Integrated Circuits, MOSFETs, Op Amps and their Applications.
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Lecture - 55
Experiment: Introduction to experimental set up of band pass filter

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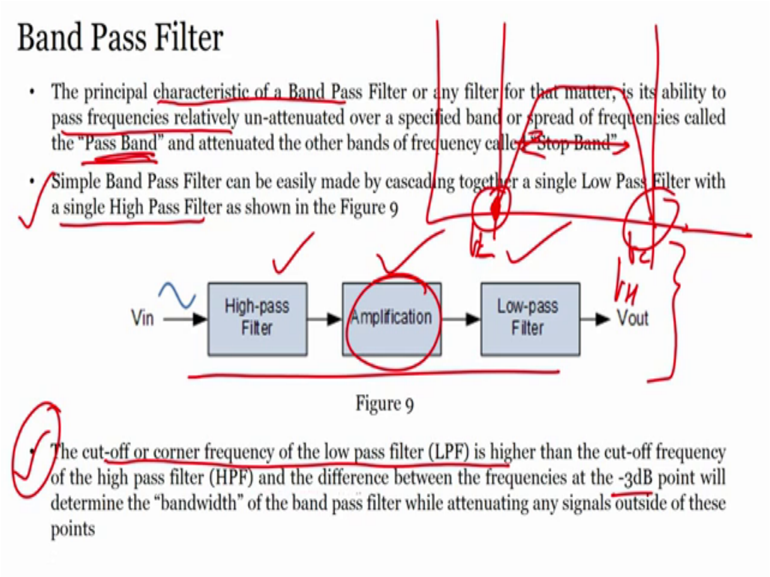

Band Pass Filter

- The principal characteristic of a Band Pass Filter or any filter for that matter, is its ability to pass frequencies relatively un-attenuated over a specified band or spread of frequencies called the "Pass Band" and attenuated the other bands of frequency called "Stop Band".
- Simple Band Pass Filter can be easily made by cascading together a single Low Pass Filter with a single High Pass Filter as shown in the Figure 9

Figure 9

- The cut-off or corner frequency of the low pass filter (LPF) is higher than the cut-off frequency of the high pass filter (HPF) and the difference between the frequencies at the -3dB point will determine the "bandwidth" of the band pass filter while attenuating any signals outside of these points

Welcome to this module. Here, we want to understand the application of the operation amplifier in terms of band pass filters. So, until now what we have seen? We have seen that if you want to pass hype band frequency, we design a high pass filter, he would not design the low band of frequency, we design a low pass filter, what about we want to pass only a certain band in your frequency range, right?

Not a low not high, but within somewhere a set of frequencies that only we need to pass. See, again and again I am talking about frequency, frequency, frequency. That is why at the starting of this particular filter session, we talk that filters are the most important or highly used circuits in the communication systems, right? That is why we talk about frequency, frequency, frequency.

So, if I want to pass a certain band of frequency, then I had to design a filter which is which will be my band pass filter, right. So, how to design this band pass filter? And can we design it with it with the help of operational amplifier, that is the idea that is the gist of this particular module that you have to understand, that the how to design a band pass filter. So, before we design the band pass filter with the system that we have with the equipment that we have here, which is our dc power supply we have our oscilloscope function generator breadboard multimeter and of course, the operation amplifier.

Let us first see what exactly the band pass filter is, right? We have seen this in theory class we are again repeating it. So, that you guys do not forget, right. See the principal characteristics of a band pass filter or any filter for that matter is it is ability to pass frequencies relatively un attenuated over a specific band, or spread of frequencies called the pass band.

What does that mean? That a pass band filter or any fill filter it is basic ability is to pass frequencies relatively un attenuated; that means, that that frequencies should not be un attenuated for a specific band, it can be low pass filter than low frequency band high pass filter high frequency band. That frequency that we want to pass it should be passed without any attenuation, right. So, that is called the pass band we already know and attenuated the other bands of the frequency called the stop band.

We know what is pass band we know what is stop band we also know, correct? Now simple band pass filter the second point can be easily made by cascading together a single low pass filter with a single high pass filters, so easy very easy, right? If I cascade a low pass filter with a high pass filter I can get a band pass filter, right here you can see the circuit and you can see a circuit not exactly circuit is a block diagram you apply a input signal you have a high pass filter you have amplification, you have a low pass filter you have the output and then you can using this particular block, when you connect like this you can get an active band pass filter.

Why active and pass filter? Because there is a amplification involved there is an amplification involved, right. Also, when you want to design source what we understand we when we want to design a band pass filter, we can integrate or cascade a high pass filter with the low pass filter, alright?

So, the cut off frequency point number 3 let us see, the cut off frequency or corner frequency of the low pass filter is higher than the cut off frequency then the cut off frequency of the high pass filter, alright. The cut off frequency of low pass filter is higher than the cut off frequency of high pass filter. And the difference between the frequencies at minus 3 dB point will determine the bandwidth of the band pass filter will determine the bandwidth of the band pass filter; that means, if I draw a band pass filter, I will have something similar to this right.

