Multistage Amplifiers

* Single-stage transistor amplifiers are inadequate for meeting most design requirements for any of the four amplifier types (voltage, current, transconductance, and transresistance.)

* Therefore, we use more than one amplifying stage. The challenge is to gain insight into when to use which of the 9 single stages that are available in a modern BiCMOS process:

  * Bipolar Junction Transistor: CE, CB, CC -- in npn and pnp* versions
  * MOSFET: CS, CG, CD -- in n-channel and p-channel versions
    * in most BiCMOS technologies, only the npn BJT is available
  * How to design multi-stage amplifiers that satisfy the required performance goals?

* Two fundamental requirements:

  1. Impedance matching:

     output resistance of stage $n$, $R_{out, n}$ and input resistance of stage $n + 1$, $R_{in, (n+1)}$, must be in the proper ratio

     $R_{in, (n+1)} / R_{out, n} \rightarrow \infty$ or $R_{in, (n+1)} / R_{out, n} \rightarrow 0$

     to avoid degrading the overall gain parameter for the amplifier

  2. DC coupling:

     we will directly connect stages: effect on DC signal levels must be considered, too
Example 1: Cascaded Voltage Amplifier

* Want $R_{in} \rightarrow \infty$, $R_{out} \rightarrow 0$, with high voltage gain.

Try CS as first stage, followed by CS to get more gain ... use 2-port models

* solve for overall voltage gain ... higher, but $R_{out} = R_{out2}$ which is too large
Three-Stage Voltage Amplifier

* Fix output resistance problem by adding a common drain stage (voltage buffer)

![Circuit Diagram]

* Output resistance is not that low ... few kΩ for a typical MOSFET and bias --> could pay an area penalty by making ($W/L$) very large to fix.
Cascaded Transconductance Amplifier

* input resistance should be high; output resistance should also be high

initial idea: use CS stages (they are “natural” transconductance amps)

* Overall $G_m = -g_{m1} \parallel r_{oc1} g_{m2} = A_v g_{m2}$ ... can be very large

BUT, output resistance is only moderately large ... need to increase it
Improved Transconductance Amplifier

* Output resistance: boost using CB or CG stage

* high-source resistance current sources are needed to avoid having $r_{oc3}$ limit the resistance
Two-Stage Current Buffers

* since one CB stage boosted the output resistance substantially, why not add another one ...

* The base-emitter resistance of the 2\textsuperscript{nd} stage BJT is $r_{\pi 2}$ which is much less than the 2\textsuperscript{nd} stage source resistance = 1\textsuperscript{st} stage output resistance

\[ R_{S2} = R_{out1} = \beta_{o1}r_{o1}||r_{oc1} \]

* Therefore, the output resistance expression reduces to

\[ R_{out} \approx g_{m2}r_{o2}r_{\pi 2}||r_{oc2} = \beta_{o2}r_{o2}||r_{oc2} \]

... no improvement over a single CB stage
**Improved Two-Stage Current Buffer: CB/CG**

* The addition of a common-gate stage results in further increases in the output resistance, making the current buffer closer to an ideal current source at the output port.

![Circuit Diagram]

* The product of transconductance and output resistance $g_m r_o$ can be on the order of 500 - 900 for a MOSFET. $R_{out}$ is increased by over two orders of magnitude ... practical limit ... on the order of 100 MΩ.

Of course, the current supply for the CG stage has to have at least the same order of magnitude of output resistance in order for it not to limit $R_{out}$.

* General “resistance matching” ... try not to lose much in doing a current divider or a voltage divider. Which of these is appropriate depends on whether the signal is current or voltage at the port.