**Biomedical Signal Processing**
**Prof. Sudipta Mukhopadhyay**
**Department of Electrical and Electronics Communication Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture - 51**
**Tutorial - II (Contd.)**

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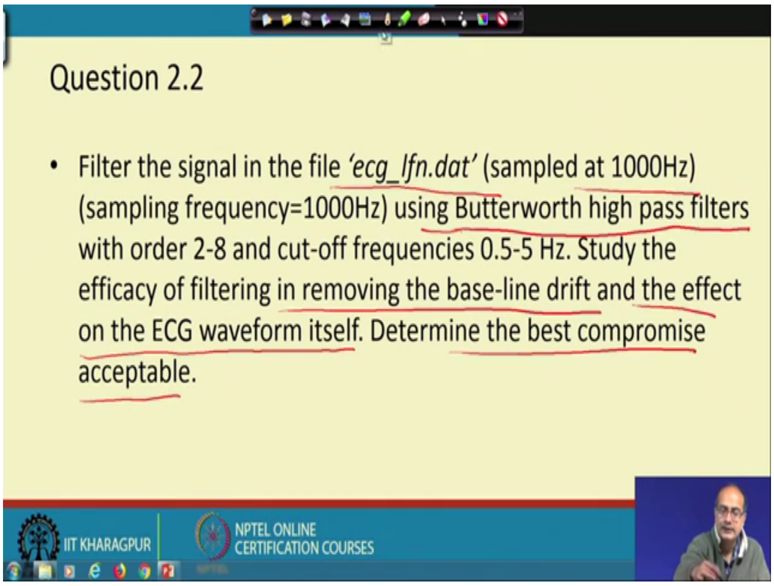


So, next exercise is again that we get a signal an ECG signal, we get that here the data file is given sampled at 1000 hertz that we have again that high frequency noise. So, we are using Butterworth high pass filter that we are we are taking the Butterworth high pass filter and study the efficiency of that filter in removing the baseline drift ok.

So, the signal is having low frequency Artifact and we need to remove the that low frequency Artifact and the effect of the that filtering on the ECG waveform itself; that means, what is the distortion in the waveform, we get along with the removal of Artifact and we need to find out the best compromise actually acceptable; that means, where we get the best amount of reduction at the same time, we need to get that where we get that least distortion in the signal waveform.

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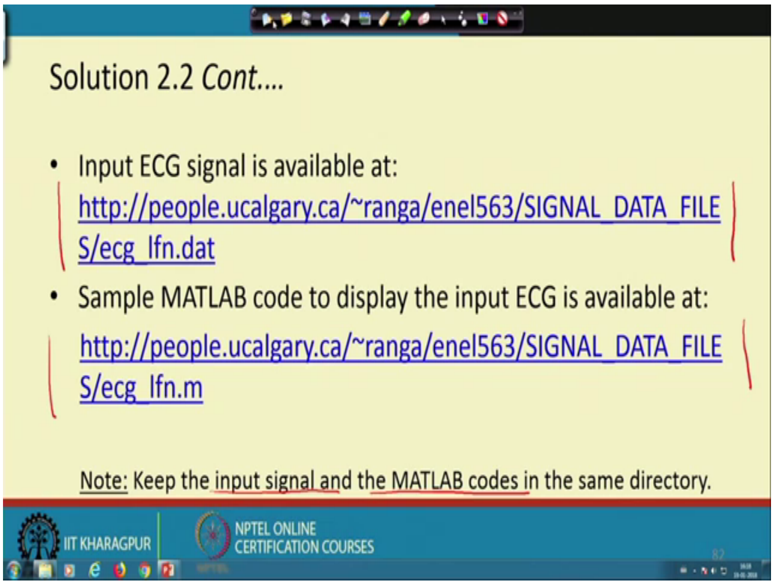


And for that actually that we are given the ECG signal that we are given the data file here in this link and the MATLAB file to read these signal and we have to keep these input signal that is the data file and the MATLAB code in the same directory that is the working directory of the MATLAB.

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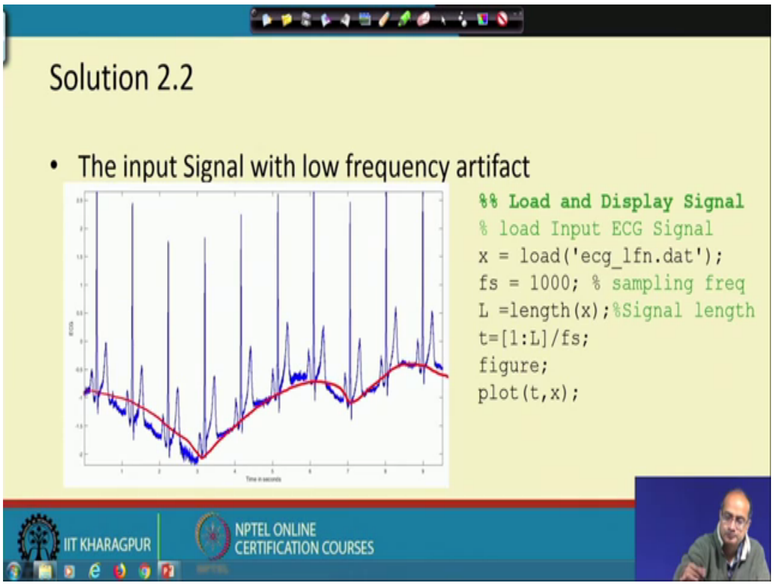


And now let us proceed; just look at the signal at the low frequency noise. So, for that first, what we do? We use the command load to load the signal, we store it in the variable x, then we initialise the variable fs with the sampling frequency 1000, then we find out that how many samples are provided. So, to check that that we use the command length on that vector that x, actually, it is a it is a vector we get and we take the length of it that gives a number of samples. So, we store that that length in the variable L.

And then to create the time axis we take another variable t where we populate it with a ramp. So, to create that ramp v within the third bracket, we write 1 is to L; that means, it will increase one to in that way up to L and have L points there and we multiply that with 1 by fs. So, that instead of the sample number we get the time instant corresponding to each of these sample and then using the command figure, we create the new pen for the figure and we plot t comma x to see that the nature of the signal.

So, if we issue that these commands in the MATLAB that prompt and this is the output we get we get the plot here in the left hand side and we get it is similarly affected by low frequency Artifact and that is a evident from the fact that the baseline is moving like this ok. So, as the moment is very slow. So, from that we can get it is a low frequency Artifact and the as the isothermal line is changing it is called that baseline Artifact.