So, what is this frequency fc ? This will be fc, this will be another fc, right. So, we are talking about these 2 points, this and these points when we talk about this particular point which is point number 3, what is that ? It is written that the cut off frequency of the low pass filter, right here low pass filter will see is higher than the cut off frequency of high pass filter. And the difference between frequencies if I say this is f L and this is f H, then a difference between f H and f L this is my band of frequencies that I want to pass, alright.

So, the and the difference between frequencies as minus 3 point will determine. The bandwidth; that means, that if I design if I design a filter then if I want to know the bandwidth high pass filter what I will do? I will design a filter like this.

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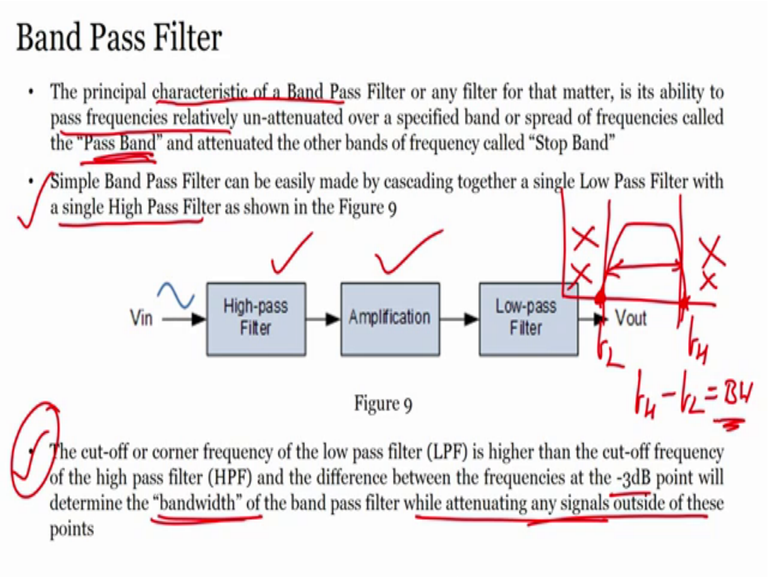

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And I know this is high frequency, low frequency f H minus f L will give me bandwidth, will give me bandwidth here band of frequency, alright.

So, what is ray written? Will determine bandwidth have been pass filter while attenuating any signal outside these points, any signal outside these points means with this point, and this point no signal here can be allowed no signal in there can be allowed, only this particular signal between this point and this points are allowed; that means, this is the band of frequency that we can pass, alright?

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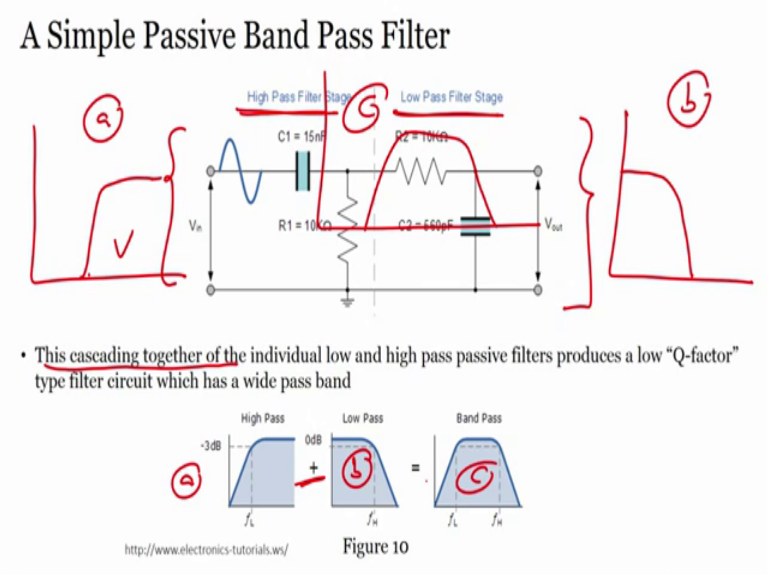

A Simple Passive Band Pass Filter

- This cascading together of the individual low and high pass passive filters produces a low "Q-factor" type filter circuit which has a wide pass band

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Figure 10

So, if this is the case and if I want to design passive band pass filter, then what can I do? If I want to design a passive band pass filter what can I do, right? So, I have a high pass filter stage, I have a low pass filter stage, and if I integrate high pass with low pass, if I integrate the high pass stage with low pass stage I will get a passive band pass filter, right. Amazingly easy, isn't it? Because it is so simple that by integrating the high pass filter to the low pass filter we can get a band pass filter.

Now, we all remember, right, we should all remember that in high pass filter there was capacitor at the input, and then capacitor was in series with a resistor. In low pass filter resistor and was series in capacitor, right. The output voltage across the high pass was measure across this resistor, output voltage across low pass was measure across the capacitor, right. So, if I integrate both it becomes a band pass filter, how? So, you see the cask these cascading stores.

So, what is high pass filter we know, right. High pass filter if I draw the frequency whether I draw the plot the plot is that high pass, means, I will have a pass from here to here. I have a low pass filter means, I will have pass from here to here, correct? So, I if I join this one, and I join this one, what I will I have? I will have if I join plot a of high band pass high pass filter, and plot b of the low pass filter. If I join both I will have plot which looks like this, right, which is my plot C, right.

