Design a 2nd order (i.e. single biquad) bandpass filter with 1MHz center frequency and 250kHz 3dB-bandwidth.

a) Calculate \( \omega_P \) and \( Q_P \).
b) Plot a 3D perspective view of the magnitude response of the filter.
c) Implement the filter with a 2nd order Sallen-Key section (see next page). Calculate all element values and the amplifier gain \( K \). For simplicity make all capacitors 1pF and choose all resistors equal size. Calculate also the resulting filter gain \( G \).
d) Verify the transfer function with SPICE for nominal values and with a 5% variation of \( K \). By how much are \( \omega_P \) and \( Q_P \) changing?
e) Calculate the sensitivity \( S_{K}^{Q_P} \) and compare the analytical and simulation results.
f) Return to nominal component values but add two 5% shunt capacitors from both terminals of \( C_2 \) to ground. By how much are \( \omega_P \) and \( Q_P \) changing?

Note: You need to show zoom-in plots of your filter response around the passband and stopband corners, for both MATLAB and SPICE results, to demonstrate that you meet the specs.
Second-order Sallen-Key bandpass section:

Design equations:

Transfer function

\[
H_{bp}(s) = \frac{G \frac{\omega_0}{Q} s}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}
\]

Center frequency

\[
\omega_0 = \sqrt{\frac{R_1 + R_2}{R_1 R_2 R_3 C_1 C_2}}
\]

Quality factor

\[
Q = \frac{\omega_0}{\frac{1}{R_1 C_1} + \frac{1}{R_3 C_2} + \frac{1}{R_3 C_1} + \frac{1}{R_2 C_1} + \frac{1-K}{R_1 C_1}}
\]

Gain

\[
G = \frac{K}{\frac{1}{R_1 C_1} + \frac{1}{R_3 C_2} + \frac{1}{R_3 C_1} + \frac{1-K}{R_2 C_1}}
\]