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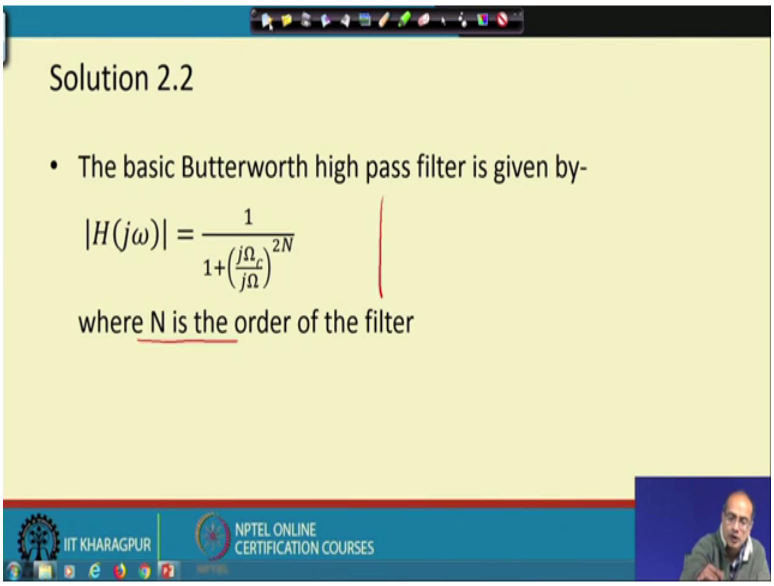


So, now let us look at the structure of the Butterworth filter which is given here and this is the expression of the Butterworth filter for the order n ok. So, we need to make use of that to create the high pass filter Butterworth filter and we need to see that what is the impact of it on the that signal.

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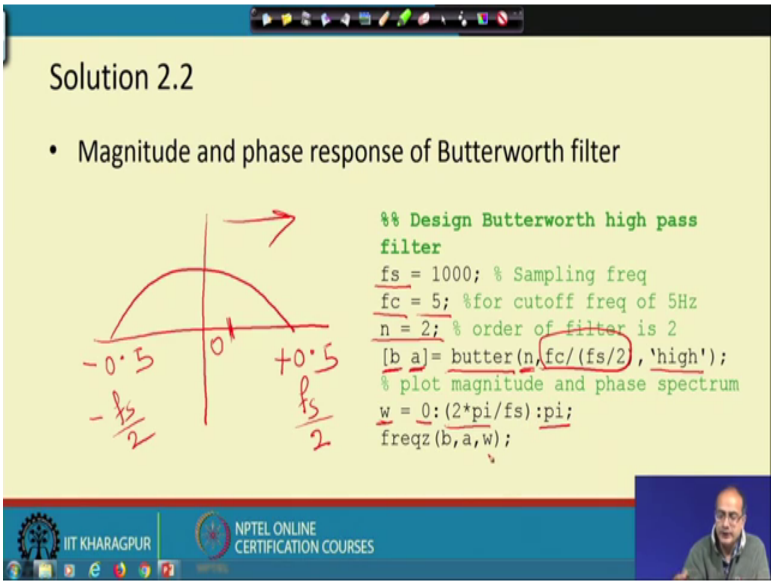


So, for that first let us check that magnitude and the phase response of the Butterworth filter. So, for that that what we choose here that we would like to take the case that we know the sampling frequency is a phase equal to 1000 and we have taken the first design that is having the cut off frequency designated as fc that is equal to 5 hertz and model order is selected as n equal to 2; for that; we generate the high pass Butterworth filter. So, for that we have issued the command that butter and the first variable is n that that is providing the order of the Butterworth filter.

Next is that our that normalised cut off frequency, if we look at that spectrum of a real signal; what we get that spectrum would be symmetric, it would be symmetric and it would if we normalise the frequency, it would be say varying from 0 to 0.5 and in the left side, it would go from minus 0.5 ok. So, in that way; so, what we can say that it is the actually half of the sampling frequency, it will come here or we can write fs by 2 and here minus fs by 2.

So, here what it is done that fc which will come somewhere, it is normalised we normalise with fs by 2. So, normalise the, that cut off frequency is the second variable third variable is suggesting that it we need a high pass filter and by issuing this command, we get the corresponding the numerator and the denominator polynomial numerator polynomial will be stored in the variable b as a vector and the vector a will store that denominator polynomial ok.

And next part is that we would like to see that with respect to that here the w; w is actually a vector. It is or we can say omega that here we have used w to express that starting from 0 to pi ok. So, we are looking at the positive part of the frequency axis and. So, instead of going from actually that minus pi to pi, we are writing only the right hand side of it and it is increasing in this way that each increment it is going 2 pi in to 1 by fs in this way ok. So, that we are going like this and here we are giving that frequency v comma a and omega that the command to draw that.

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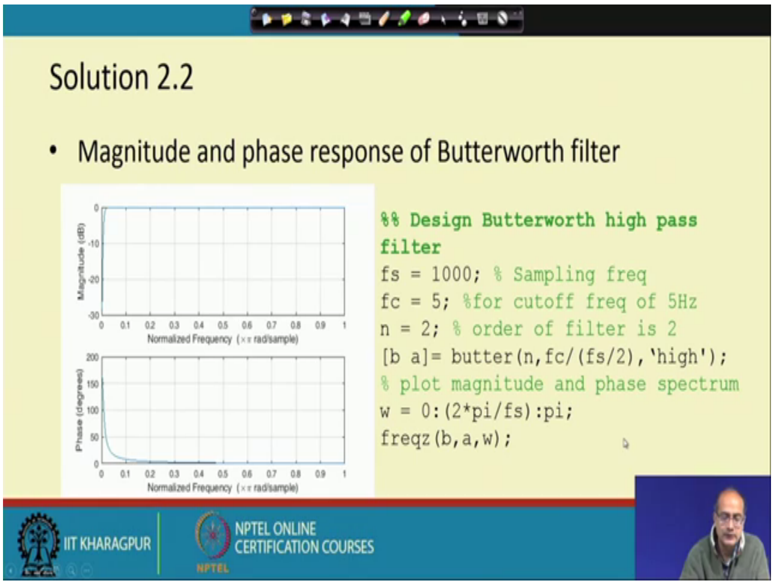


The two actually the plots; so, here we show that with respect to the then radial frequency that how actually it is changing that we get that a sharp increase we get a sharp increase in the magnitude and very quick change. So, if you recall that previous experiment when we have a single 0 that in the x real axis at radius 1 corresponding to that that both of them that phase and the magnitude the response is looks much better ok; the only thing the phase response probably was better because it was there a linear one ok; however, we need to also keep in mind that here the order is 2.