So, this is what is shown here. You see, high pass a low pass b, we integrate it, we join it become C which is band pass. This is what we are doing here, right. So, point is for designing a passive band pass filter, passive band pass filter, we can cascade the individual low and high pass filters and produces a Q factor typical type of filter circuit which has a wideband pass, which has a wide pass.

So, the cascading together of the individual low pass and high pass filter produces a low Q factor, right. Type filter circuit which has a wide band pass, cool? Very easy. So, you can also design this kind of circuit, right. This is your simple passive band pass filter.

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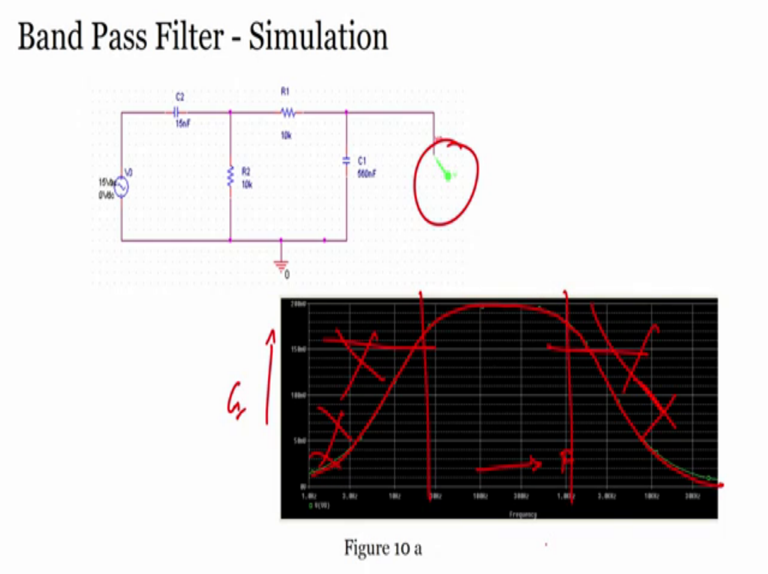

Band Pass Filter - Simulation

Figure 10 a

Now if there is a simple passive band pass filter then let us do the simulation, there is the simulation, see if I connect it, and if I do the simulation, what I get? I have the frequency on the y axis, sorry x axis and gain on the y axis, right.

Gain frequency, right, and when I design this I see at the output voltage plot similar to this which is the gain or is frequency, and I will have a band, I have a band which I am allowing to pass. I have a band which allowing to pass, outside this it cannot pass. So, I did here it cannot pass, there is a band at which minus 3 dB we had to work emulate. So, we can have some band which is around this value, right.

This you can do again with simulation, and you can find it whether it makes sense or not, right. the point is you can design a band pass filter with your passive components.

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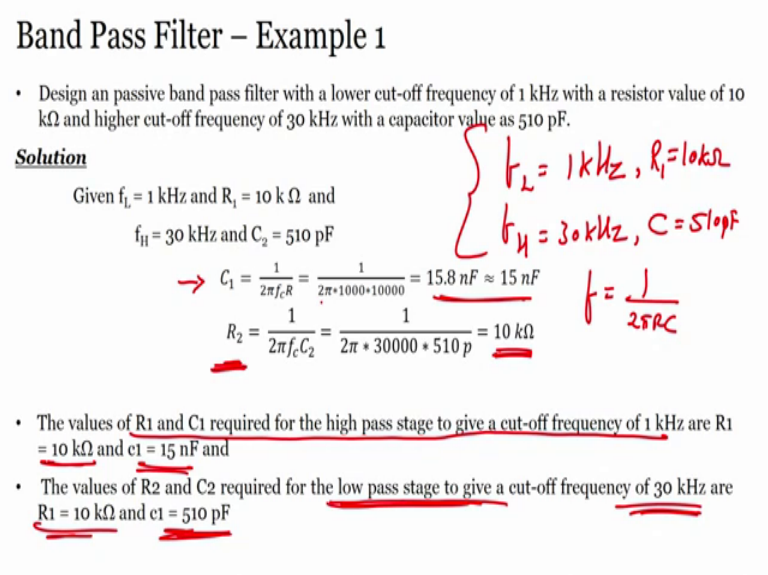

Band Pass Filter – Example 1

- Design an passive band pass filter with a lower cut-off frequency of 1 kHz with a resistor value of 10 kΩ and higher cut-off frequency of 30 kHz with a capacitor value as 510 pF.

