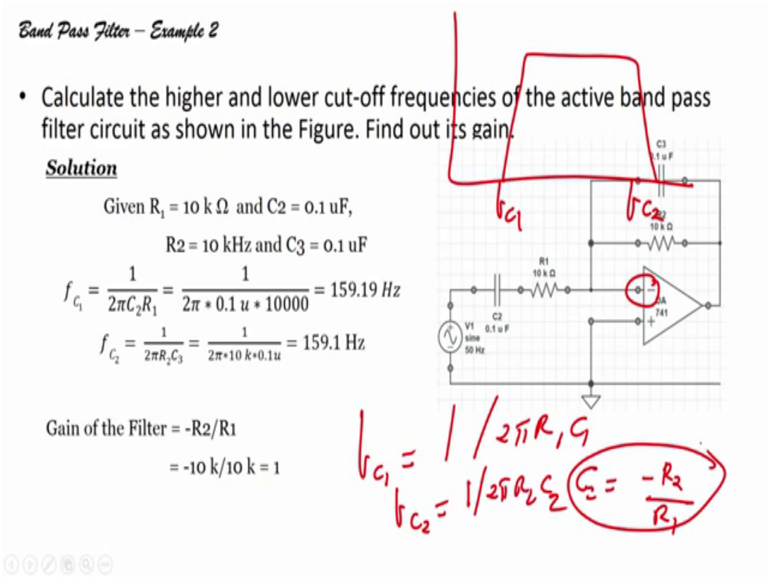


Now, if you are given a circuit; if you are given a circuit, right. Again this is a band pass filter and you are applying the signal to the inverting terminal, so, its a inverting amplifier right. Inverting amplifier, we understood, so, gain of inverting amplifier, we already know minus R 2 by R 1 right frequency we know f equals to let say we right f C1 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; we know this formula right. What is gain? Calculate the higher and lower cut off frequency of active band pass filter as shown in figure. Find out its gain. If I let us find out its gain first, right 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 cut off 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; we get the value of f C 1 and f C 2, easy very easy right, super easy.

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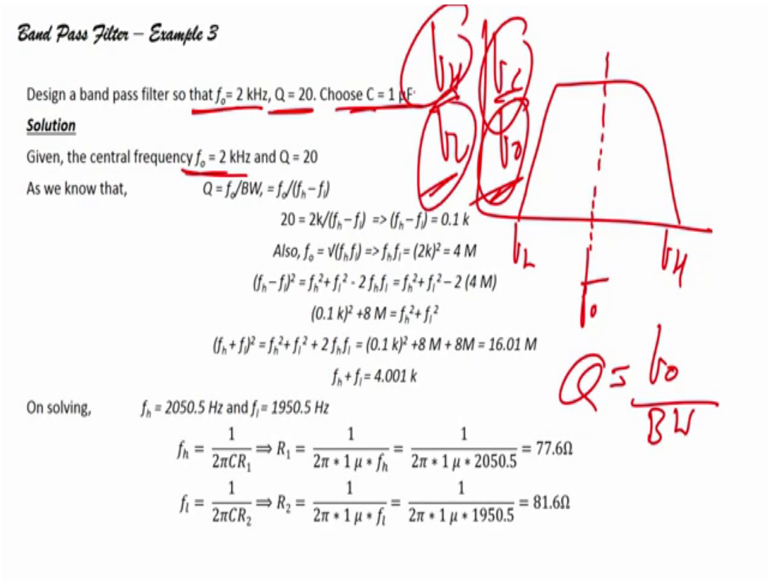


Then let us do one more problem; let us solve one more problem; design a band pass filter. So, that f o equals to 2 kilo hertz, using different way of putting the things with some people say f C some say f L f H, some say f o right does not matter, do not worry about it. Never get confused with this kind of terms right. So, we know f o 2 kilo hertz, quality factor 20 C equals to 1 micro farad. In this case, central frequency f o, so what is f O? See central frequency. So, you have this right f L f H right and this will be central frequency ok. So, f o right and quality factor can be f o, divided by band width quality factor can be f o divided by band width.

When I say f H, people say f L, people say f C, people say f o. This is term for everything ok. That does not mean everything, is same this is critical frequency, this is central frequency; this is higher cut off, this is lower cut off. So, you have to understand, what are the terms? The point is do not get confused. If the, you see a suddenly new term do not get confused ok.