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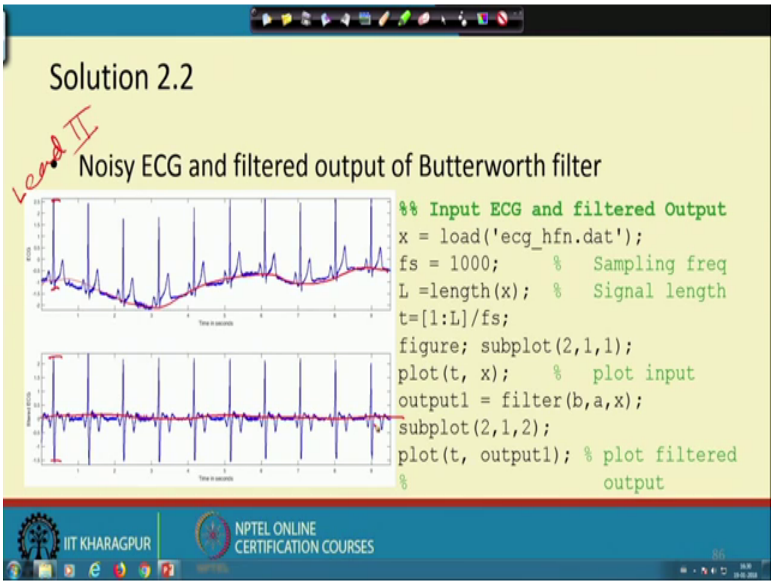


So, now let us look at how the noisy ECG and the filter output looks like. So, to do that we need to make the plot and here first, we again show that how to load that signal this already, we have done we know that using the load command we can do again just to remember we are showing this thing that fs is the sampling frequency L is the length of the signal vector x or the number of samples there and we create the time axis t, the figure and the sampling plot that for that we create the new pen figure and we use the subplot command to actually divide the pen into two parts into two rows and first row that of the top row we use to plot the input signal with respect to the time t.

And then we compute that filter response by using the command filter the first variable is the numerator polynomial second one is the denominator polynomial, already we have designed the Butterworth filter and from there we got these coefficients and the third variable is the input signal vector.

So, the output termed as output one that we actually plot in the next slot or the lower half of the part of the pen and we use the command t comma output one ok. So, these are the commands to use and here we show the output in this left hand side and what we get that baseline Artifact; what was there in the input signal that is completely absent the baseline has become completely horizontal. So, we are successful in removing the baseline.

However there is a change in the that the signal amplitude that if we look at that signal earlier it was from about say in between minus 1 to minus 1.5 in the lower end and the upper end, it is about 2.5 for the first one.

Now, you see it has become more symmetric it has gone to minus 1.5 upper side about 2 and the shape has changed now the input signal ECG signal if you recall that the different ECG lead configuration, this one is taken from lead two, this is taken from lead two configuration, but here it the signal looks like the coming from lead one. So, much distortion has come because of the filtering ok.

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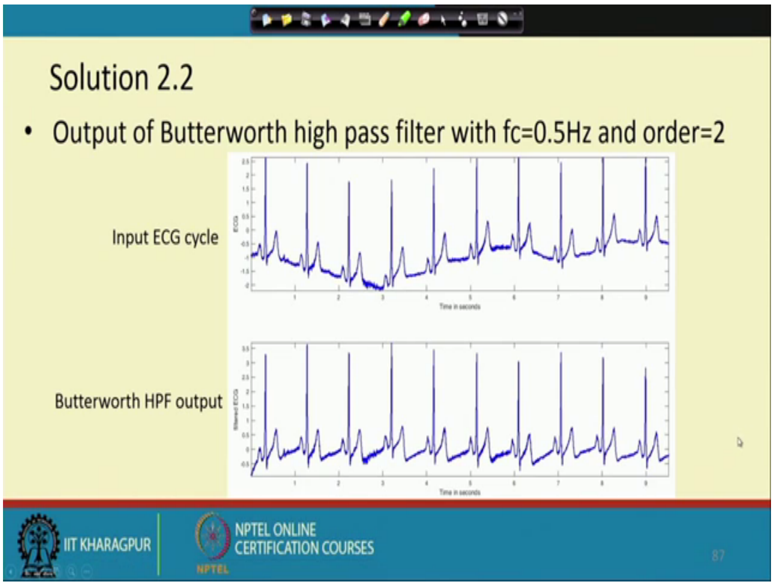


So, let us see that how the thing will change now to appreciate it better we see it here that how the thing looks like that for that cut off frequency 0.5; that means, previous one we have the frequency 5 hertz. Now we have gone to a new place 0.5, we see it has improved the signal output quality the distortion is less; that means, what we can conclude that in the previous case that we were actually losing a good part of the signal energy also which cause the distortion.

Now, the signal looks more towards the output signal and if we look at that overall that as it has come near the 0 line, the amplitude will also remain to be the more or less the same that it is minus 0.52 about 3 and here it was about say minus 1 to 2.5 ok. So, it is much more desirable and it is much better compared to the previous case when the cut off frequency was 5 hertz.

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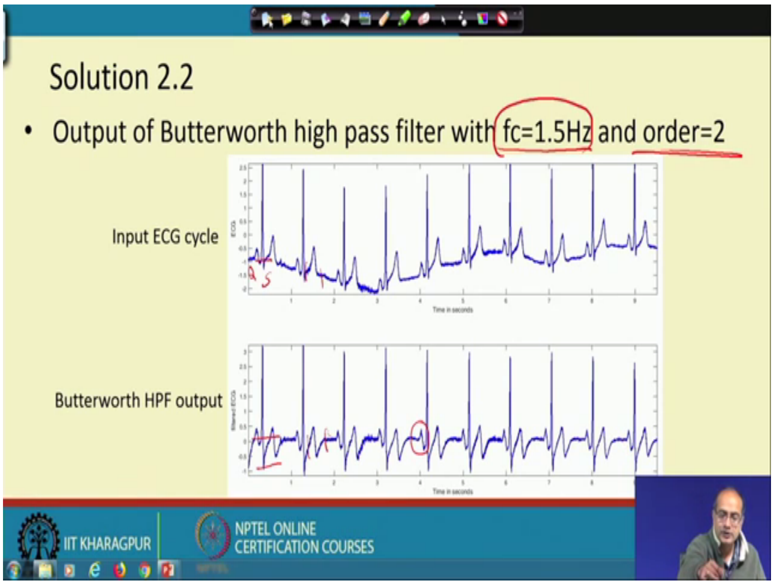


Now, next is that we are changing the cut off frequency that it is move to 1.5 hertz and the order remains to be at 2 ok. Again, we get good response that we are getting the output and all that pretty well, it looks almost near the previous one; the only thing what we can see that if we look at the relative difference between the that q and the s waves here we see that they are stretched. So, that part there is some distortion and if you look at the t wave t wave was a positive hump which has become now an oscillation ok. So, we see some distortion is creeping in by increasing the cut off frequency from point 5 to 1.5 ok, the p wave unfortunately it has actually less impact on it. So, that is the overall change with respect to the previous one we can say.