Solution

Given $f_L = 1$ kHz and $R_1 = 10$ k Ω and

$f_H = 30$ kHz and $C_2 = 510$ pF

$$\rightarrow C_1 = \frac{1}{2\pi f_c R} = \frac{1}{2\pi * 1000 * 10000} = 15.8\,nF \approx 15\,nF$$

$$R_2 = \frac{1}{2\pi f_c C_2} = \frac{1}{2\pi * 30000 * 510\,p} = 10\,k\Omega$$

$f_L = 1kHz,\ R_1 = 10k\Omega$

$f_H = 30kHz,\ C = 510pF$

$f = \frac{1}{2\pi RC}$

- The values of R1 and C1 required for the high pass stage to give a cut-off frequency of 1 kHz are R1 = 10 kΩ and c1 = 15 nF and
- The values of R2 and C2 required for the low pass stage to give a cut-off frequency of 30 kHz are R1 = 10 kΩ and c1 = 510 pF

And let us take an example of band pass filter, let us take an example of band pass filter. So, you had to design a band pass filter, right. Passive band pass filter with the low cut off frequency of 1 kilohertz with a resistor of 10 kilo ohm, and high cut off frequency of 30 kilo hertz with a capacitor of 510 pico farad, this is the question given to you. And let us solve how we can design and passive band pass filter with this particular value.

So, what is given V R given 1 kilohertz. So, low cut off frequency f L, 1 kilo hertz ok, with a resistor value of 10 kilo ohm. So, let us say R 1 10 kilo ohm. Higher cut off frequency f H, 30 kilo hertz, capacitor C 510 pico farad, right? Now what is the formula? F equals to 1 by 2 pi RC; that means, that if I substitute the values I will have capacitor C 1 equals to 1 upon 2 pi fc R, right, I have 2 pi into fc which is my 1 kilo hertz into my R which is 10 kilo ohm, then I will have value which is 50 nano farad, approximately 15 point 8 nano farad or 15 nano farad.

If I use another formula which is 1 upon 2 pi RC. So, if I want to measure the R 2 R 2 would be 10 kilo ohm, correct? So, from here what we find is that we can measure the value of R 1, and we can measure the value of R C 1 given this following this following units values, alright. And the value of R 2 C 2 required for low pass stage C. So, from here R 1 and C 1 require for high pass stage to give a cut off frequency of 1 kilo hertz or

10 kilo ohm and 50 nano farad, where R 2 C 2 for a low pass filter is 30 kilo hertz and 10 kilo ohm and 510 pico farad, right.

So, this values we can calculate, and from this now we can design a passive band pass filter. We can design a passive band pass filter. Now do not always rely on whatever I am saying, right. Always try to do your measurements by yourself. It is not that always whenever teacher gives you a solution it may be correct here it is, but I am just saying, right. You are to calculate by yourself and calculates whether the values that is there are correct or not.

If not, you correct it because it is just putting formula f equals to 1 upon 2 pi RC two pi into RC R equals to 1 upon 2 pi fc, right.

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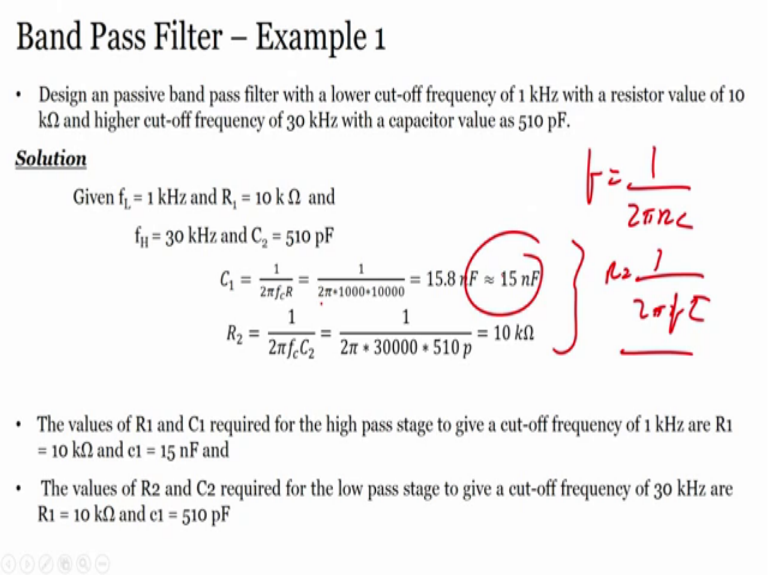

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f_H = 30 kHz and C_2 = 510 pF

$$C_1 = \frac{1}{2\pi f_c R} = \frac{1}{2\pi * 1000 * 10000} = 15.8\,nF \approx 15\,nF$$

$$R_2 = \frac{1}{2\pi f_c C_2} = \frac{1}{2\pi * 30000 * 510\,p} = 10\,k\Omega$$

$$f = \frac{1}{2\pi RC}$$

$$R_2 = \frac{1}{2\pi f C}$$

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- The values of R2 and C2 required for the low pass stage to give a cut-off frequency of 30 kHz are R1 = 10 kΩ and c1 = 510 pF

Fine put the formula and find the values, do not realize it if there is something here 15.9 nano farad, this is a wrong and it is not like that, you try by yourself also.

