Some techniques for increasing the bandwidth of an amplifier - broadening:

* Input compensation
* Feedback
* Neutralization
* Cascade amplifiers

Frequency response is usually limited by the existence of Miller capacitance, = capacitance connecting input and output ports of the amplifier. It is often a problem that does not exist in the ideal case. Trade-off: larger gain = larger capacitance at the input = smaller dominant pole frequency.

Consider a simplified circuit for CE amplifier:

\[ V_o = -g_m R_L \cdot V_i \]
\[ \frac{V_o}{V_i} = -g_m R_L \cdot \frac{R_f}{R_s + R_f} \cdot \frac{1}{1 + j \omega C_m R_f} \]
\[ R_S = R_f \]
\[
\frac{V_o}{V_i} = -g_m \frac{R_e}{R_e + \frac{1 + g_m}{\frac{R_e}{R_e + R_s}}}
\]

The wideband voltage gain
\[
\text{Av} = -g_m \frac{R_e + R_s}{R_s + R_e}
\]

The 3dB bandwidth
\[
B = \frac{R_e + R_s}{C_m R_e} \quad (\star)
\]

One sees that the bandwidth may be increased if \( R_s \) is made very small. In other words, the input voltage source should be an ideal voltage generator.

Note: equation (\star) is somewhat misleading if neglected the "base-spreading" resistance which is in series with \( R_s \).

\[
B = \frac{R_e + R_s + R_f}{C_m R_e \left( R_e + R_s \right)} \quad \text{more accurate expression}
\]

Conclusion: Extension of the bandwidth may be achieved if the output resistance of the previous stage is made small.

Input Compensation

Consider a circuit given in the following figure

\[
A_v = -g_m R_e \frac{2 R_s}{2 R_e + 2 R_s}
\]
Where: 
\[
\omega_c = \frac{V_{SS}}{1 + j\omega C_m R_m}
\]
\[
A_v = -g_m R_L \frac{V_{SS}}{1 + j\omega C_m R_m} \frac{1}{\frac{1}{R_s} + \frac{1}{R_L}}
\]

Therefore:
\[
A_v = -g_m R_L \frac{V_{SS}}{R_s + R_L}
\]

Assume that Cs is selected so that:
\[
\omega C_m = Cs R_L
\]

\[
A_v = -g_m R_L \frac{V_{SS}}{R_s + R_L} \quad \text{independent of frequency}
\]

Therefore, the frequency response of the circuit is going to be determined by the location of the non-dominant pole in the output circuit of the amplifier. That is

\[
\omega_{BR} = \frac{1}{R_L(C_m + C_o)}
\]

**Example 5.4:** Consider the voltage amplifier shown in the figure.

\[R = 100 \quad V_{BE} = 0.63\]
\[C_m = 4\text{pF} \quad C_o - \text{assumed small}\]
\[h = 2.1 \text{mH} \quad q = 2(q_2(q_2+1)) = 1000\]

Determine Cs to cancel input Miller capacitance and calculate the 2dB bandwidth of the circuit.

(Note: in the book only a portion of the biasing circuit is drawn)
**Biasing:**

\[ V_B = \beta_{T b} 0.2k + V_{BE} \quad (1) \]

\[ I_B = \frac{V_{cc} - V_B}{11k} - \frac{V_B}{35k} \quad (2) \]

**Theoretical**

\[ I_B = \frac{V_{cc} - (\beta_{T b} 0.2k + V_{BE})}{11k} - \frac{\beta_{T b} 0.2k + V_{BE}}{35k} \]

\[ I_B = \frac{12 - (100 \times 0.2 \times I_B + 0.63)}{11k} - \frac{100 \times 0.2 \times I_B + 0.63}{35} \]

**Solving for \( I_B \) one obtains**

\[ I_B = 0.1 \text{ mA} \]

and

\[ I_C = \beta I_B = 100 \times 0.1 \text{ mA} = 10 \text{ mA} \]

\[ g_m = \frac{I_C}{V_T} = \frac{10 \text{ mA}}{26 \text{ mV}} = 0.384 \text{ S} \]

\[ r_T = \frac{\beta}{g_m} = \frac{100}{0.384} = 260 \Omega \]

