GROUP 18

Aman Saini (2020EEB1155)

Ansaf Ahmad (2020EEB1160)

Anirudh Sharma (2020EEB1158)

CONTROLLER DESIGN ON MATLAB PLATFORM USING ANALOG FREQUENCY RESPONSE

OBJECTIVE

To design a cascade ventilator transfer function for a given analog respiratory system transfer function, according to desired specifications provided.

For lungs: $$L(s) = \frac{1}{(s+1)}$$

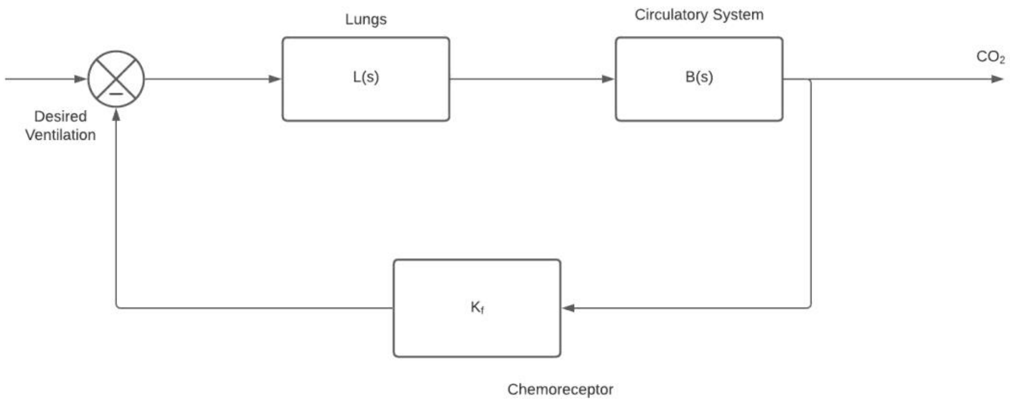
For blood circulation system: $$B(s) = \frac{0.1}{(s+0.5)(s+0.1)(s+0.2)}$$

Overall transfer function: $$H(s) = \frac{0.1}{(s+1)(s+0.5)(s+0.2)(s+0.1)}$$

The output of this system is the carbon-dioxide concentration in blood vessels. Chemoreceptors in the human brain sense the carbon-dioxide concentration and provide feedback to the brain to motor control ventilation to the lungs. The chemoreceptors serve as a simple gain block (Kf = 0.1 nominally) for the sensing action in the feedback path.

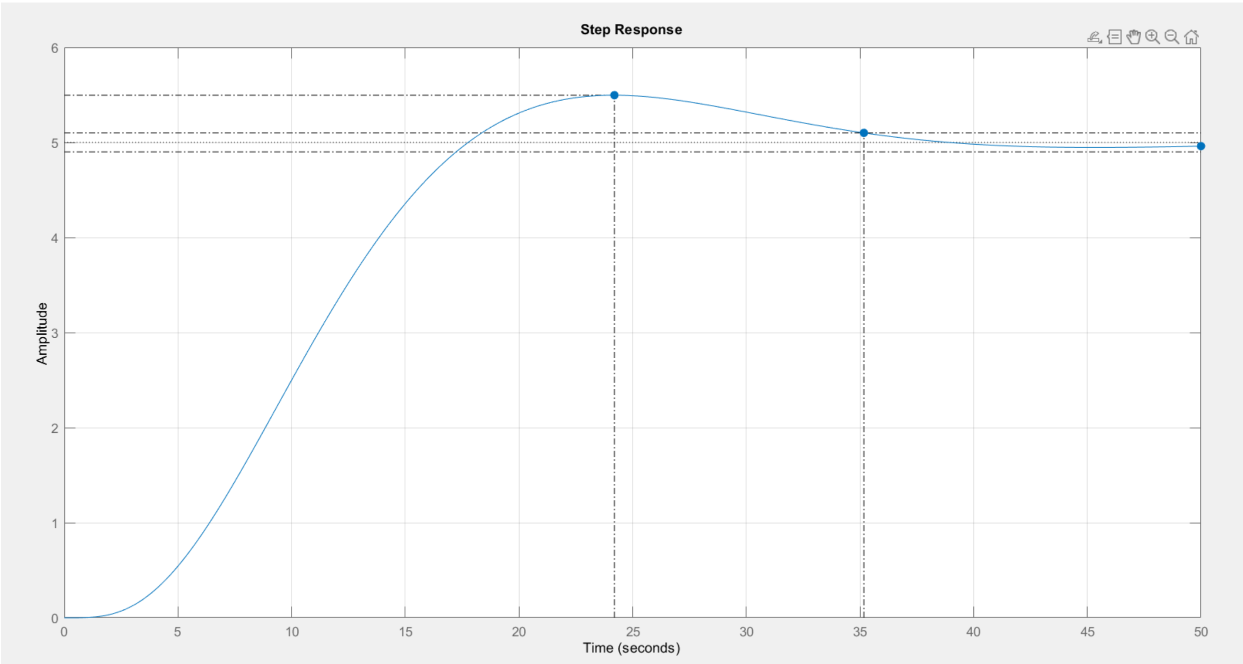
It is given that:

- An endocrinal problem in the patient may lead to flawed chemoreceptors that may change the nominal feedback gain up to ten times in the worst case.
- An asthmatic patient may, on the other hand, have the time constant of lungs increased by up to a factor of ten in the worst case.