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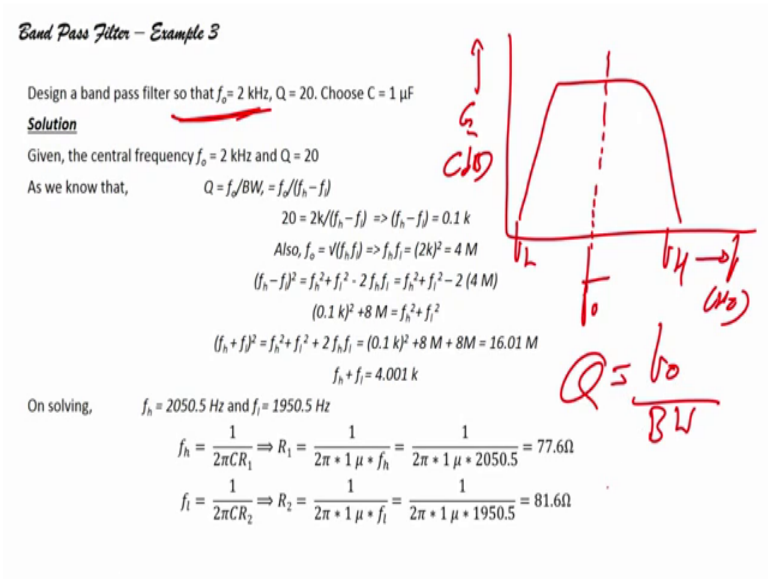


It is a central frequency is given by f o, you have seen here, right; for this particular plot. This is again your gain, in decibels. This is your frequency in hertz, correct equals to f o by band width. What is band width? Band width is nothing but lower frequency minus upper frequency right, f L minus f H or higher frequency minus lower frequency; so, with terms positive right.

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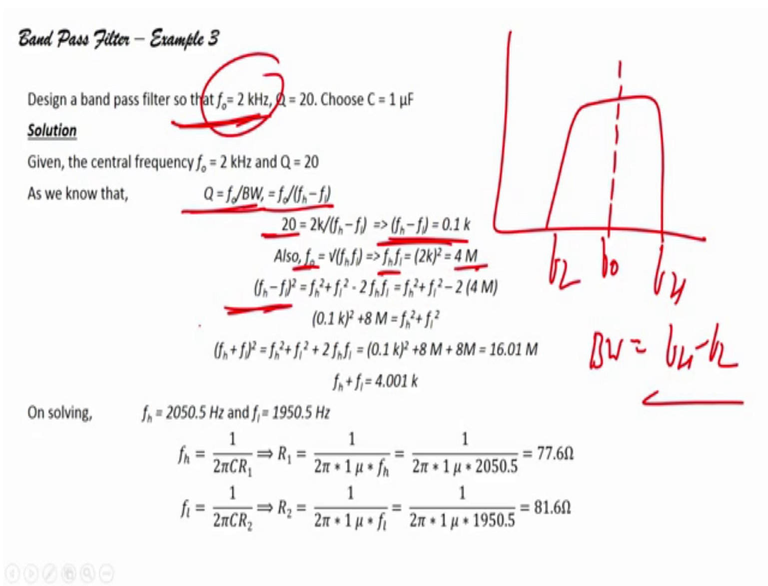


If you have this f H f L right f o band width, f H minus f L right. So, we have written Q equals to f o divided by band width f o divided by f H minus f L substitute value Q equals to 20 right. Then f o is 2 kilo hertz right divide by f H minus f L. So, f H minus f L will be 0.1 k. Now f o equals to under root of f H into f L, then also we know right. Which is nothing, but f H, f L equals to 2 k whole square equals to 4 M right. Now f H minus f L whole square is what is like similar right; this is very easy you see mathematics.