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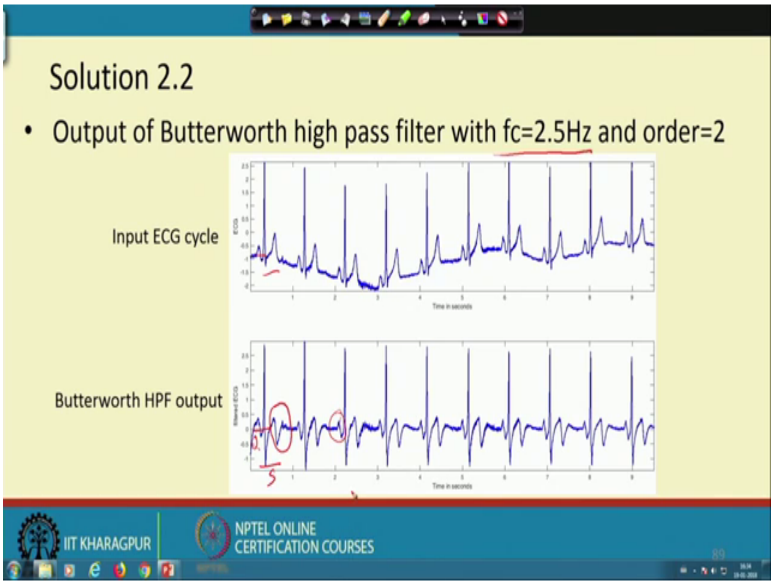


Now, let us move forward we move the that cut off frequency further away from 0 it move to 2.5, we see that the oscillation has moved in such a way it looks like the t wave is almost inverted and the difference between the that q and s point, it has increased with respect to the input signal. So, distortion is much more in this case and for our p wave also I think some amount of distortion it is there though it is you cannot put into words that amount of distortion.

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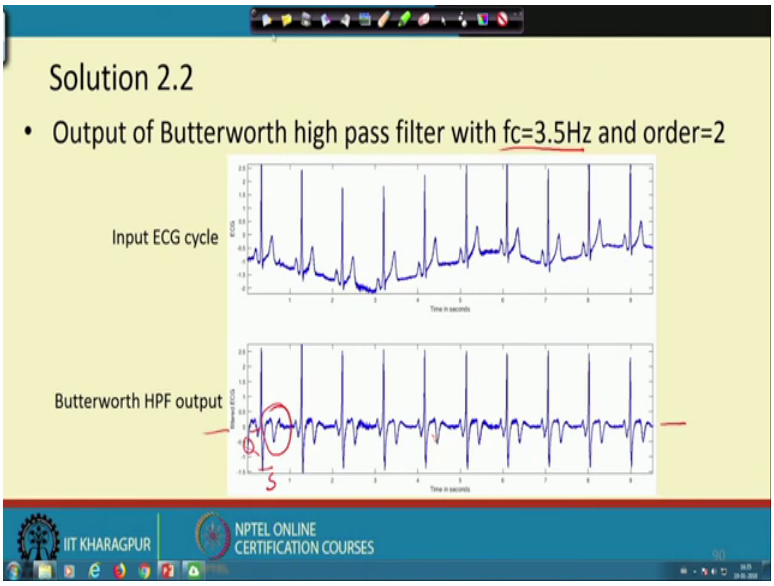


So, now let us look for the next attempt again that the cut off frequency is moved up and we get that in this case that we have that for 3.5, again, it is very much successful in removing the baseline artefact; see that we are getting almost horizontal line, but then again all those problems what we had in the previous case that the increase in the difference between the q and the that s wave or the shape of the t wave all those things remains be to the same as the previous case.

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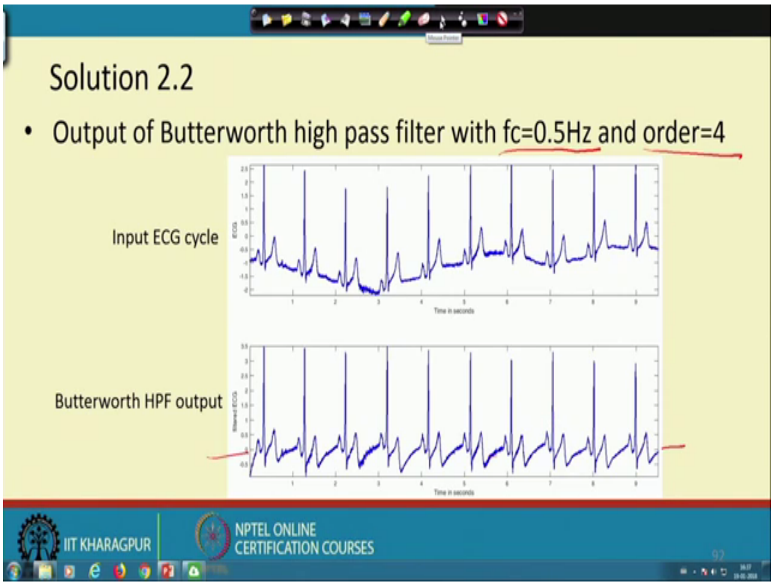


So, we cannot say the signal is undistorted signal has undergone a lot of distortion. So, it is not a very good choice. Now, we come back again from the experience that again we come back at the frequency 0.4; sorry 0.5 hertz at one of our previous choice and model order is increased to 4. So, with that we get actually again much better output the baseline artifact has gone to 0 the baseline has come to a horizontal line passing through 0 and our qrs complex it looks very similar to the original one only thing there is a shift.

Because of the baseline wandering is removed there is a shift. So, the whole thing is shifted bit upward water in the first cycle and in that way that what we see that the t wave p wave they seems to be pretty close to the original one. So, it is difficult to comment anything beyond that in a qualitative way.

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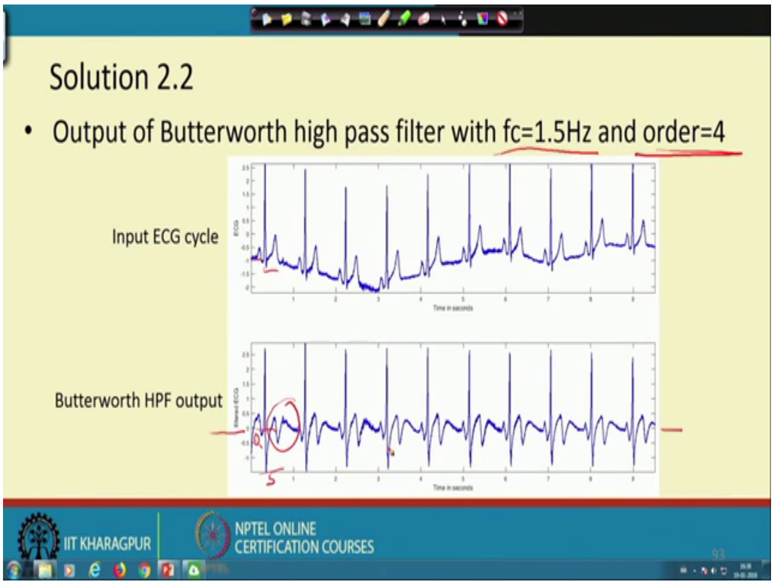


So, now let us again try to increase the cut off frequency again and from 0.5, it is move to 1.5 and model order kept constant as four again what we notice, though it is successful in removing the baseline and keeping it to the value that a horizontal line passing through 0 the signal distortion has again come back the t wave it looks like flipped the difference between the q and the s wave that has increased compared to the original signal.