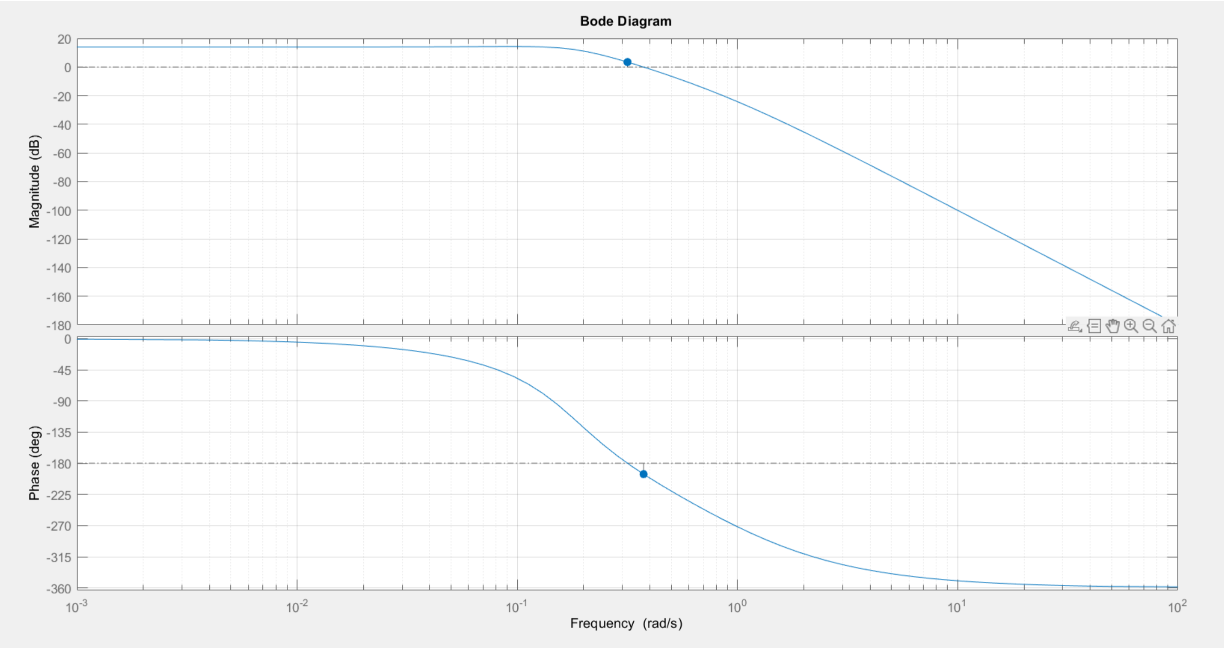
Respiratory System model of a person

Although in case of flawed receptors the response of the system becomes unstable altogether. These variations in respiratory system model leads to the person ending up requiring aid in breathing through mechanical ventilators. We need to design one such ventilator which will maintain a phase margin of 45° (for medical reasons) regardless of parameter variations. To understand the given closed loop system, we plot the step response of the system.



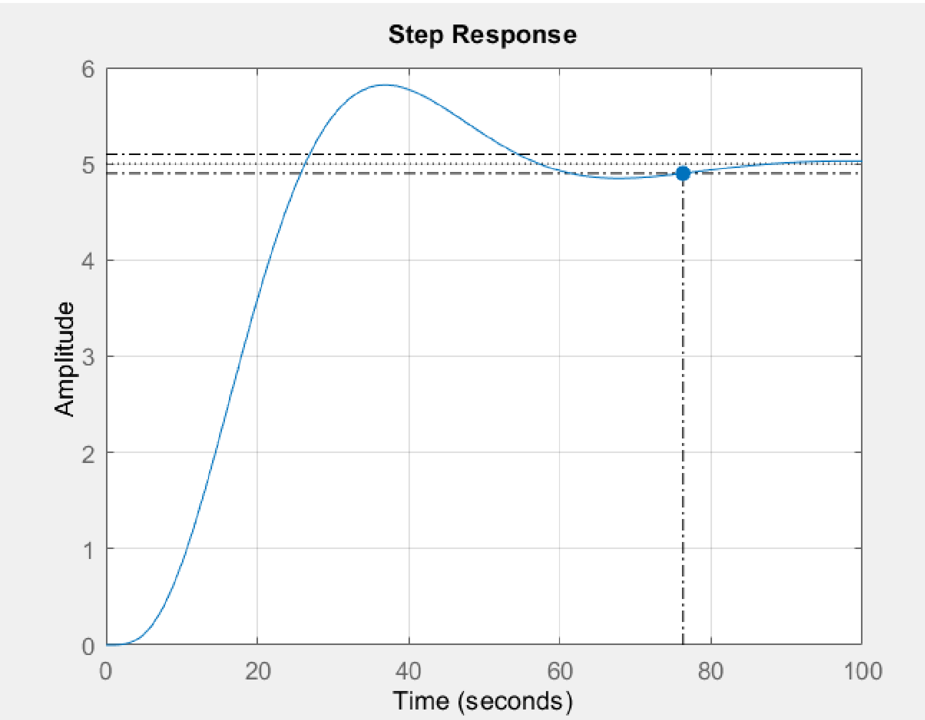
Step Response of the Respiratory Transfer Function of a healthy human.

