Design a 2\textsuperscript{nd} 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 and phase responses of the filter;
c) Implement the filter with a 2\textsuperscript{nd} 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 $\pm$5\% variation of $K$. By how much are $\omega_P$ and $Q_P$ changing?
e) Calculate the sensitivity $S_K^{\omega_P}$ and compare the analytical and simulation results;
f) Return to nominal component values but add two 5\% shunt capacitors from both terminals of C1 and C2 to ground (so total of four parasitic capacitors). By how much are $\omega_P$ and $Q_P$ changing?

(The Sallen-Key bandpass filter design equations are shown on the next page.)
Second-order Sallen-Key bandpass section:

![Sallen-Key Bandpass Circuit](image)

Design equations:

- **Transfer function**
  \[ H_{BP}(s) = \frac{G \omega_0 s}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2} \]

- **Center frequency**
  \[ \omega_0 = \sqrt{\frac{R_1 + R_2}{\sqrt{R_1 R_2 R_3 C_1 C_2}}} \]

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

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