So, there has been a huge change in that way which is not. So, desirable, the signal has actually get related compared to the case that when the cut off frequency was 0.5.

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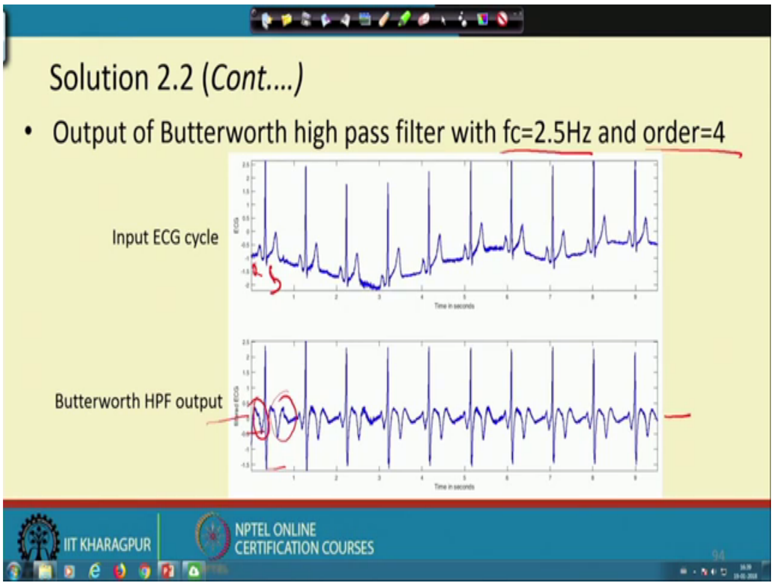

Now, again we push it further we move the cut off frequency 2.5 keeping the filter order at four and what we see that again it is very much successful in removing the baseline, but not only the q wave is affected the p wave is also getting affected the p waves are missing and the difference between the q and the s wave that has increased here we know that. So, it is works done actually with cut off frequency one point five. So, suddenly it cannot be the best choice.

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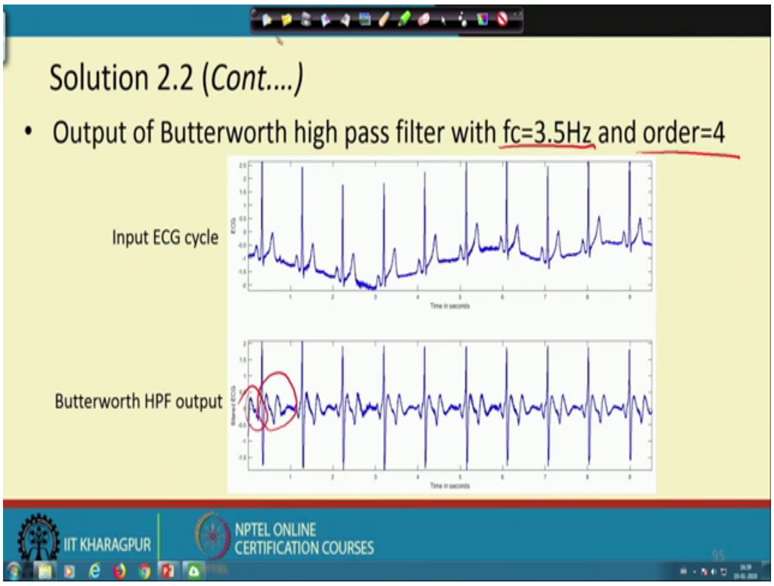


So, we continue our investigation and next, we move it further we take it to cut off frequency at 3.5 keeping the model order same at 4. So, again we see that now the q or s complex, it looks like a oscillation equal in both the sides like lead one configuration and. So, L huge distortion is there in qrs complex, the t wave is completely destroyed the p wave also is destroyed. So, it is certainly not a desirable output in terms of the signal the signal is very much distorted though again it is successful at removing the baseline artefact.

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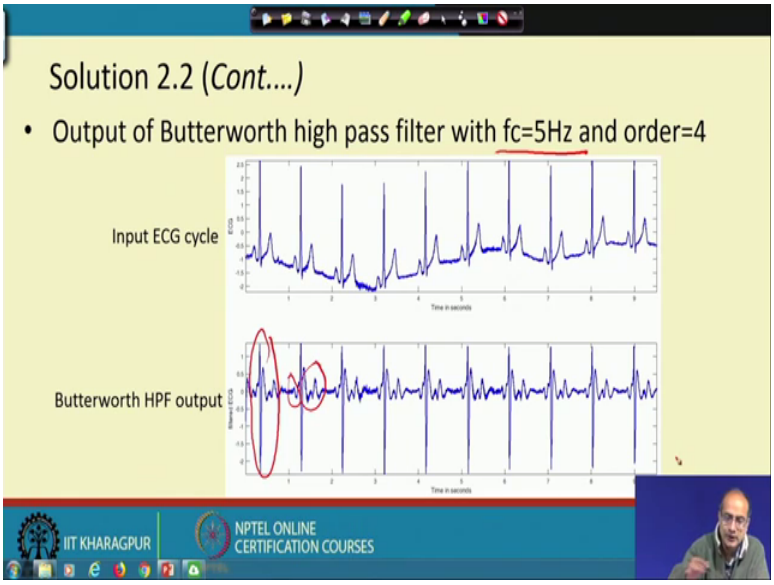


Next, we look that another attempt by increasing the cut off frequency we see the distortion have increased and overall qrs complex, it looks entirely different not only that the p wave is destroyed the t wave is destroyed. So, the overall signal, it looks completely different in this case ok. So, this is also not a desirable filter for our application.