We observe that standalone closed loop system with nominal gain and time constant values has a settling time of almost 35 sec and a steady state of gain of 5. We also plot the bode plot of the given respiratory system to find the phase margin and gain margin for nominal parameter values.



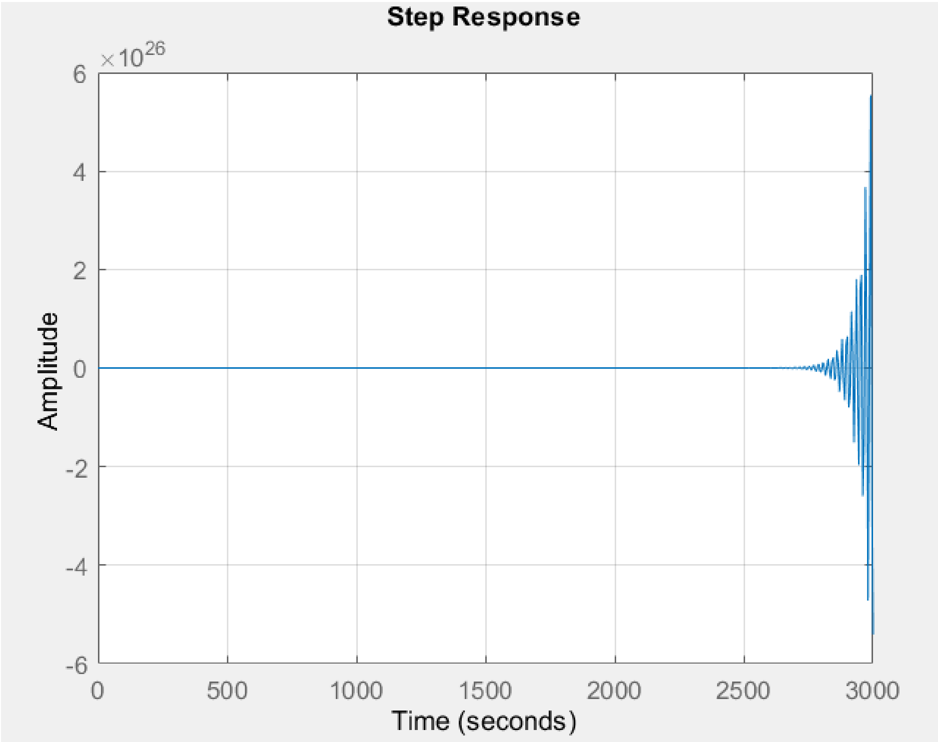
From the bode plots, the Phase and Gain Margin of the original respirator system is GM = -3.48 dB and PM = -15.68º. Now we require to introduce a controller in the form of ventilator in the given closed loop system that incorporates the parameters that are prone to variation.

Further observations: The step response of the Asthmatic patient in the worst-case scenario is as follows:

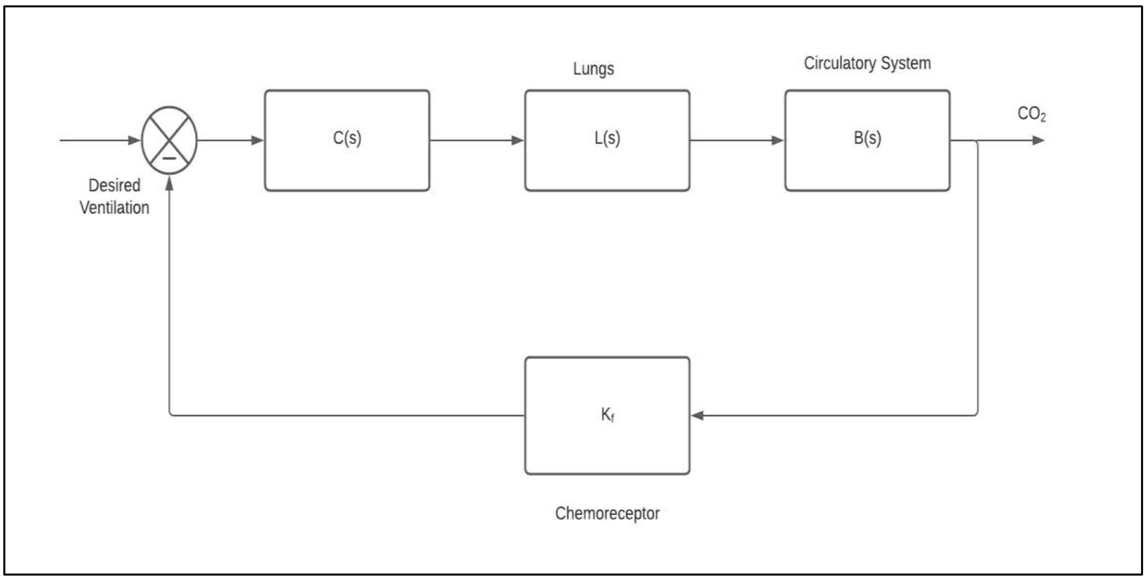


We observe that the settling time is the only quatity that is affected considerably, the new settling time in the condition is: 76.3 sec, the steady state gain remains the same.