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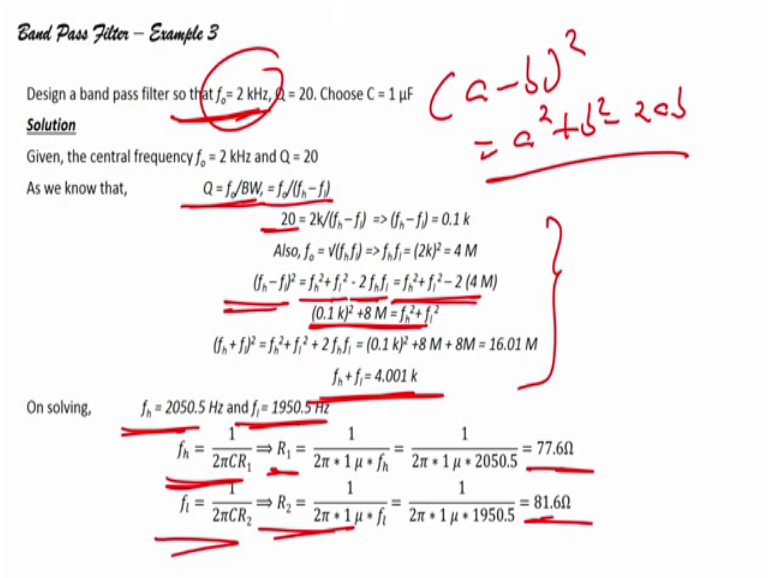


So, easy math basic mathematics, what is this; a minus b whole square equals to a square plus b square minus 2 a b right. This is what is written f h square plus f l square minus 2 f h into f l. This is nothing, but f h square plus f l square minus 2 times 4 M.

So, when we substitute, the value will get this finally, when you solve this equation; when you solve this 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 1 equals to 1 by 2 pi R C R 2 will be this value; R 2 will be this value correct. So, this is how we can design the band pass filter, these how we can design the band pass filter.

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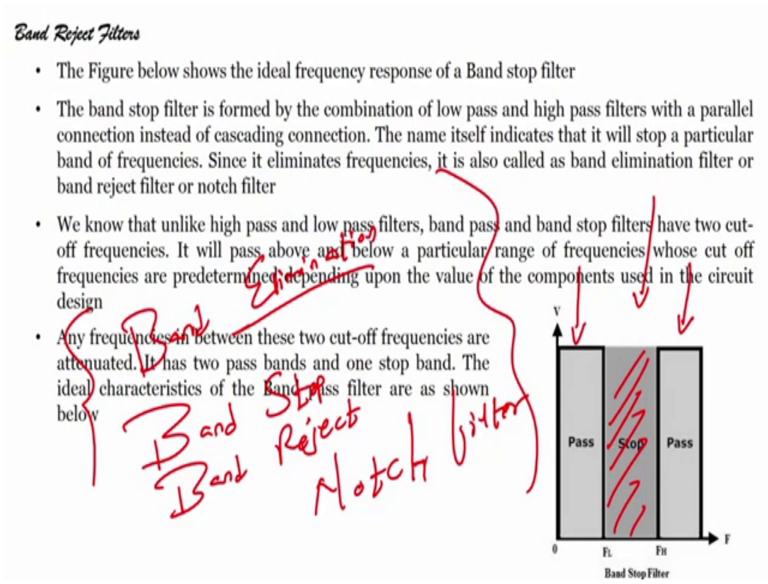


Now, once we have seen, how the band pass filter can be; how the band pass filters can be designed? Let us see how band stop filter can be designed? And what are band stop filters, what are band reject filters right? So, you see here the plot, if you see the plot, what do you see is this [noise] is the band; which is stop band? This is the pass band, this is the pass band right. So, this is ideal in actual you will get something like this, all right.

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 do not require, we can stop it by designing a filter using operational amplifier right. The figure shows ideal frequency, response of band stop filter the band stop filter is formed by combination of low pass and high pass filters ok.

So, band stop filters can be again designed 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 of band stop, low pass and high pass, with a parallel connection. Instead of cascading connection you see. So, in case of; 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; we are connecting low pass filter and high pass filter. But in the parallel connection; in a parallel connection ok, so, you remember that, when you had to design a band reject filter or band stop filter; you had to connect, your low pass and high pass in a parallel connection. The name itself indicates, it will stop a particular band of frequencies. Since it eliminate frequency this is also called band elimination filter or band reject filter or notch filter you see.

So, it has lot of names right, lot of names. What are the names? Let us write down band stop filter, band reject filter; band reject filter, band elimination; band elimination filter, also called notch filter; notch filter. You see four different names for band reject filter, band stop band reject band elimination, notch filter, all right. So, any question comes to your exam or any question comes in your interview, then you can answer, that yes we know all this filter. Because all this filters are the same filter. Which is my band reject filter ok, it is called by many names, it is called by many names, very easy right; very easy to understand, op amps and its application is not it.