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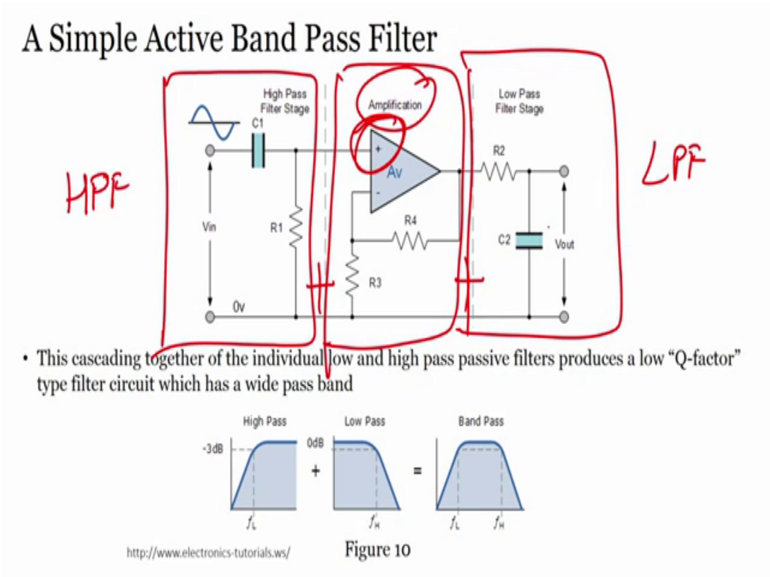

A Simple Active Band Pass Filter

- This cascading together of the individual low and high pass passive filters produces a low “Q-factor” type filter circuit which has a wide pass band

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Figure 10

So now you know how to design a RC passive band pass filter, right. So, what if I have a simple active band pass filter? What if I have a simple active band pass filter, alright. So, again what I need? I will need a high pass, I will need a low pass, and I have to use a active means op amp. Here I have am using again a non-inverting amplifier, right. So, you see you have a high by high pass filter at stage one which is here. You have low pass filter at stage 2 which is here, and then you have your inverting amplifier non-inverting amplifier here, right. We apply this input signal to the non-inverting terminal of the amplifier.

That means that now by cascading the high pass with low pass ends and integrating high pass with amplification and then connecting it to low pass, this will give us the this will give us a high a simple active band pass filter, alright. What I am saying? We have high pass filter, high pass filter, we have low pass filter, and we have amplifier, right. non-amplifier when we integrate it, this plus, this plus this, we get we get an active band pass filter an active band pass filter, right, this cascading together.

This cascading together of individual low pass and high pass filter produces a low Q vector, type filter circuit which has a wide band pass which has a wide pass band, right? and this is how we can create your active band pass filter, right. Here you can see, here you can see we get the active band pass filter, easy extremely easy, right.

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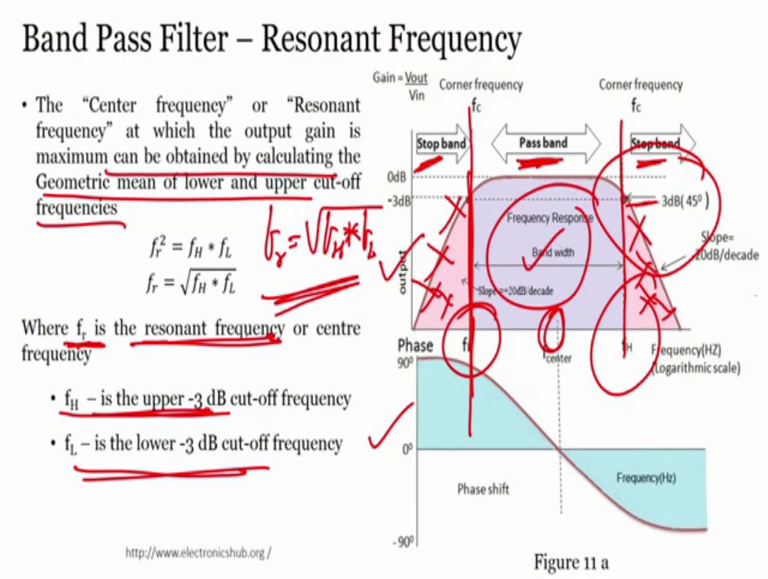

Band Pass Filter – Resonant Frequency

- The "Center frequency" or "Resonant frequency" at which the output gain is maximum can be obtained by calculating the Geometric mean of lower and upper cut-off frequencies

$$f_r^2 = f_H * f_L$$

$$f_r = \sqrt{f_H * f_L}$$

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Where f_r is the resonant frequency or centre frequency

- f_H – is the upper -3 dB cut-off frequency
- f_L – is the lower -3 dB cut-off frequency

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Figure 11 a

So, this is easy, then let us see the resonant frequency? What is the resonant frequency. So, here you see when you when you when you have this kind of plot, when you have this kind of plot, the there is a f L there is a f H, right. Frequency above this will not be past 3 dB, not allowed to be pass frequency below this not allowed to be passed, only this frequency will be allowed to pass.

That is why it is called pass band. This not allowed stop band, not allowed stop band, corner frequency or fc this is center frequency f edge, right. If you calculate if you consider phase, then you would have a phase shift like this, alright? You have phase shift which is shown here, right. With respect to center with respect to f L with respect to fH, alright.