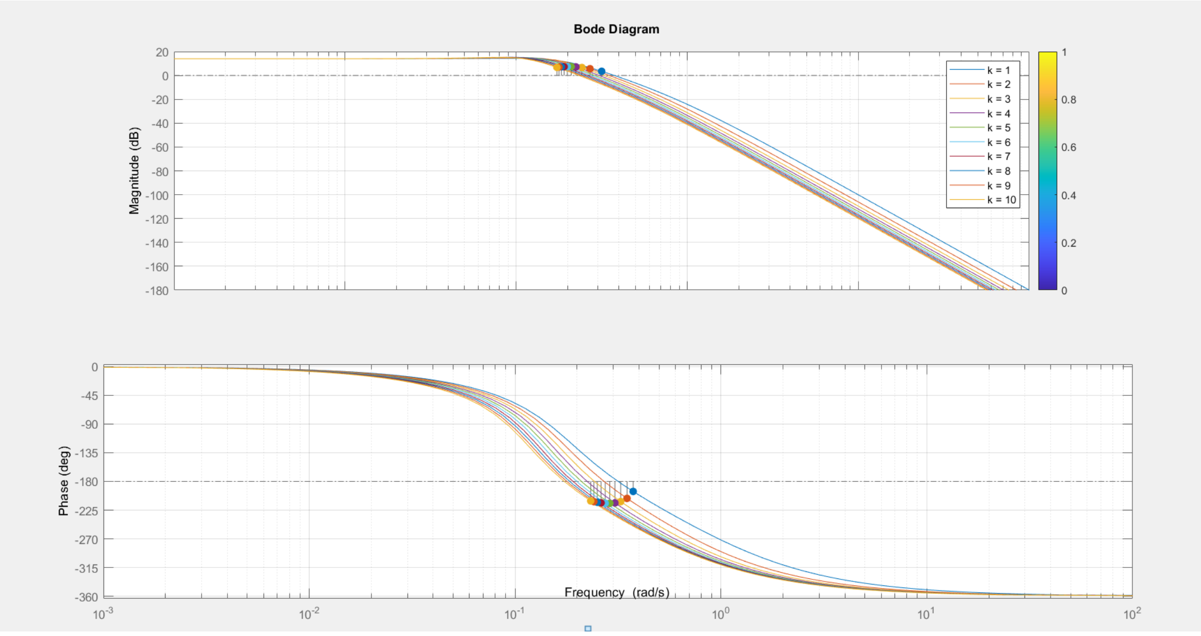
The step response of a someone with endocrinal problem in the worst-case scenario (K_f = 1) is as follows:



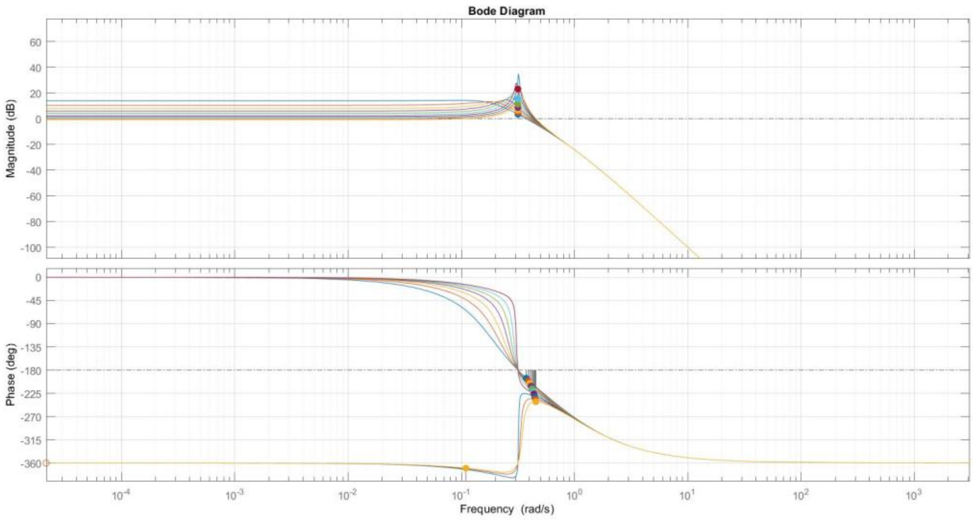
The Respiratory System is unstable in the worst-case scenario, which is a problem because the output of the system which is CO_2 concentration of the body which becomes unstable. Since the Error function in the system is a motor control signal feeding into lungs, this also controls the ventilator breaths (which are triggered by the patient himself). These ventilator breaths finally control the expansion and contraction of the lungs, as the ventilator deliver oxygen rich air and pumps out CO2.



Thus, we arrive at the basic structure for the system including ventilator as a mechanical aid for breathing as given in above diagram. To decide upon a structure for ventilator transfer function we study the Variation in Gain and Phase Margin with variation in system parameters through bode plots, which gives us more insight in the behavior of the system (without ventilator).