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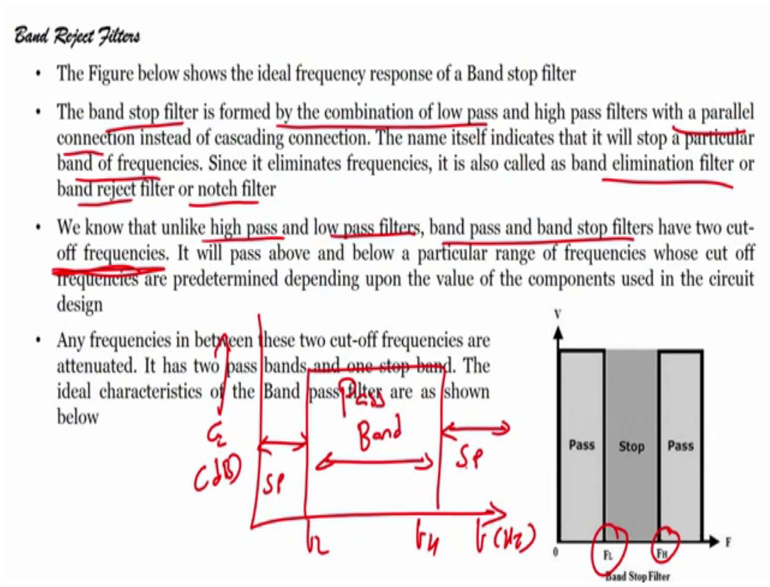


So, the band stop filter is formed by combination of low pass and high pass in a parallel connection right. Second is it will stop band of frequencies is also called band reject notch band elimination, we know that unlike high pass, and low pass filter band pass. and band stop filters have two cut off frequencies right, see here, one and here two same way in band pass filter. We have, we had one and we had two and this was our stop band, this was stop band, this was pass band, right. You do not; you do not had to write P B S P S ok. You have to write stop band, you have to write pass band, you have to write gain. Its very important what you write on the axis? Even you know, it is obvious that is the frequencies, still you have to mention. When you are plotting a graph, what is your y axis what is your x axis? You had to write full form pass band; pass band, you have to write full form stop band ok.

So, whenever you show in a exam or in your class or in your interview if you are asked please plot everything correctly, it is please plot everything correctly. Now it has two cut off frequency, when we have; when we have band, pass and band reject filter? It will pass above and below a particular range of frequency, whose cut off frequency has 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 cut off frequency; any frequency between these two cut off frequencies are attenuated; 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 a actually; do not band pass, but band reject filter shown in this particular figure.

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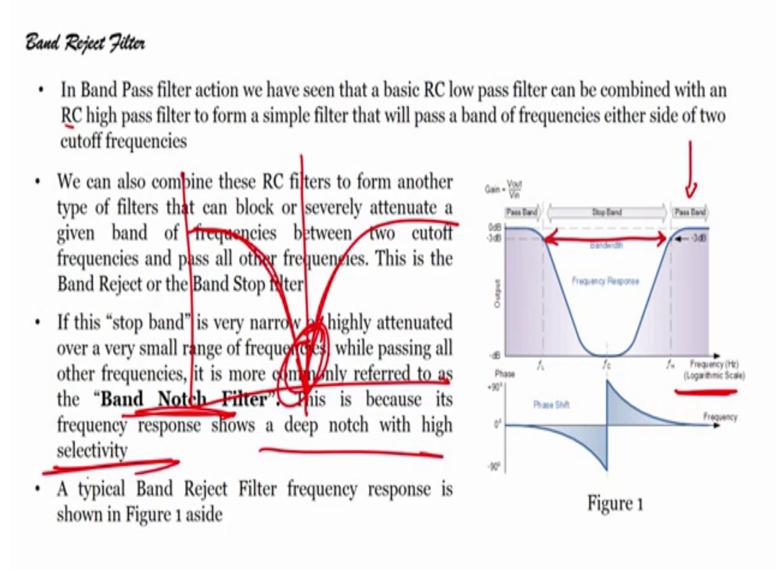


So, band reject filter; in band reject filter, in band pass filter, what we have seen? We have seen the basic R C low pass filter, combined with the R C high pass filter to form a simple filter. That will pass the band of frequencies either side of two cut off frequencies. This we have seen in the case of band pass filter right.

