Suggested Reading: Read as many of the following as you can. All of the recommended references are on reserve at Barker Library.

1. Lundberg sections 30 and 33-36.
2. Grebene sections 7.3 and (skim) 9.
3. Gray and Meyer sections 6.2-6.4 and 10.3.

Problem 1: A basic operational amplifier circuit with an NPN input stage is shown on the next page. Calculate the following amplifier parameters.

(a) Input Bias Current.
(b) DC Small-Signal Differential Gain.
(c) Common-Mode Rejection Ratio.
(d) Compensation capacitor size to achieve 45 degrees of phase margin for unity-gain feedback. Hint: phase margin can be found from a Bode plot as the difference between the phase and -180 degrees when the magnitude is unity. That is, for 45 degrees of phase margin, the phase of the system must be -135 degrees when the magnitude is one.

Assume the following transistor parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>NPN</th>
<th>PNP</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>200</td>
<td>40</td>
</tr>
<tr>
<td>$V_A$</td>
<td>50 V</td>
<td>20 V</td>
</tr>
<tr>
<td>$\tau_F$</td>
<td>2.5 ns</td>
<td>25 ns</td>
</tr>
<tr>
<td>$r_e$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$c_{ds}, c_{je}, c_{cs}$</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Problem 2: Repeat Problem 1 for the following PNP input operational amplifier. Create a summary table on the first page of your problem set comparing the values found in each layout.
Problem 3: For each of the following circuits use the “Gilbert Principle” to determine $I_o$ as a function of the other circuit variables. All of these circuits simplify to simple expressions.

A differential output is denoted by an $I_o$ superimposed on an arrow, and double emitter arrows with $2A_E$ indicate that transistor has double the emitter area of the other transistors, thus its $I_S$ is twice as large.

Finally, use the method of open circuit time constants to estimate the $-3\text{dB}$ frequency for the circuit in part (a) only.

(a) $I_1$ $I_2$ $I_o$

(b) $I_1$ $I_2$ $I_o$

(c) $I(I+x)$ $I(I-x) 2I$ $I_o$

(d) $I(I+x)$ $I(I-x) 2I$ $I_o$
\[ V_{cc} \]

(e) \[ I_s \rightarrow I_o \]

(f) \[ I_s \rightarrow I_o \]

(g) \[ I_s, I_y \]

\[ I_s(1+x), I_s(1-x), I(1+y), I(1-y) \]

\[ I_o \]
**Problem 4:** Find $I_o = f(I_x)$, assuming well-matched transistors, negligible base currents and $I_1 = 1A$. Also, assume $Q_A$ and $Q_B$ have respective emitter areas $24A_E$ and $2A_E$ while all other transistors have emitter area $A_E$.

What famous function does $I_o$ approximate for small $I_x$?