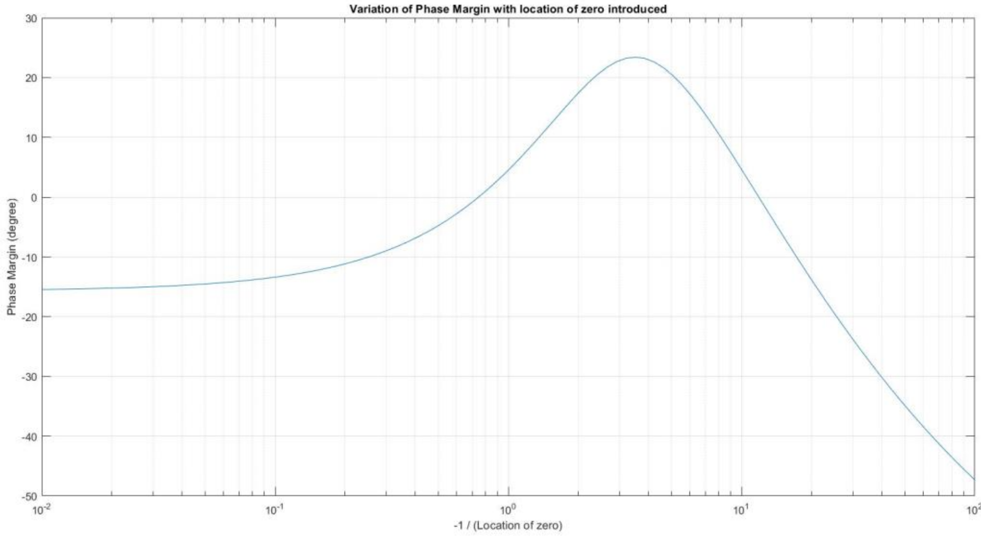


Variation in the bode plots with variation in time const. of the lungs (k)



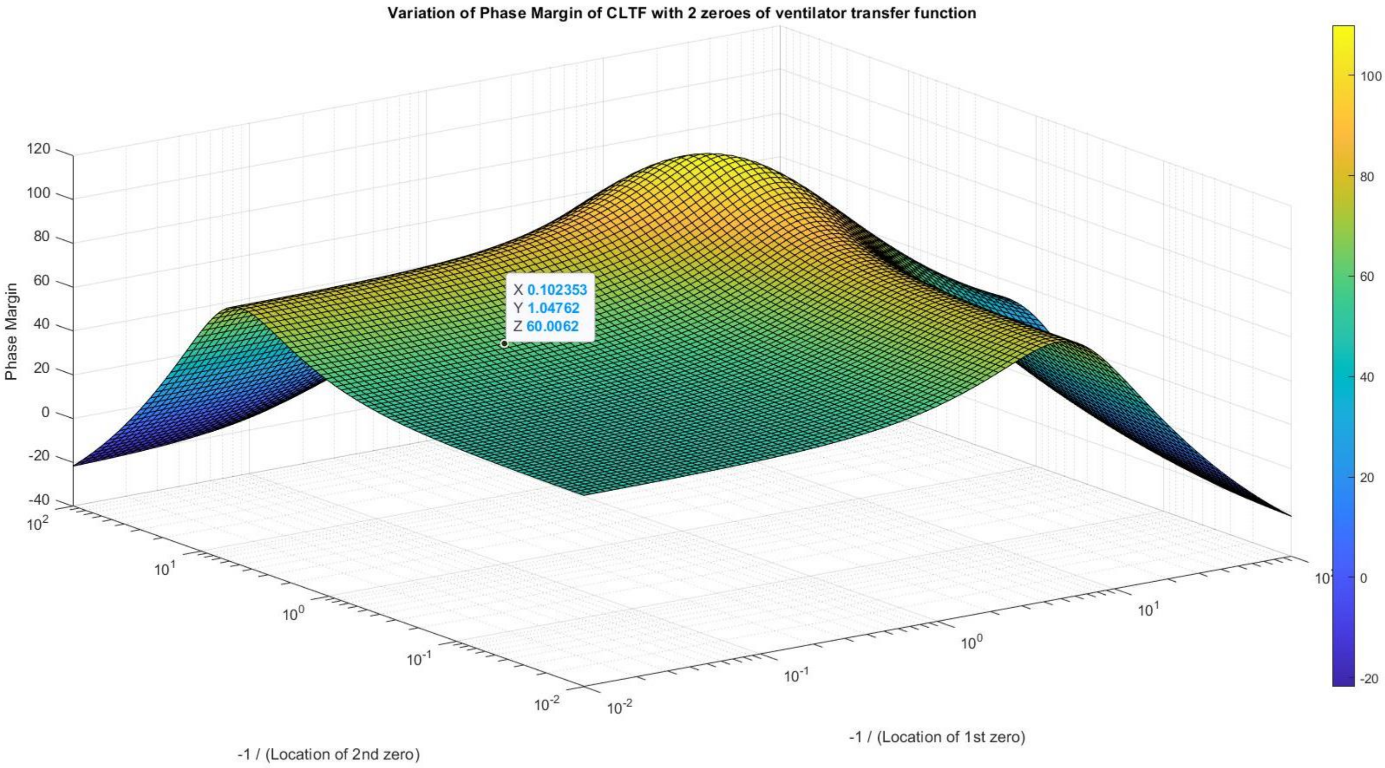
Variation in the bode plots with the variation in Chemoreceptor gain Kf

Since, we see that for all the variations, Phase margin of the closed loop system (without ventilator) is negative, we introduce a zero to our ventilator transfer function. And we study the dependence of Phase Margin on the location of the zero introduced.