So, we can also combine this R C filter to form another type of filter that can block or severely attenuate a given band of frequencies between two cut off frequencies and this is called your band reject or band stop. Now you see here, you see pass band; pas band, stop band gain is given by V out and V in, we have in decibels, we have frequency. If it is in logarithm, logarithmic scale, logarithmic scale then we had to write down it is in log write. If it is not had to write down, it is hertz right frequency. Now band width, band width is f H minus f L, this is your central frequency, this is your central frequency ok.

So, if this stop band is very narrow or highly attenuated over a very small range of frequency. While passing all other bands, it is more referred to as band notch filter what does that mean; what does that mean? It means that, if instead of having this; this band width, if I have like, this very narrow band; you see very narrow band right, then it is called band notch filter.

It is called band notch filter this is because its frequency response shows a deep notch deep notch you see deep notch right here with high selectivity; with high selectivity only that particular small band of frequencies are stopped right and it looks like a deep notch that is why its called also called band notch filters same filter band reject filter is also called band a typically band reject filter response is shown here all right is shown in this figure.

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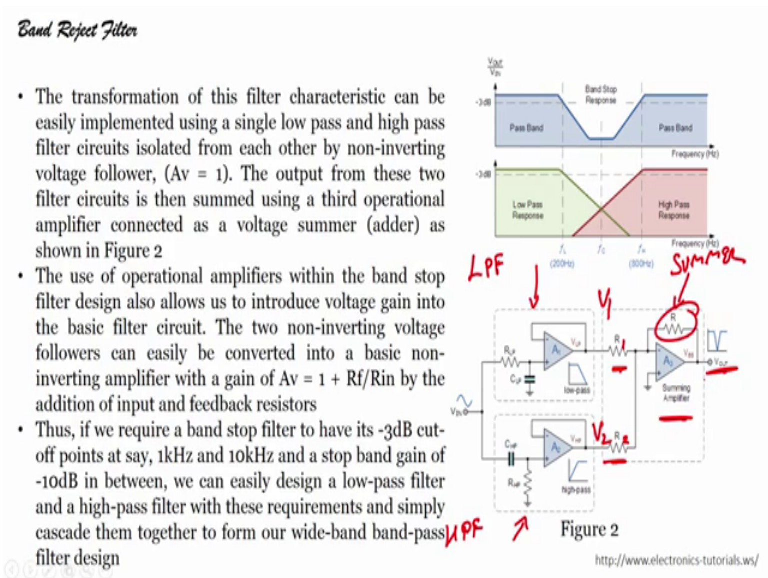

Now, let us see further the transformation of this filter characteristics can be easily implemented as you can see here right. So, you see this is the band pass; band pass band stop response low pass response high pass response and here there is center frequency this will be the band which is rejected this is the band which is rejected ok. 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 one.

I have this low pass active filter I have high pass active filter I have a summer summing amplifier correct I have a summing amplifier is not it. We have seen summing amplifier we have seen op amp as a summing amplifier you see R R output voltage fed here that is like V 1 R 1 V 2 R 2 right this output will be R f into V minus R f into R f is this one R f into V 1 by R 1 plus V 2 by R 2 right this 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 filters when I connect the low pass and high pass active filters in parallel connection as you can see here 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 than we can design a notch filter or band reject filter by selecting different values of resistors

So, resistors and capacitors of course. So, the transformation of this filter characteristics can be implemented a single using a single low pass and high pass filters circuit by non inverting voltage for lower 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 summer amplifier within the bands of filter design also allows us to introduce voltage gain right, so, because we have used now the amplifier.

So, we can also amplify the signal and we can also improve or gain the voltage we can also introduce the voltage gain the two non inverting voltage followers can be easily converted to into a basic inverting amplifier with a gain of A f equals to 1 plus. So, you see this is the amplifier this is the 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; we can introduce a voltage gain correct we can introduce a voltage gain right now this both are unity gain 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 I use a inverting amplifier they can I can easily tune my gain thus we require band stop filter to have its minus 3 d B cut off frequency say 1 kilo hertz and 10 kilo hertz or stop band gain of minus 10 d B in between we can easily design a low pass filter and high pass filter with these 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 filter design I can form the band reject filter design.

