Topics:

1. Broad band vs. Wideband
   - Open circuit time constants O.C.T.
   - Bootstraping the capacitors
2. F.B. Amplifiers
3. Increasing the gain by inserting Zeros in the T.F.
   - Shunt Peaked Amplifiers
4. Distributed Amplifiers
5. Tuned Amplifiers G.BW.
   - Effect of $C_{gd}$ and cancelling it
6. Multi section Matching Networks
   - Andrea's Amplifier example
   - Fano's $S_{11}$-BW Relation
7. Transformer Matching Networks
Broadband & Wideband

- O.C. Z: Good for B.W. estimating of an all-pole system with one dominant pole
- Approximation fails when several poles are close or on top of each other

Example:

\[
\tau_{gs} = c_{gs} R_s \\
\tau_{gd} = c_{gd} (R_s + R_L + j\omega R_s R_L) \\
\tau_L = c_L (R_L \parallel R_b)
\]

Cancelling \( \tau_{gd} \)

\[ \tau_{gs} \]

Cancelling \( \tau_L \)

\[ \Rightarrow \text{Power-Speed Trade-off} \]
Feedback Amplifiers:

For low order systems [systems with one dominant Pole]

Product of Gain x B.W. is constant

Shunt-series Amplifier

After using F.B.

\[ G \downarrow \]

\[ R_i, R_o \downarrow \Rightarrow \text{matching acquired} \]

\[ B.W. \uparrow \]

\[ A_N = - \frac{R_L}{R_E} \left( \frac{R_F - R_E}{R_F + R_E} \right) \]

\[ R_{in} = \frac{R_E (R_F + R_L)}{R_E + R_L} \]

\[ R_{out} = \frac{R_E (R_F + R_S)}{R_E + R_S} \]

\[ BW = \frac{1}{\pi \left( A_N \left( \frac{G_s}{g_m} + \frac{R_L g_{gd}}{2} \right) \right)} \]
Addition of Zeros to the T.F.

Concept:

\[ V_s \quad R_s \quad R_L \quad C_L \quad \text{out} \]

At \( t = 0^+ \):

\[ N_{out} = \frac{c_s}{c_L + c_s} \quad N_s \]

\[ c = (R_L \parallel R_s)(c_L + c_s) \]

\[ \frac{N_{out}}{N_s} = \frac{R_L}{1 + R_L c_s} + \frac{R_s}{1 + R_s c_s} = \frac{R_L}{1 + R_L R_s} \]

\[ Z = \frac{-1}{R_s c_s}, \quad P = \frac{-1}{(R_L \parallel R_s)(c_L + c_s)} \]

If \( P = Z \rightarrow R_s C_s = R_L C_L \)
- **Application**

If $\frac{R_s}{C_s} = R_L \frac{C_L}{R}$,

$$\frac{V_{out}}{V_{in}} \approx \frac{Z_{out}}{Z_{in}} \rightarrow \text{constant over frequency up to a fraction of } \pm$$

- **Shunt Peaking Amplifier**

$$Z = (R + L) \frac{1}{C_s} = \frac{R \left[ s \left( \frac{L}{R} \right) + 1 \right]}{s^2 C + s R C + 1}$$

$$\Rightarrow \frac{|Z|}{R} = \frac{1 + (W^2 Z)^2}{\sqrt{(1 - W^2 Z^2) + (W^2 Z)^2}}$$

$$m = \frac{R_c}{4R}, \quad \tau = \frac{L}{R}$$

<table>
<thead>
<tr>
<th>$m$</th>
<th>Normalized B.W.</th>
<th>Normalized Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. B.W.</td>
<td>$\sqrt{2}$</td>
<td>1.85</td>
</tr>
<tr>
<td>$\Omega_2 = R/\omega = R c$</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Maximally flat</td>
<td>$1 + \sqrt{2}$</td>
<td>1.72</td>
</tr>
<tr>
<td>Best group delay</td>
<td>3.1</td>
<td>1.6</td>
</tr>
<tr>
<td>No Shunt Peaking</td>
<td>$\infty$</td>
<td>1</td>
</tr>
</tbody>
</table>
6/ Shunt peaking cont'd

Shunt and series Peaking

Shunt and double series Peaking

⇒ basically the order of matching network is increasing and it's resembling a synthesized TL.

T-coil B.W. enhancement

In above structures parasitic caps are charged and discharge serially so the current available to charge a cap is more and hence the risetime is shorter at the expense of delay
⇒ the ultimate case: A distributed amplifier
- Distributed Amplifier

\[ A_N = n g_m \left( \frac{Z_0}{2} \right) e^{-tdw} \]

Additive gain, very high B.W. up to \( \frac{f_T}{2} \)

- to reuse the signal going into the isolated termination

A. Arbabian, A.M. Niknejad (ISSCC 2008)

J. Roderick, H. Hashemi (ISSCC 2009)
8 - Wideband Amplifiers

- Increasing the B.W. through Matching Network:

\[ G_{Tu,\text{max}} = \frac{1}{1 - |S_{21}|^2} \]
\[ G_{s,\text{max}} = \frac{1}{1 - |S_{11}|^2} \]
\[ G_{L,\text{max}} = \frac{1}{1 - |S_{22}|^2} \]

\( G_{L,\text{designed}} \)

\( \Rightarrow \) To fix the mismatch (Balanced Amplifiers)
9. High order Matching Networks

A. Bevilacqua, A.M. Niknejad (ISSCC 2004)

mitigating the effect of $C_{gd}$

→ unilateralization (cascode, source-coupled pair)

→ Neutralization
10. Transformer Matching

\[ V_1 = L_1 I_1 + M S I_2 \]
\[ V_2 = M S I_1 + L_2 S I_2 \]

\[ V_1 = L_1 I_1 + M S I_2 \]
\[ V_2 = M S I_1 + L_2 S I_2 \]

\[ L_1(1-K^2) \]
\[ n = \frac{L_1}{L_2} \]

**Mesh Analysis**

\[ \frac{N_{out}}{N_S} = \frac{RLMS}{s^2(L_1L_2 - M^2) + s(R_5L_2 + RL_1) + R_5RL} \]

\[ \frac{N_{out}}{N_1} = \frac{RLM}{L_1L_2 - M^2} \]

\[ s = \frac{1}{(s-P_1)(s-P_2)} \]

If \( P_2 \gg P_1 \Rightarrow P_1 = -\frac{R_5RL}{R_5L_2 + RL_1} \)

\[ P_2 = P_1 + P_2 \Rightarrow \theta = \frac{-R_5L_2 + RL_1}{L_1L_2 - M^2} \]

Mid-band \[ \frac{N_{out}}{N_S} = \frac{RLM}{R_5L_2 + RL_1} \]

As \( R_S \to \infty \Rightarrow A = R_1^{\frac{L_2}{L_1}} = K\left(\frac{N_2}{N_1}\right) \)