Variation in Phase Margin with the location of zero introduced

We see Phase margin never reaches 45º for any zero introduced. We can consider adding a pole near the origin to reach 45º phase margin at the cost of settling time, which increase drastically to 4-5 mins, that can be fatal for the patient. Hence, we introduce another zero in order to make the system reach desired requirements, and we study the variation of Phase Margin with the location of the zeros of the Ventilator transfer function.



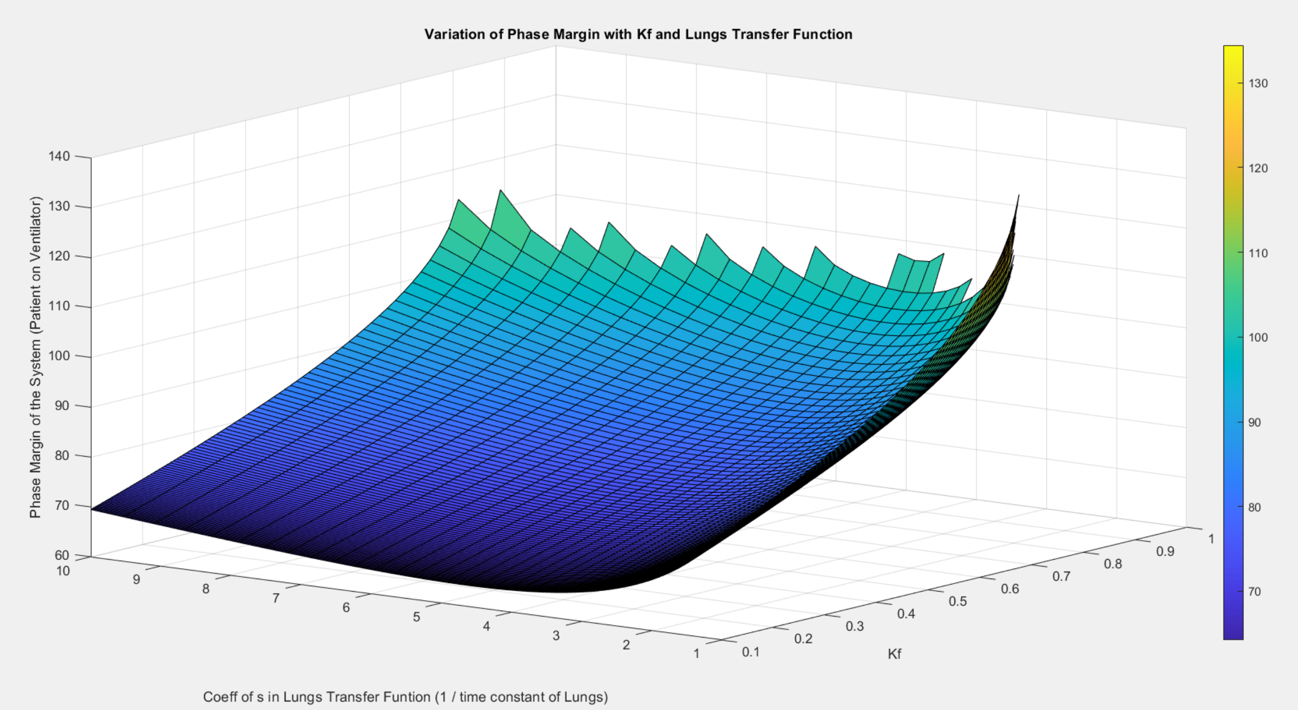
Variation of Phase margin of CLTF with 2 zeroes of ventilator transfer function

We find many such points where phase margin is greater than 45º, and chose one of them to construct the required ventilator function. We set the 2 zeros as s = -0.1 and s = -1, with the overall gain of transfer function = 0.29863.

Thus, the required Ventilator transfer function is

C(s) = 0.29863 * (s+1) * (10s+1)

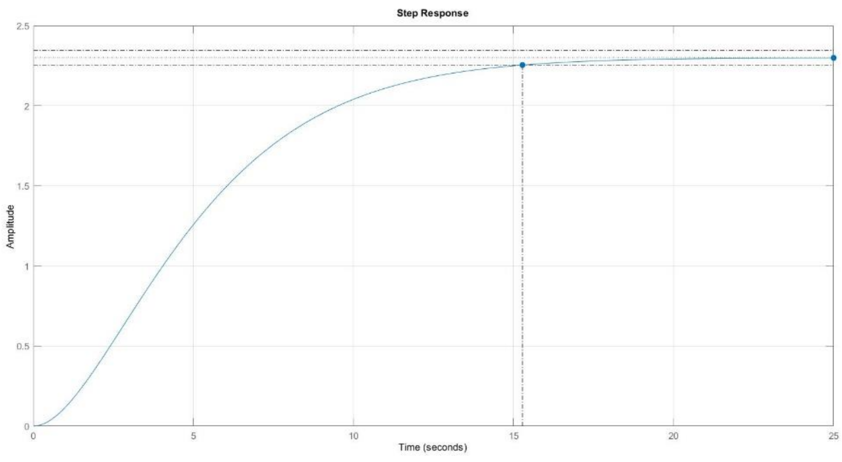
Next thing to check if the Overall system (in presence of ventilator) maintains the minimum phase margin of 45º even with the variation of parameters K_f and K.