**High-frequency gain of the CE stage is**

\[ A_p = -g_m R_L = -0.384 \times 600 = -230.4 \]

\[ C_{w1} = (1 - A_p) \cdot C_p = 925.5 \text{ pF} \]

\[ C_T = \frac{g_m}{\omega T} - C_p = \frac{0.384}{2 \pi \times 300 \times 10^6} - 4 \text{ pF} = 199.72 \text{ pF} \]

\[ C_H = (C_1 = C_T + C_{w1} = 1125.3 \text{ pF} \]
To perform the input compensation:

\[ C_s \times R_s = C_{eq} \times R_t \Rightarrow C_s = \frac{C_{eq} \times R_t}{R_s} \]

In this case, \[ C_s = 112.3 \text{ pF} \times \frac{260}{500} = 58.516 \text{ pF} \]

The bandwidth is now determined by the pole in the output circuit. That is:

\[ B_w = \frac{1}{2\pi R_L (C_s + C_m)} = \frac{1}{2\pi \cdot 600 \cdot 6.10^{-12}} = 4.17 \times 10^8 \text{ rad/sec} \]

\[ B_f = \frac{B_w}{2\pi} = 66.3 \text{ MHz} \]

Problems with input compensation:

* It is not always possible to have access to the output resistance of the previous stage. Usually this resistance is internal resistance.
* Parasitic capacitance \( C_m \) is not very consistent from device to device. Even minor changes in fabrication process may cause \( C_m \) to vary. These variations are amplified by the gain of the CE stage and therefore the Miller capacitance may vary significantly.

* The analysis neglected effects of \( R_b \).

As a result, the input compensation is rarely used.

Feedback:

* One of the most important concepts in electronics.
* 99% of electronic circuits use some form of the feedback.
* Allows for designs that are robust with respect to:
  * Temperature variations → externally important.
  * Component variations → externally important.
In an amplifier circuit, the feedback that is applied is negative feedback.

**Negative Feedback Block Diagram**

\[ V_o = G \cdot e = G (V_i - H \cdot V_o) \]

\[ V_o (1 + GH) = G \cdot V_i \Rightarrow V_o \cdot \frac{V_o}{V_i} = \frac{G}{1 + GH} \quad \text{transfer function of the closed loop system} \]

If \( |GH| \gg 1 \),

\[ \frac{V_o}{V_i} = \frac{1}{H} \Rightarrow \text{independent of the gain } G \text{ - controlled only by the feedback gain } H \]

Consider an amplifier with a transfer function having a dominant pole. That is,

\[ G(s) = \frac{A_0}{1 + j \omega / \omega_p} \]

The gain-bandwidth product for the amplifier is \( GB = \omega_p \).

When the amplifier is connected in a feedback configuration (with the unity feedback \( H \)), the closed loop gain may be expressed as

\[ G_{CL} = \frac{G(s)}{1 + G(s) \cdot H} = \frac{A_0}{1 + \frac{1}{j \omega / \omega_p} + \frac{A_0 \cdot H}{1 + \frac{1}{j \omega / \omega_p} + \frac{A_0 \cdot H}{ \omega_p (1 + \omega_p \cdot H)}}} = \frac{A_0}{1 + \frac{1}{j \omega / \omega_p} + \frac{A_0 \cdot H}{ \omega_p (1 + \omega_p \cdot H)}} \]
Therefore, the gain of the closed loop amplifier is given by

\[ A_{cl} = \frac{A_o}{1 + \alpha H} \]

and its pole frequency

\[ \omega_p = \omega_p (1 + \alpha H) \]

Use of negative feedback always increases the bandwidth of a circuit at the gain reduction. The overall gain-bandwidth product is preserved.

There are four types of feedback in amplification circuits:

1. Current-to-Voltage
2. Voltage-to-Current
3. Current-to-Current
4. Voltage-to-Voltage