Blocks for SPAM Receiver

RF Amplifier from Antenna (and “LNA”)

What does “Matched” mean? Handout (developed by SPAM “Alumni”) shows that conjugate gives maximum power transfer...
Small-Signal View of Amplifier

At low frequencies (neglecting resonance effects):
- $V_{in} = \text{voltage divider (at } R_{in})$
- $V_{out} = -g_m V_{in} R_L$

At high frequencies:
We need to consider both $Z(\omega)$’s and $C$’s…

Look Ahead:
If $\omega_0$ for two $Z(\omega)$ are NOT the same… problems

Reminders about ac Parameters

For $I_c=5\text{mA}$, $\beta=80$, $\tau_f=30\text{ps}$ (and other parameters per SPICE deck)
- $g_m=qI_c/kT=0.193$ and $r_\pi=\beta/g_m=414\Omega$
- $C_j=C_{je}(V_{BE}) + g_m \tau_f$
  $= 1.3\text{pF } f(V_{BE}) + 5.8\text{pF}$
  $\sim 7.1\text{pF}$
- $C_u=C_{jc}(V_{BC}) \sim C_{jc}=1\text{pF}$
- $R_{in} \sim 200\Omega$ for CE:
  $R_{i||r_f} = 4\text{K}\Omega$

Parameter | Value
---|---
$\beta$ | 80
$\tau_f$ | 30ps
$C_j$ | 1.3pF
$C_u$ | 1.0pF
A quick comment about $f_T$

Reminder about $f_T$

\[ \frac{i_c(s)}{i_b(s)} = \beta(s) \]

at $\omega_T \cdot \beta(s) = 1$

(a review from EE113 notes…)

\[ \beta(s) = \frac{\beta}{1 + s R_x (C_e + C_r)} \leq 1/2 \pi f_{3dB} \]

\[ \omega_f = \frac{g_m}{C_e + C_r} = 2 \pi f_T \]

(from data sheet)

@20mA $\quad g_m=0.772$

\[ C_e + C_r = \frac{(0.772)/(2 \pi \times 10^9)}{C_e + C_r} = 24.6 \text{pF} \]

(Now check out the SPICE deck…)

About Today’s Lecture:

• More on Feedback (HO#11)
  (including example with $r_e$)

• Smith Chart (HO#10 + #12)

• Examples on Matching (HO#10)
  ✓ (Radmanesh examples… HO#8!!)
  ✓ Last Year’s MT… (no HO#… solutions in another week)
A Simple (Practice) Biasing Example

Assume $I_c=5\text{mA}$
$I_{R1}=I_{R2}=0.5\text{mA}$ (a bit big but…)
and $V_X=3\text{V}$

$$\frac{9\text{V}}{R_1+R_2} = 0.5\text{mA}$$
thus $R_1+R_2 = 18\text{K\Omega}$
and given $V_X=3\text{V}$
$R_2 = 6\text{K\Omega}$, $R_1 = 12\text{K\Omega}$
$R_1\parallel R_2 = 4\text{K\Omega}$

Note: for “fun” you might think about finding $R$’s for $3\text{mA}$ and $1\text{mA} = I_c$

Turning to the $I_c$ biasing

$(3\text{V} - 0.7\text{V})/R_e = 5\text{mA}$
which in turn gives $r_e+R_e=460\Omega$

Now, moving on the the small-signal (ac) modeling...
we’ll continue to consider the matching issues, per the last few lectures, after we address the basic small-signal issues

Putting these numbers together…

$$g_m R_{\text{equiv}} = 0.193 \times 10^3 = 193$$
$$C_{\text{miller}} = C_0(1+g_m R_{\text{equiv}}) = 194\text{pF}$$
$$C_{\text{in}} = 7.1\text{pF}$$

$$v_{\text{in}} = v_s \frac{375}{375+50} = 0.88 v_s$$
$$v_{\text{out}} = -(194)(0.88)v_s = -171v_s$$

Large voltage gain is not always good…
Bandwidth and Low Noise are key metrics…

$1/2\pi R_{\text{in}} C_{\text{L}} \sim 2.1\text{ MHz!}$
How do we get modest gain and BW!

Gain-BandWidth-Product (GBP)...trade-off gain for BW*

![](image)

w. tuned load; peaked at $R_{\text{equiv}}$.

To do this we can use

**FEEDBACK***...

\[ A_{\text{cl}} = A_{\text{ol}} (1 + A_{\text{olf}}) \]

Where "ol" is "open-loop" and "cl" is "closed-loop"

* Assumption: Single-pole roll-off

** For the full story...see Brodersen Notes (UCB :)

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FB Configurations and “bottom-line” Results--

Gain, Resistances and BW

**Gain Expressions:**

(Extreme limiting cases...see supplemental notes for derivations)

\[ A_v(\text{shunt-shunt}) \approx \frac{R_f}{R_S} \]
\[ A_v(\text{series-series}) \approx \frac{R_i}{r_e} \]

**Impedances** (either Output or Input):

Series...\[ R_{\text{in|ol}}[1+T] ... T = A_{\text{olf}} \]
Shunt...\[ R_{\text{in|ol}}^{-1}[1+T] \]

**Bandwidth:**

\[ \omega_{3\text{dB|cl}} = \omega_{3\text{dB|ol}}[1+T] \]

**What is T? (“loop gain”)...

(now let’s see what this really means!)
**Series-Series--Nodal Analysis Results…**

Comment: Natural Units are “transconductance gain” $i_o/v_{in}$

$$f = v_{in}/i_o = r_e$$

$$\frac{v_m}{i_T} \approx R_{T1}(1 + g_m r_e)$$

All three terms are “scaled” by:

$$i_o = \frac{g_m}{(1 + g_m r_e)} v_{in} \left(1 + g_m r_e\right)$$

Approximately (if $1 <<$ the second term in the denominator)

$$v_o = \frac{-g_m R_L}{1 + g_m r_e} \approx -\frac{R_i}{r_e}$$

An Example (continued)

**Voltage Gain (w.fb):**

$$-35.2 \quad (-R_{equiv}/r_e = 75)$$

**Lower $R_{equiv}$**

(motivation to follow:)

**Voltage Gain**

$$-35.2$$

(1 + 35.2)

$$1 + g_m r_e$$
Shunt-Shunt--Nodal Analysis Results…

\[ \begin{align*}
R_{\text{in}} \big|_{\text{open-loop}} &= R_F \parallel R_{IT} \\
R_{\text{out}} \big|_{\text{open-loop}} &= R_{oT} \parallel R_F \\
\text{Open-loop} &\quad v_o = -g_m \left( R_F \parallel R_{IT} \right) \left( R_{oT} \parallel R_F \right) i_j \\
\text{Approximately} &\quad a = \frac{v_o}{i_i}
\end{align*} \]

The “closed-loop” expressions will then be modified by this expression for \( 1 + T \)

\[ \begin{align*}
\text{Gain Expression (Shunt-Shunt)} &\quad \frac{v_o}{i_i} = \\
&\quad \left( 1 + \frac{g_m \left( R_F \parallel R_{IT} \right) \left( R_{oT} \parallel R_F \right)}{1 + \frac{R_F}{R_F}} \right) \left( R_F \parallel R_F \right) \\
&\quad \approx -R_F \quad \text{(if } 1 << \text{ than the second term in the denominator)}
\end{align*} \]

\[ \begin{align*}
&\quad i_j = \frac{v_x}{R_S} \\
&\quad A_v = \frac{v_o}{v_x} = \frac{v_o}{i_j R_S} \\
\therefore \quad A_v &\approx -\frac{R_F}{R_S}
\end{align*} \]