Variation of Phase Margin of overall system (in presence of ventilator) with variations in the parameters of the system

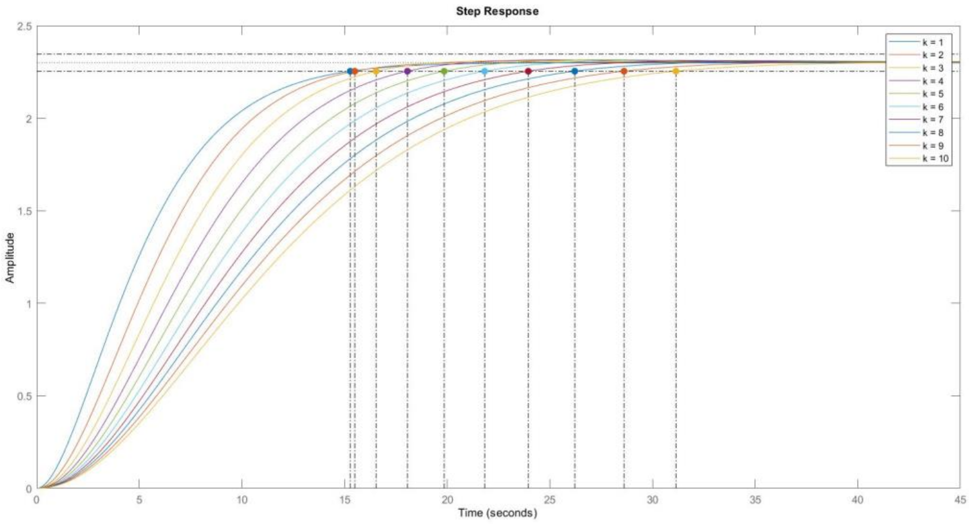
TESTING OUR VENTILATOR FUNCTION WHEN THE PARAMETERS ARE VARIED

We first look at the step response of a healthy person (on the ventilator) for a better comparison.



Step Response of a healthy human on ventilator

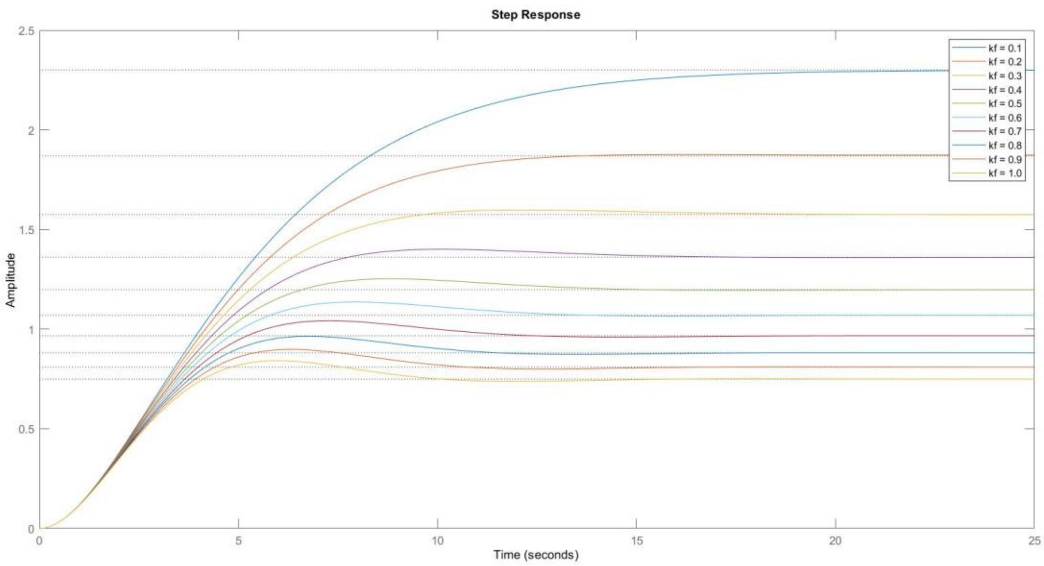
We test out the robustness of the ventilator by varying the time constant of the lungs and studying the step response.



Ventilator step response with variation in time constant

We see that the settling time is less than 35 sec (settling time of healthy person) which makes the ventilator safe to use for an asthmatic patient.