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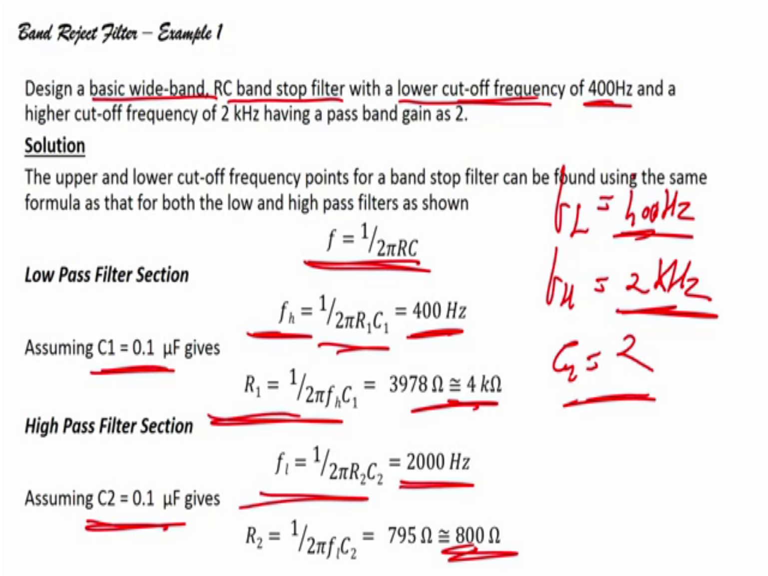


So, let us now; let us now design a basic wide band RC band stop filter RC band stop filter with a lower cut off frequency of 400 hertz right. So, f L equals to; f L equals to 400 hertz f H 2 kilo hertz, gain 2 right now we know this formula. So, f h is equals to 1 upon 2 pi R 1 C 1. So, we will get 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; we have found the value of R 1, we have found the value of R 2, we already know value of C 1 we already know value of C 2 do we know it yes we know it

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

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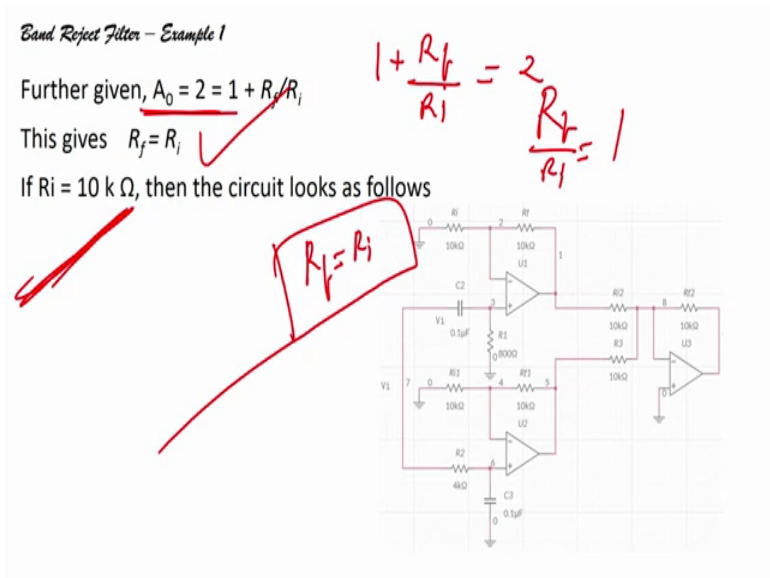


So, now further what is given further is given that gain is 2 right. So, let me design a band reject filter with a non inverting amplifier. So, gain will be 1 plus R f by R i right R f by R i equal to 2. So, R f by R i equal to 1 or R f equal to R i R f equals to Ri equals to 10 kilo ohm right if R i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

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

So, now, what we see is using the operational amplifier we can design; we can design a band pass filter we can design a band reject filter we can design; we can design a high pass filter; we can design a low pass filter now once you know low pass and high pass your life becomes super easy because using a low pass and high pass in different combination will give us the band pass filter or will give us the band reject filter right will give us the band pass filter or will give us the band reject filter correct.

So, now we have also seen how you can design this circuit for band pass, you have seen this circuit for band reject, you 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 you 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 ok. 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 you can design a filter using operational amplifier all sight

So, till then what you do is, you just look at this lecture understand how this 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 ok. So, you take care read this and have fun bye.