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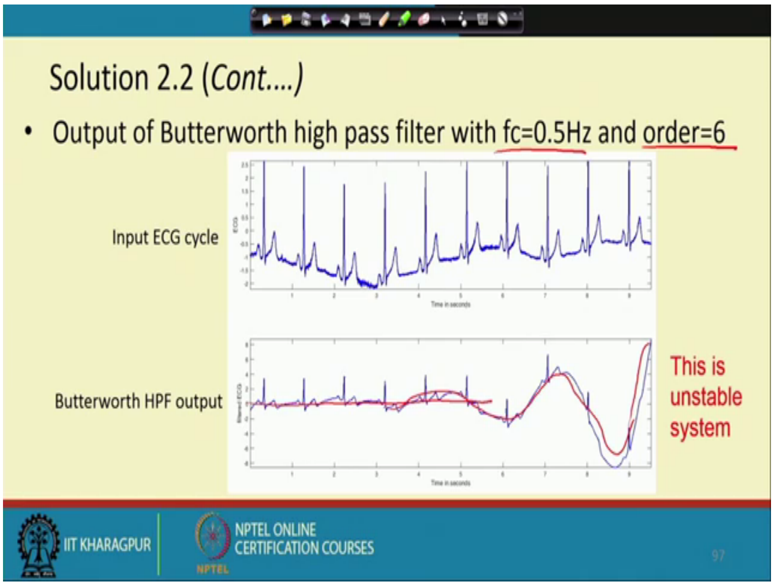


Now, let us move further what is tried that model order has been increased further to 6 and the cut off frequency is set to 0.5 hertz ok. So, in this case what we notice that initially that the signal looks like well behave and it is having that the artifact is removed, but slowly there is a build-up and it looks like baseline wandering and it is actually keep on increasing. So, it has actually become an unstable filter in this case, what has happened in this case that as we are using a IIR filter 1 of the pole, it must be outside the unit circle that the amount, it is out of the unit circle it is very small. So, at the beginning, we do not actually notice that the growth of the signal.

But slowly as a time pass that it grows to the extent that it makes it visible and then the output becomes actually exponentially high and we lose the signal completely ok. So, what we get that we have got a unstable filter with model order 6 and cut off frequency 0.5.

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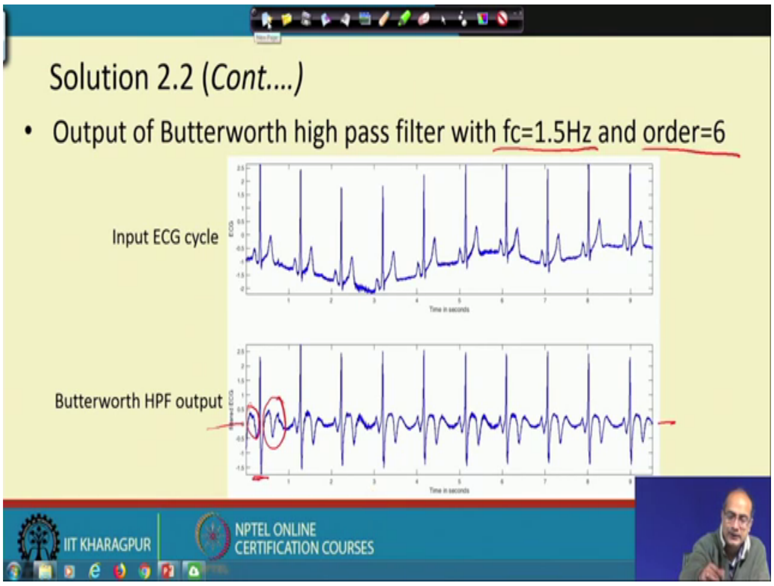


So, next another attempt is made with cut off order keeping at 6 and that cut off frequency 1.5 in this case, what we get that the baseline artifact is moved, but probably because the cut off frequency is increased, we are losing the part of the signal strength also. So, the qrs complex is affected the t wave looks like a inverted wave the p wave is also distorted ok.

So, we get a good amount of distortion, but in this case; one good thing that the signal what we get it is stable because the filter is stable.

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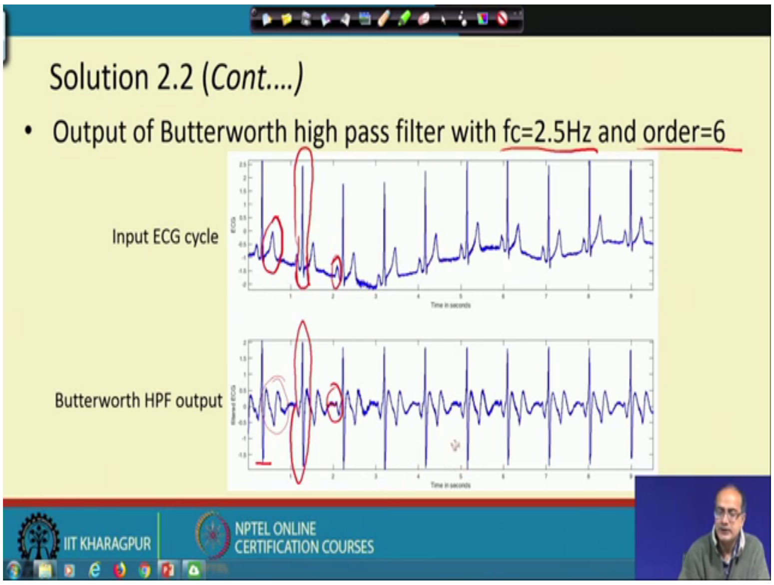


Now, we try further again we increase the cut off frequency to 2.5 for the model order of the Butterworth filter equal to 6 for that again what we see that there is good amount of the distortion in the output waveform the qrs complex is distorted the t wave is distorted here in the output.

Please look at this was the input t wave how it is distorted this was the, that within these that qrs complex it was given. Now the qrs complex looks like a oscillation which is equal almost in both the sides and if you look at the p wave the p wave looks likes it is it is completely lost kind of thing. So, there is a huge amount of distortion in the signal. So, this is not a suitable combination.

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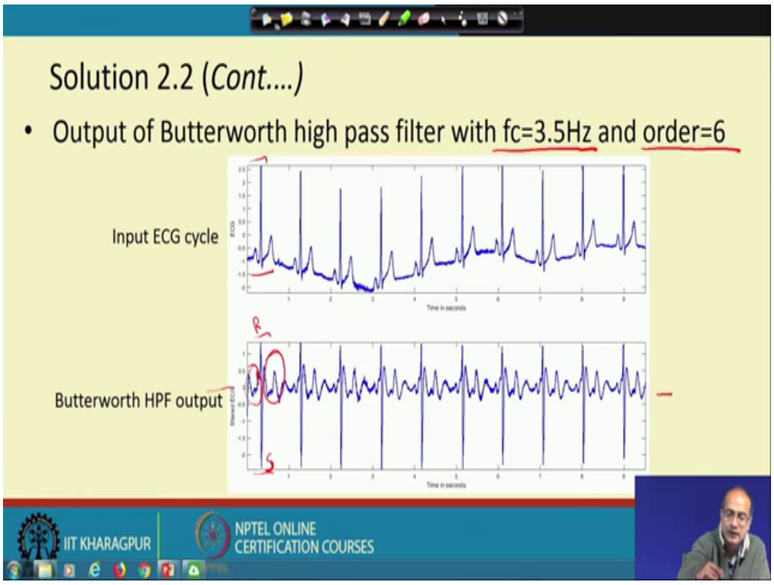


Next we try to we keep the model order same at 6 and push up the that cut off frequency to 3.5 again we are successful in removing the baseline artifact, but the distortion again is becoming more though the oscillations are not symmetry it look as if the qrs complex what was there earlier it has been above to be inverted kind of thing that we are unable to find out the s point here more clearly if this is the r. So, qr s has actually become as prominent as the that the r wave in the original and t wave is distorted p wave is missing. So, certainly it is not a good actually choice for removing the baseline artifact.