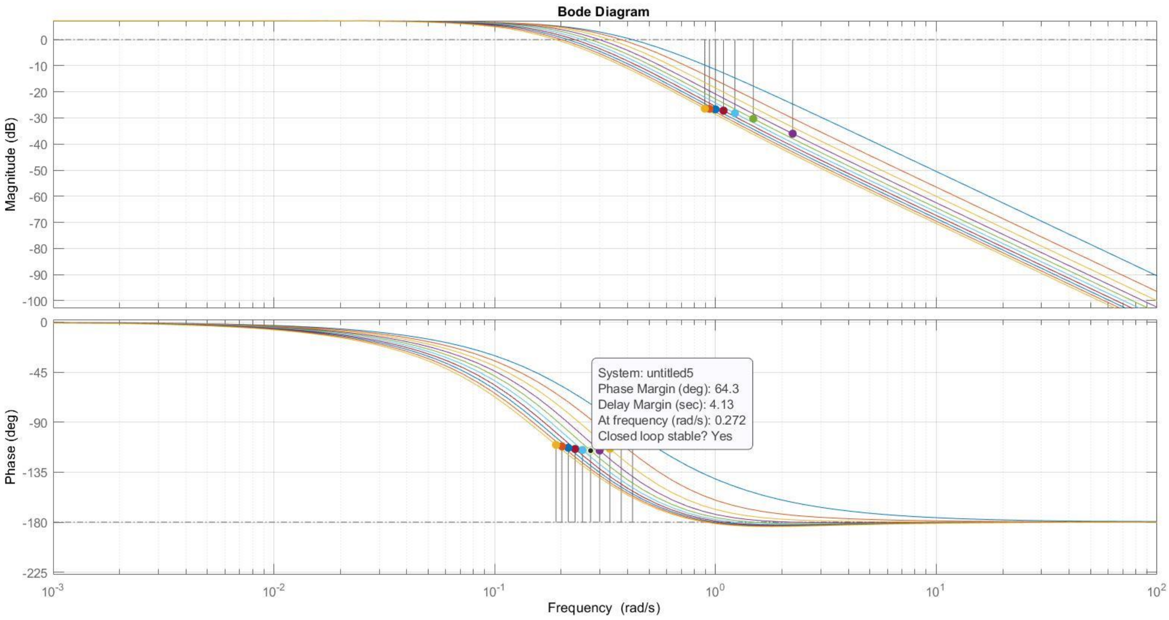
Now we vary the chemoreceptor gain K_f and study the step response.



Ventilator step response with variation in K_f

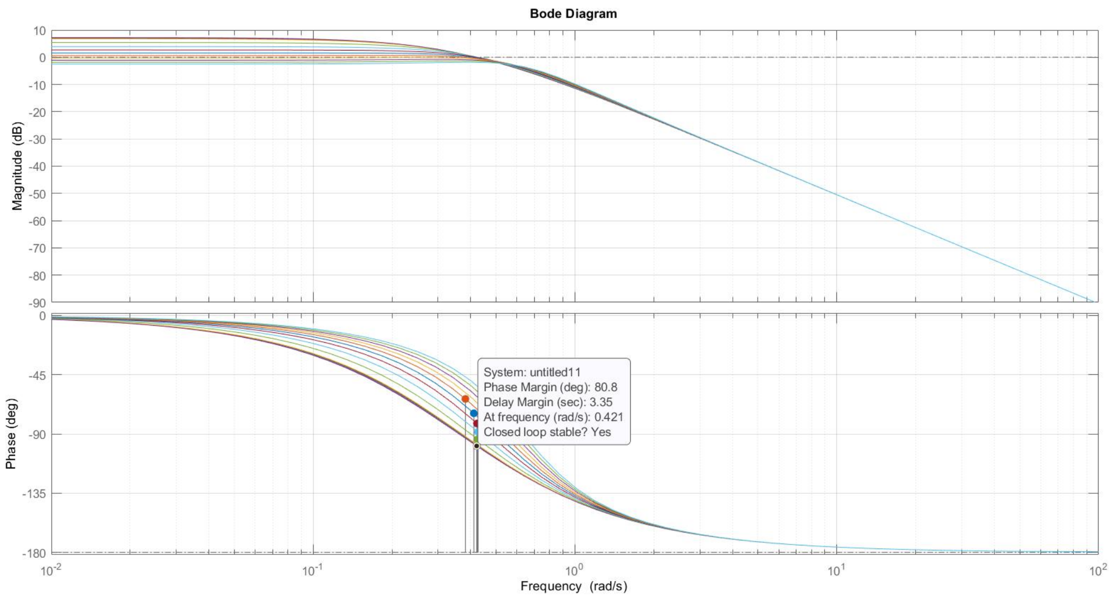
We see that the settling time is well within bounds, but one thing to note is that the steady state gain reduces considerably, which can be taken care of using a simple gain filter.

Since we have taken care of the settling time and steady state gain, we finally test the ventilator and the phase margin of the final CLTF we obtain using bode plots.



Variation in Phase margin with variation in time constant of lungs.

When we varied the time constant of lungs, we noticed the trends as given in above diagram. A minima was obtained with phase margin = 64.3^{o}, and the variation in phase margin is almost negligible.



Variation in Phase margin with chemoreceptor gain K_f

When we varied the chemoreceptor gain K_f, we observed the following:

- The variation of phase margin is considerable unlike the previous case where we varied the time constant of the lungs.
- A minima of 80.8^o is obtained which is within system requirements.
- The phase margin is more sensitive with respect to chemoreceptor gain Kf as compared to time constant of the lungs (which can be seen from the bandwidth of phase margin in the above bode-plots).

CONCLUSIONS:

Hence our final ventilator transfer function is:

$$C(s) = 0.29863 * (s+1) * (10s+1)$$

For all the variations in time constant of lungs and chemoreceptor gain K_f, the ventilator maintained a phase margin greater than 45^o and the desired steady state response, which fulfills our system requirement.

We also observed that the system CLTF is more sensitive to the variations in chemoreceptor gain K_f than the time constant of the lungs, which can be seen from the bode plots and variation in step response of the system as we change K_f.

We observe that the variations in K_f can be carefully recorded using steady state CO_2 concentration in the blood of the patient, and as the settling time of the system is very less, the steady state error can easily be reduced with a simple variable gain filter.