Now, the centre frequency or the resonant frequencies center frequency or the resonant frequency at which the output gain is maximum can be obtained by calculating geometric mean of lower and upper cut off frequencies. We have seen this already in the lectures, but let us again look at the formula, we know that the resonant frequency or the center frequency can be can be obtained by calculating geometric mean of the lower and upper cut off frequencies; that means that, f R equals to square root of f H into f L, right. F H into f L, where fr is the resonant frequency, fH is the upper minus 3 dB cut off frequency, this one, f L is lower minus 3 b tb cut off frequency, this one f L, right.

Now, we know the formula for resonant frequency, we know the formula for resonant frequency. So, what we get ? What we get here is that we now know what is the resonant frequency ok, we also know how what is a formula for resonant frequency, alright. correct ?

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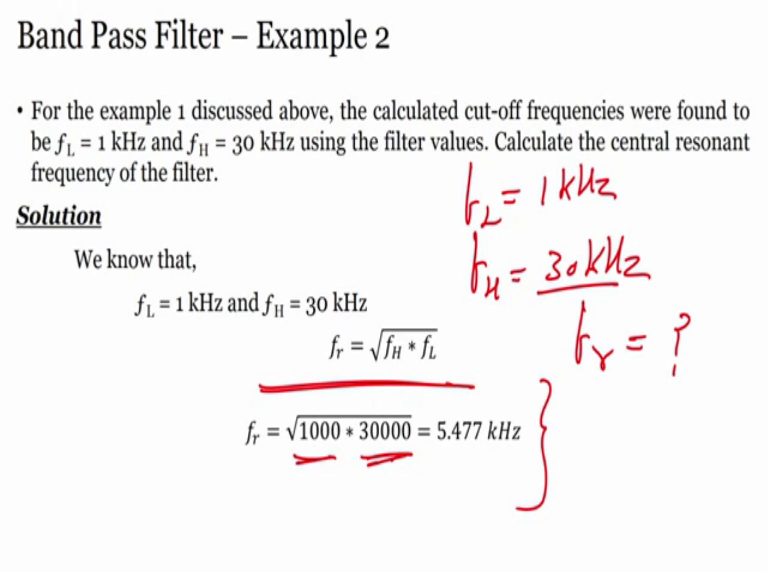

Band Pass Filter – Example 2

- For the example 1 discussed above, the calculated cut-off frequencies were found to be f_L = 1 kHz and f_H = 30 kHz using the filter values. Calculate the central resonant frequency of the filter.

Solution

We know that,

$f_L = 1$ kHz and $f_H = 30$ kHz

$$f_r = \sqrt{f_H * f_L}$$

$$f_r = \sqrt{1000 * 30000} = 5.477\ kHz$$

$f_L = 1$ kHz

$f_H = 30$ kHz

$f_r = ?$

So, if I take an example, if I take an example, the calculator cut off frequency was found to be f L equals to f L equals to 1 kilohertz, f H equals to 30 kilo hertz, calculate central resonant frequency f R is this, right? We already know the formula for fr, fr is square root of fH into f L if I substitute the values fH is my 1 kilo hertz. So, thousand hertz fH is 30 kilo hertz. So, 30000 hertz, then I have my fare resonant frequency or central frequency is 5.477 kilo hertz.

So, again an example of band pass filter, you can you can find the solution of this kind of problems at home, it is very easy to find, isn't it? Very easy extremely easy, it cannot be easier than this, right. So, try to find it at home.

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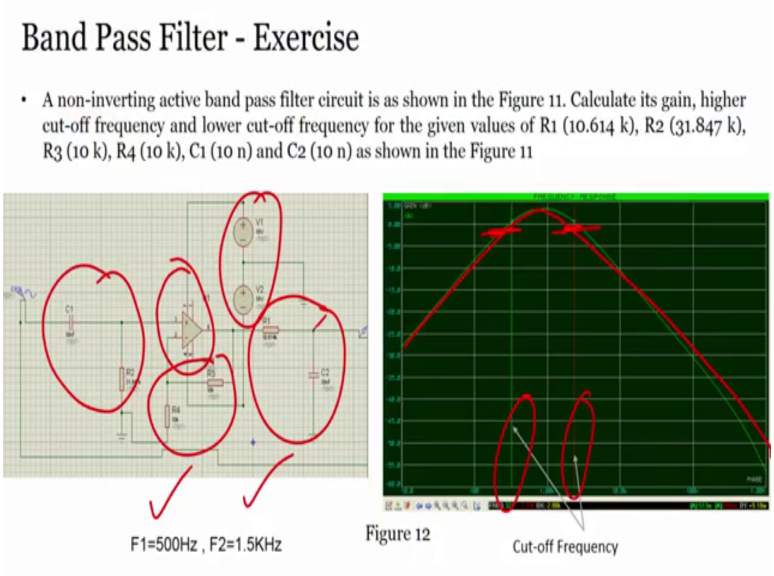

Band Pass Filter - Exercise

- A non-inverting active band pass filter circuit is as shown in the Figure 11. Calculate its gain, higher cut-off frequency and lower cut-off frequency for the given values of R1 (10.614 k), R2 (31.847 k), R3 (10 k), R4 (10 k), C1 (10 n) and C2 (10 n) as shown in the Figure 11

F1=500Hz , F2=1.5KHz

Figure 12

Cut-off Frequency

Now, this is our exercise again you can use a p spice, right and we have a non-running active band pass filter as shown here, right, you can see bias voltage, right. You are looking at the low pass filter, you are looking at the high pass filter, you are looking at the non-inverting amplifier here, right. And then when we use this you will get a curve like this, signal like this, you have to find what is fH and what is f L, right?

