Suppose you were tasked with the design of a voltage amplifier to satisfy some output range, \( a_{v0} \), \( f_u \), and \( f_p \). How would you start? You start by choosing a topology.

**Choice of Topology**

The choice of topology is usually dictated by the gain, the output range, input and output impedance. For example, if \( a_{v0} \approx 1 \), a common-gate amplifier may suffice. If \( a_{v0} > 1 \), then one or more gain stages may be necessary. Recall that the gain of a common-source is \( g_m r_o \), and that of a cascade of a common-source and a common-gate (cascode) is about \((g_m r_o)^2\). Using \( g_m r_o = \frac{2}{AV_{ds}^{sat}} \), it is possible to determine which topology is required to satisfy the gain requirement.

A load resistance depending on its value may dictate the use of a voltage buffer (common-drain). The output range may specify whether the NMOS or PMOS version of a transistor configuration is be used for the various stages. Suppose you settle on a cascode followed by a common-drain, what do you do next?

**Frequency Response**

The next step is to perform an analysis to determine how the pole/zero locations depend on device parameters. The second stage needs to be designed first because it acts as a load on the first stage. Note, however, that several design iterations of the entire amplifier may need to be performed before the final solution is reached.
Small-signal model of the common-drain stage

\[ R = r_o || R_L \]
\[ C_1 = C_{gd3} + C_{gd2} \] plus the parasitic capacitance due to \( I_{B1} \)
\[ C_2 = C_{gr3} \]
\[ C_3 = C_{db3} + C_L \] plus other parasitic capacitances due to \( I_{B2} \)

**KCL on \( v_o \):**
\[ v_o \left( g_{m3} + \frac{1}{R} + s(C_1 + C_2) \right) - v_s (sC_2 + g_{m3}) = 0 \]

**KCL on \( v_s \):**
\[ i_s + v_s s(C_1 + C_2) - v_o sC_2 = 0 \]

\[ \therefore v_o = -i_s \frac{1 + s \frac{C_2}{g_{m3}}}{s \left( 1 + \frac{1}{g_{m3}R} \right) C_1 \frac{1}{g_{m3}R} C_2 \left( 1 + s \frac{C_3 + C_2 + \frac{C_2 C_3}{C_1}}{g_{m3} \left( 1 + \frac{1}{g_{m3}R} \left( \frac{1 + C_2}{C_1} \right) \right)} \right)} \]

\[ \omega_{c1} = \frac{g_{m3}}{C_2} \]
\[ \omega_{p1} = 0 \]
\[ \omega_{p2} = -\frac{g_{m3} \left( 1 + \frac{1}{g_{m3}R} \left( 1 + \frac{C_2}{C_1} \right) \right)}{C_3 + C_2 + \frac{C_2 C_3}{C_1}} \]
The analysis suggests that the first pole is at zero. This incorrect result is due to the fact that the resistance at the drain of $M_2$ was neglected to simplify the analysis. That pole will be calculated correctly later.

For $g_m R \gg 10$, $|\omega_{p2}| \approx \frac{g_m}{C_1 + C_2 + \frac{C_2 C_3}{C_1}}$

The next step is to choose a suitable value for $\omega_{p2}$, then compute $g_m$ neglecting the parasitics, then account for the parasitics. You may have to iterate more than once before your answer converges to the final value.

The first pole is $\omega_{p1} = -\frac{1}{R_{p2} C_{D2}}$.

$R_{D2} = r_{o1} + r_{o1}(1 + g_m r_{o2}) \approx r_{o1}(1 + g_m r_{o2}) = \frac{|a_v|}{g_m}$

$C_{D2} = C_1 + \frac{C_2}{g_m R + 1} \approx C_1 + \frac{C_2}{g_m R}$

$\omega_{p1} = -\frac{g_m}{|a_v| \left( C_1 + \frac{C_2}{g_m R} \right)}$

For a two pole transfer function $a_e(j\omega) = a_{v0} \left( \frac{1}{1 + j \frac{\omega}{\omega_{p1}}} \right) \left( \frac{1}{1 + j \frac{\omega}{\omega_{p2}}} \right)$, the magnitude response is $|a_e(j\omega)| = |a_v| \frac{1}{\sqrt{\left( 1 + \left( \frac{\omega}{\omega_{p1}} \right)^2 \right) \left( 1 + \left( \frac{\omega}{\omega_{p2}} \right)^2 \right)}}$.

Thus, at the unity gain frequency

$\left| a_{v0} \right| \frac{1}{\sqrt{\left( 1 + \left( \frac{\omega_u}{\omega_{p1}} \right)^2 \right) \left( 1 + \left( \frac{\omega_u}{\omega_{p2}} \right)^2 \right)}} = 1 \Rightarrow \omega_u = |a_{v0}| \omega_{p1} \sqrt{\frac{1}{1 + \left( \frac{\omega_u}{\omega_{p1}} \right)^2} - \frac{1}{\left| a_{v0} \right|^2}} \approx |a_{v0}| \omega_{p1} \frac{1}{\sqrt{1 + \left( \frac{\omega_u}{\omega_{p2}} \right)^2}}$

$\omega_{p1} = -\frac{g_m}{|a_v| \left( C_1 + \frac{C_2}{g_m R} \right)} \Rightarrow |\omega_u| \approx \frac{g_m}{C_1 + \frac{C_2}{g_m R} \sqrt{1 + \left( \frac{\omega_u}{\omega_{p2}} \right)^2}}$. Use this equation to determine $g_m$. This may require several iterations.
After designing the gain stage, return to the output stage and redesign it, this time accounting for the parasitics due to the gain stage. Then redesign the gain stage yet again. You may need to go back and forth a few times before you reach the final solution.

You may wish to choose $M_2$ to be identical to $M_1$. You may also wish to design current source $I_{b1}$ to provide an output resistance equal to that of the cascode connection of $M_1$ and $M_2$. Current source $I_{b2}$ can be similar in size to $M_3$. Of course you should provide justifications for all choices.

The third pole coming from the source of $M_2$ is usually at a high enough frequency that it is ignored. Similarly, the zeros are usually ignored. But you should check to make sure that these assumptions apply in your design.