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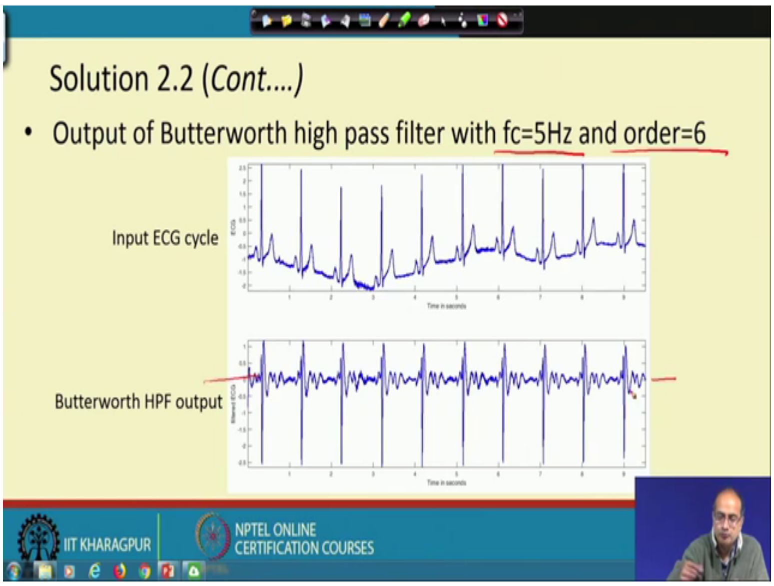

Next, we take the cut off frequency as 5 for the high pass filter and model order remains to be the 6 again what we find that it is pretty much successful in removing the baseline artifact, but again it suffers from that the distortion of the input signal that is the ECG waveform the lead to configuration one and we see the distortion is even more than the case what we have with the cut off frequency at 3.5. So, this is again we have to reject and we need to look for a better combination for this one.

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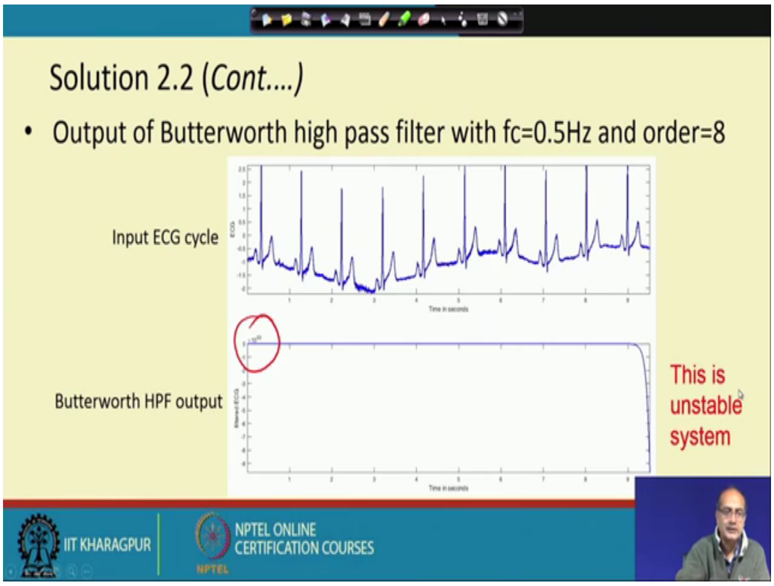


So, we go for now model order 8 and cut off frequency 0.5. So, what we get in this case that Butterworth high pass filter, if we give we get the output is actually becoming very high look at the value that it is becoming very high. So, it is clearly; it has become a unstable filter and that is the conclusion we get that we are not getting the that the output in a rational way.

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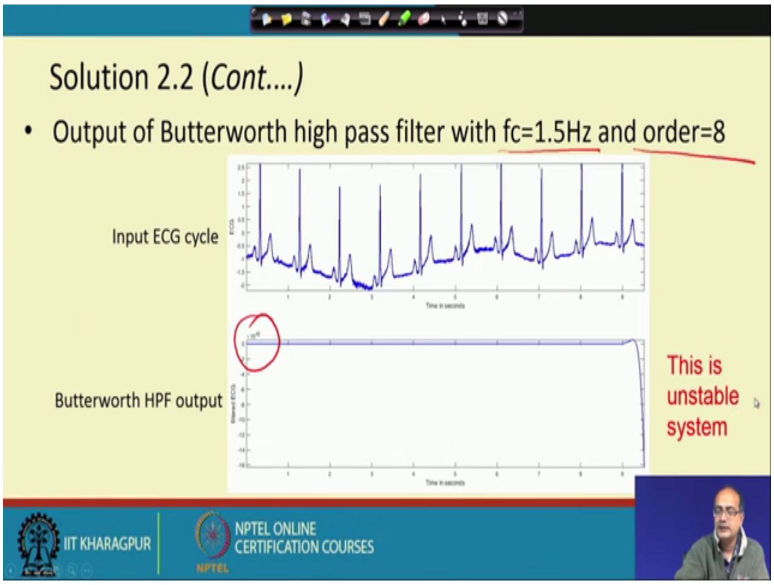


So, these has to be rejected. Next we look at that that again keeping the model order eight we increase the cut off frequency again we see the same problem again we end up with a that a unstable filter and that the transient is going pretty long and we are unable to get any desirable output or rather our signal.

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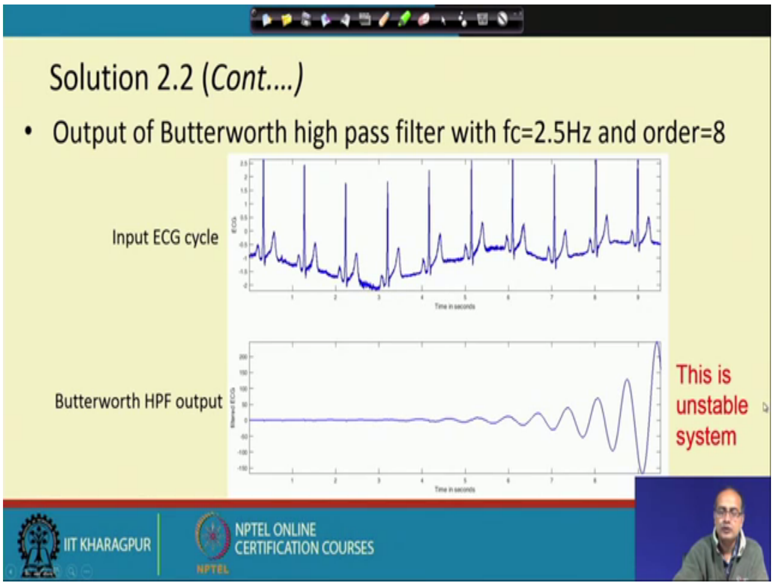


Waveform is completely lost increasing the frequency further to 2.5 cut off frequency moving to 2.5 helps to make the situation better, but the signal initially it is about 0 then it is we can get that it is building up. So, again it is a very unstable filter ok, it is again the though the that it is not actually diverging from the beginning, but still it remains to be a unstable filter and that we cannot actually make use of it for any useful application.