What is this frequency ? And what is this frequency, right? This will be at minus 3 dB, minus 3 dB, alright. So, when you see this, you solve it and you will find that f H or f 1 is 500 hertz, f 2 is 1.5 kilo hertz or f f L is 500 hertz f H is 1.5 kilo hertz, alright. So, if you do this kind of problem, you can solve it using p spice. So, the advantage of of this p spice is you do not really require the equipment that we are showing it to you here; however, until and unless you really work on the equipment work on the circuit, you will not get idea where the problem was, because when you when you start working with the circuit, you will find lot of problems that you will encounter while you design the circuit, alright?

Theoretical design is one game simulation is another game experimentalist third game, right. Here to play all the games to be successful alright? So, do not leave anything behind, learn theory learn simulation run experiments.

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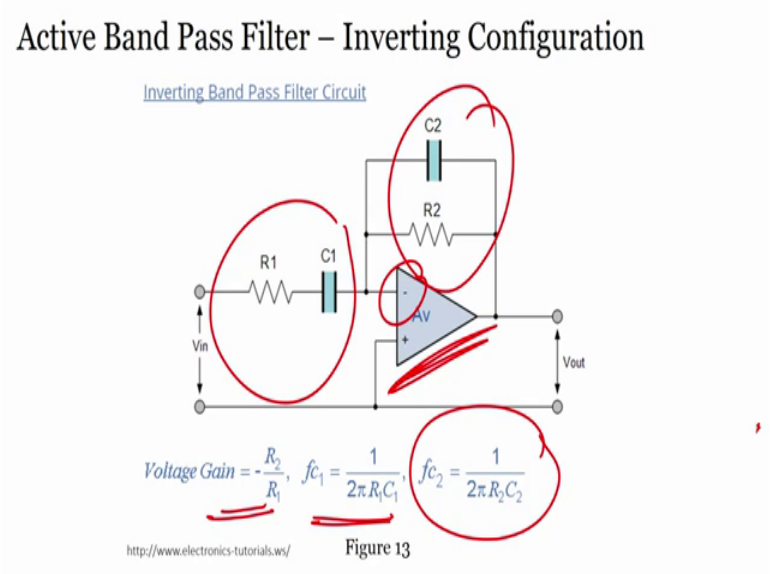

Active Band Pass Filter – Inverting Configuration

Inverting Band Pass Filter Circuit

$Voltage\ Gain = -\frac{R_2}{R_1}$, $fc_1 = \frac{1}{2\pi R_1 C_1}$, $fc_2 = \frac{1}{2\pi R_2 C_2}$

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Figure 13

Ah so, coming back to the screen, this is the active band pass filter inverting configuration, right. Inverting configuration, here the formula is again the same fc 1 is nothing but fc 1 is your this one. So, we had to see 1 upon 2 pi RC one fc 2 is 1 upon 2 pi RC 2, right? And your voltage gain is minus R 2 by R 1 because this is inverting op amp.

So, earlier it was non-inverting band pass filter this is inverting band pass filter, it does not matter whichever you use because they are the idea of using op amp is to use as an amplifier, alright? So, if you want to amplify the signal along with filtering you can use the operational amplifier in inverting or non-inverting type.

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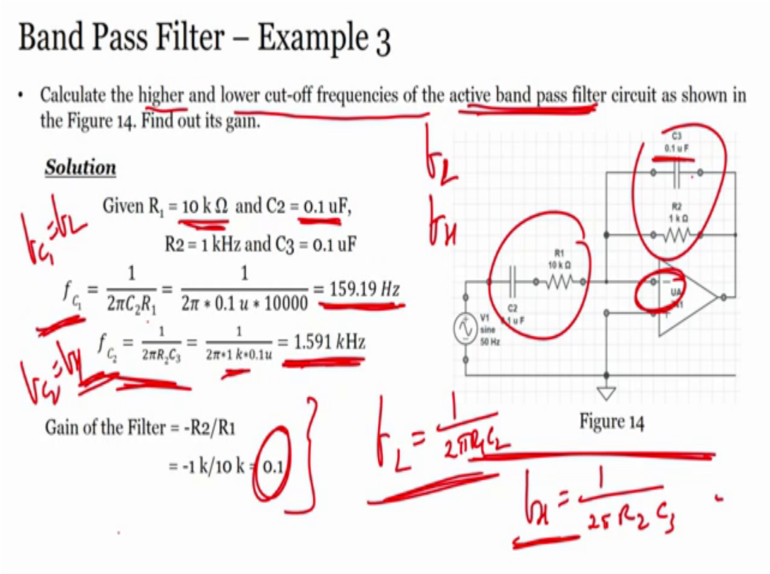

Band Pass Filter – Example 3

- Calculate the higher and lower cut-off frequencies of the active band pass filter circuit as shown in the Figure 14. Find out its gain.

Solution

Given $R_1 = 10\ k\Omega$ and C2 = 0.1 uF,

R2 = 1 kHz and C3 = 0.1 uF

$$f_{C_1} = \frac{1}{2\pi C_2 R_1} = \frac{1}{2\pi * 0.1\,u * 10000} = 159.19\ Hz$$

$$f_{C_2} = \frac{1}{2\pi R_2 C_3} = \frac{1}{2\pi * 1\ k * 0.1u} = 1.591\ kHz$$

Gain of the Filter = -R2/R1

= -1 k/10 k = 0.1

$f_{c_1} = f_L$

$f_{c_2} = f_H$

f_L

f_H

$f_L = \frac{1}{2\pi R_1 C_2}$

$f_H = \frac{1}{2\pi R_2 C_3}$

Figure 14

This is one more example, right. This is one more example, before which we will go to the actual experiment, is band pass filter if calculate higher and lower cut off frequencies of active band pass filter, right? As in figure 14.

Suppose we are given this value this figure, and we are asked to find f L or f what is that higher and cut off frequency ok, f L and fH if you are asked to find, then how can we find this frequencies based on the values given in the circuit, right?

So, R 1 is given, C 2 is given, R 2 is given, C 3 is given. Now fc 1 is nothing but I have told you earlier, right. fc or f L, right. F L you can say fc 1 fc 2 or f L also is nothing but 1 upon 2 pi R 1 C 2, right? F H or fc 2 1 upon 2 pi here R 2 C 3, R 2 C 3, right. So, from here if I substitute the values as C 2 is what ? 0.1 microfarad R 1 is what ? 10 kilo ohms, I get value 159.19 hertz, alright. If I put the value here, right? R 2 is what? R 2 is my 1 kilo ohm. C 3 is what? C 3 is 0.1 micro farad, then I get value of 1.591 kilo hertz, what is the gain? Gain is R 2 by R 1, why minus R 2 by R 1? Because if you see the screen you will find that it is an inverting amplifier inverting amplifier, right?

So, gain is minus R 2 by R 1 or it is minus 1 by 10 or this 0.1 gain is 0.1 do not write minus 0.1 ok, this is wrong gain is 0.1, alright. So, f equals to 1 upon using this formula f L fs you get f L you get fH, now see lower and higher frequency. We can also say cut off frequency one cut off frequency do that that is why it is fc 1 and fc 2, right. So, do not get do not get confuse that what is fc suddenly from f L is nothing but you can also write f C 1 equals to f L, fc 2 equals 2 fH, this also correct, alright, this is also correct.

So, what we understood is, that once we know the formula which is so super easy formula 1 upon 2 pi RC, right. then we can solve lot of things when you are given a circuit and you are asked to find the value of upper and lower cut off frequency, right, which is right in front of you of this particular figure. From this particular figure now, you can very easily find what is the lower cut off frequency, what is higher cut off frequency, or upper cut off frequency and what is the gain of the amplifier.

What is the gain of this amplifier, easy? Super easy, right? So, we will see ah. So now, I help you to understand what exactly this band pass filter is, and we have seen how you can design a passive band pass filter by using the high pass filter and low pass filter by integrating high pass filter and low pass filter together in passive way it becomes passive band pass filter. If you use a op amp in between the high pass filter and the low pass filter it becomes your active high pass filter a active band pass filter, right. And instead of in op amp you can use non-inverting operational amplifier you can use the inverting operational amplifier.

So, by using this non-inverting and inverting impression amplifier, your formula for gain would be slightly different inverting amplifier it will be minus R 2 by R 1 or minus rf by R in non-inverting amplifier will be 1 plus rf by R in, right? Otherwise the things remain super simple. For frequency formula always remember it is f equals to 1 upon 2 pi RC, in case of a high bias high pass filter and low pass filter the high pass filter you can see the first C. And first are you had to calculate for the low pass filter the feedback it registers and capacitor is there that you had to calculate whatever the value is there, once you know f H once you know f L if f H minus f L will give you this band which is your bandwidth and that is your bandwidth of your band pass filter.

Now, once we know this, let us now perform the experiment, and will continue this experiment in the next module. Because now we have understood or we have refreshed the theory that we have already learned earlier, right. So, if you are everyday you just spend some time and or in a week you spend some time apart from the understanding what are the new uploaded videos, if you go back and see the old videos, you will understand what kind of theories you have learn.

And once you understand this, I do not have to speak for half an hour on one hour just to make you understand again the same theory. That we have done try to try to refresh your theories right, but at the same time I do not want to just you know keep on assuming that you know everything let us not experimental directly.

That is why this is a reason that we have I have told you again the details about the band pass filter, I had told you about how the passive band pass filter is, I had told you how the active and pass filter is, I had told you how you can how you can fabricate or how you can design the active and passive band pass filter. And now in the next module we will implement it on the breadboard, alright?

So now you have you know this, let us see in the next module how you can implement it, and let us get the values at the input signal and output signal let us measure it let us see what kind of output waveform, we see and let us comment on it, alright. So, till then I will see in the next module, you take care, bye.