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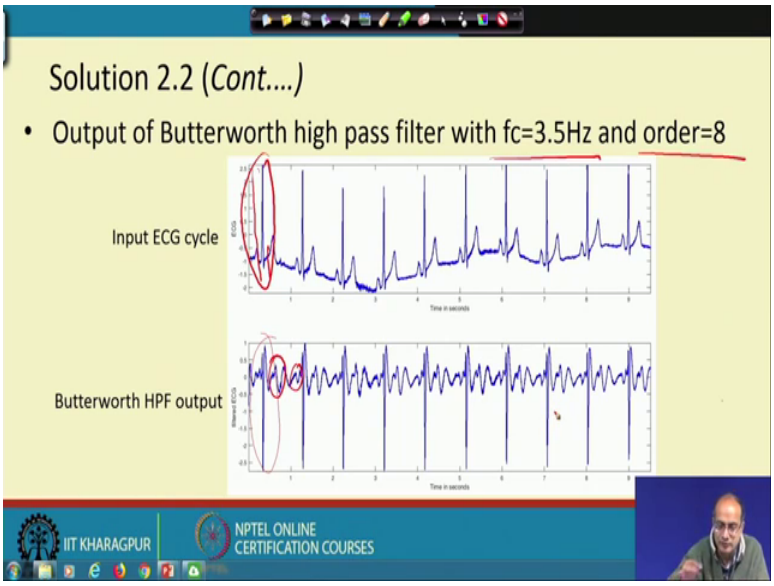


So, we move forward we change the cut off frequency keeping the model order same as 8 with cut off frequency 3.5, we are happy to get a stable filter output; however, the signal distortion is pretty high what we get the qrs complex, it seems to be inverted here this is the qrs complex rather this part that it is got inverted the t wave looks like a oscillation rather than a positive hump the p wave also is distorted ok, p wave has become z. So, we presume that it has happened because we are losing some part of the low frequency component of the input signal.

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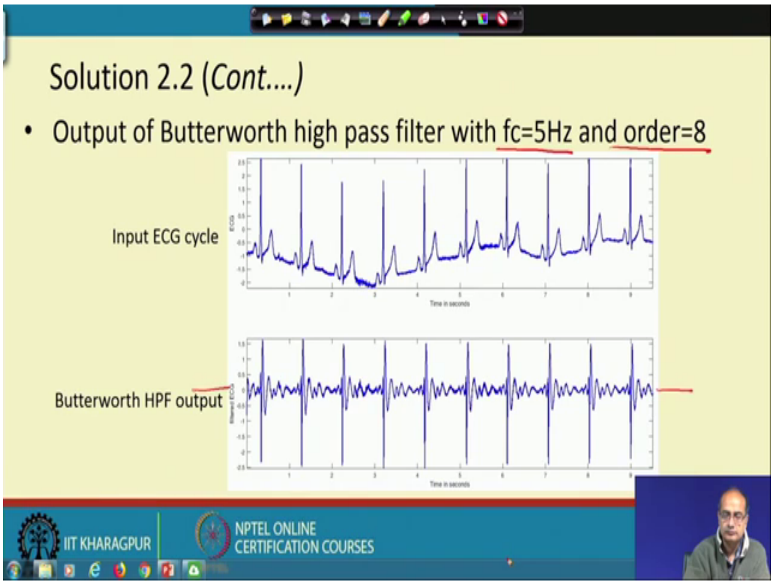


So, let us look for the another case that if you go for cut off frequency 5 hertz and model order 8, we could get again a stable filter and it is successful in removing the that baseline artifact, but what we see the signal distortion is too high. So, again because of the signal distortion due to the loss of the input signal energy between 0 to 5 hertz that this filter makes it unusable for the baseline artifact removal.

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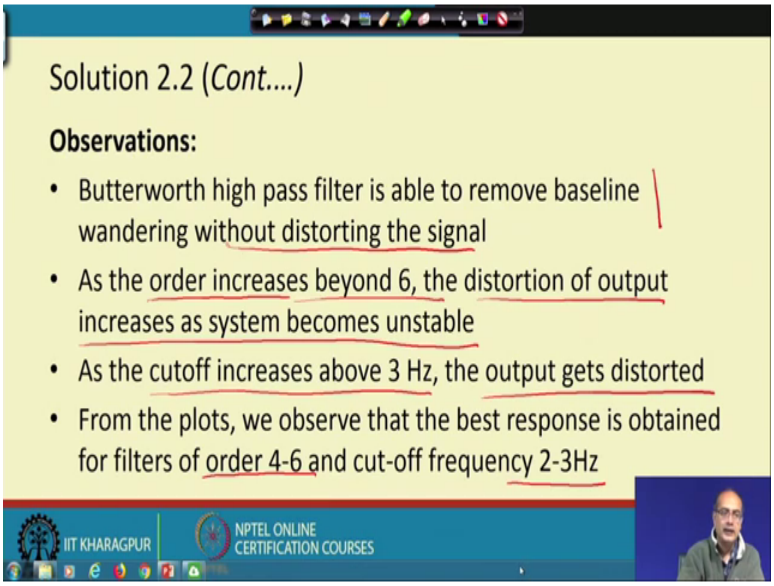


Now, let us summarise the whole thing. Let us look at that what are take away from these experiment the first point is that Butterworth high pass filter is able to remove the baseline wandering without distorting the signal; that means, if we properly choose the parameters, then we can achieve the baseline wandering we can take it out or remove from the signal without distorting the signal, but for that we need to choose the parameters carefully and the two parameters here they are important one is the cut off frequency another is the selection of the proper model order.

The second observation is as the order increases beyond 6 actually from 6 onward we get the distortion of the output increases and it becomes unstable from the 6 order itself we have noticed that it is becoming unstable and so such a high model order. So, is not desirable for the filter.

Now, the next part is that cut off frequency above three the output also gets distorted. In fact, the best result; what we could get it was for the cut off frequency between actually that at the point 0.5. So, that the last observation is from the plot, we observe the best response is obtained for the model order 4 to 6 and the cut off frequency between 2 to 3. In fact, for we can say even lower frequency, we get actually good output ok. So, that is the take away for this experiment.

Thank you.