Conversion gain (\(V_{RF} \rightarrow V_{out}\))

\[ A_L = \frac{2}{\pi} \cdot g_m \]

\(\Rightarrow\) assume LO devices are perfect switches

\(\Rightarrow\) IF signal is divided between \(V_{LO} \pm V_{RF}\) freq.

**Miner load**

\(\times\) Filtering for LO, harmonics

\(\times\) \(T_x \rightarrow LC\) load

\(R_x \rightarrow RC\) load for Homodyne

\(RC/LC\) load for heterodyne

---

Up-conversion miner could look like:

![Up-conversion circuit diagram](image)

\(\times\) LC tank load

\(\times\) \(R_p = \) resistance of tank \(@\) resonance

\(\times\) Can use \(R_E\) degeneration if headroom permits

\(\times\) Conversion gain (\(V_{BB} \rightarrow V_{RF}\)) = \(\frac{2}{\pi} g_m R_p\)

\(\times\) \(V_{RF} = V_{LO} + V_{BB}\)
Down-conversion mixer: \( W_{LO} - W_{RF} = W_{IF} \)

\[ \begin{align*}
  \text{easy IF filtering}
\end{align*} \]

\[ \begin{align*}
  R_C & \quad \text{RC load - low pass} \\
  & \quad \text{response to eliminate} \\
  & \quad \text{higher harmonics} \\
  & \quad \text{i.e. LO-IF isolation not} \\
  & \quad \text{a major issue}
\end{align*} \]

\[ g\text{eff} \quad \text{optional} \]

\[ g_c = \frac{2}{\pi} g\text{eff} R_L \]
Double-balanced mixer:

\[ I_2 - I_1 = (I_{DC} + I_{RF} \cos \omega_{RF} t) \cdot s(t) \]
\[ I_4 - I_3 = (I_{DC} - I_{RF} \cos \omega_{RF} t) \cdot s(t) \]

\( \text{Note } v_{I+} \text{ & } v_{I-} \text{ connections relative to } I_3, I_4 \)

\[ I_{01} = I_1 + I_3 \]
\[ I_{02} = I_2 + I_4 \]
\[ I_{out} = I_{01} - I_{02} \quad \{ \text{differential mixer} \} \]
\[ = (I_1 + I_3) - (I_2 + I_4) \]
\[ = (I_1 - I_2) - (I_4 - I_3) \]
\[ = [2I_{RF} \cos \omega_{RF} t] \cdot s(t) \]
\[ = \frac{4}{\pi} \cdot I_{RF} \left[ \sin \left(\omega_{LO} - \omega_{RF} \right) t + \sin \left(\omega_{LO} + \omega_{RF} \right) t \right. \]
\[ + \frac{1}{3} \sin \left(3\omega_{LO} - \omega_{RF} \right) t + \frac{1}{3} \sin \left(3\omega_{LO} + \omega_{RF} \right) t + \cdots \]
Gilbert-cell mixers (Rx)

\[ G_c = \frac{\text{amplitude of IF output}}{\text{amplitude of RF input}} \]

\[ = \frac{\frac{4}{\pi} \frac{I_{RF}}{2} \cdot R_L}{2 U_{RF}} = \frac{2}{10} g_m R_L \]

* Good LO-IF isolation \(\leftrightarrow\) matching \((M_1, M_2 \& M_3, M_4, M_5, M_6)\)

1% matching \(\Rightarrow 40\text{dB isolation}\)

0.1% matching \(\Rightarrow 60\text{dB isolation}\)

(possible with careful analog layout techniques)

Sources of mismatch: \(\Delta W, \Delta L, \Delta V_T, \text{Cox}\)

Photolithography \(\rightarrow\) \(N_a, \text{tox}, \text{Eox} \)
RF transducers

(A) Common Source:

* Linearity enhanced through source degeneration

\[ R_S C_R \quad \downarrow \quad \text{IRF} \quad \downarrow \quad L_S \quad \Rightarrow \text{no thermal noise} \]

\[ \Rightarrow \text{no DC drop (extra headroom)} \]

\[ \Rightarrow |Z_L| = \omega L_S \text{ helps} \]

* \( V_{\text{bias}} \) sets \( I_{\text{DC}} \)

* \( R_B \) large

\[ \Rightarrow \text{reduce loading on } V_{RF} \]

\[ \Rightarrow \text{reduce noise} \]

\[ g_{\text{m, eff.}} = \frac{g_m}{\frac{1}{s^2 L_s C_R} + s (g_m L_s + C_R R_s) + 1} \]

* Good attenuation of high freq. content

(2-pole rolloff)

-40dB/dec.

* Careful about \( W/L_S \) portion of \( Z_{in} \) - could de-Q LNA drain LC tank
(B) common-gate:

\[
\text{If } g_m \gg \frac{1}{R_s}, \quad g_{\text{meff}} \approx \frac{1}{R_s}
\]

\[
U_p = \frac{1 + g_m R_s}{R_s C_g} \approx \frac{g_m}{C_g} \Rightarrow \text{very wideband transconductor!}
\]

\[
U_P = W_T
\]

\[\text{node/dec. } [1\text{-pole roll-off @ high freq.}]\]

(C) Differential transconductor

+ fully differential
+ Ls x Ls optional
+ good CMRR @ low freq.

* Cp limits high-freq. CMRR
* no even harmonics \{ matched\}
* significant 3rd order nonlinearity - IM3
* tail current source uses up headroom
* node x voltage has even order harmonics
(1) **Balanced CS transconductor** (pseudo-differential)

\[ V_{RF} \]

* Best voltage headroom

* No current source \( \Rightarrow \) CMRR = 0 for all freq.

* CMRR is obtained through perfect balance

* Long-channel assumption

\[ I_d = \frac{k_v}{2} \left( \frac{U}{V} \right) (V_{AS} - V_T)^2 \Rightarrow \text{no third order component} \]

\( \Rightarrow \) Excellent IIP3

+ harmonic filtering: (widely used in PAs also)

\[ g_{meff} = \frac{g_m}{1 + g_m^2} \]

* Node x voltage has even order harmonics

\( \Rightarrow \) Use \( L_1, C_1 \), etc. to create high-\( Z \)
"Multi-tanh" transconductor

\[ \begin{align*}
& V_{RF}^+ \rightarrow I_T \rightarrow V_{RF}^- \\
& I_T \rightarrow V_{RF}^+ \rightarrow I_T \rightarrow V_{RF}^- \\
& I_T \rightarrow V_{RF}^+ \rightarrow I_T \rightarrow V_{RF}^- \\
& V_{RF}^+ \rightarrow I_T \rightarrow V_{RF}^- \\
& \end{align*} \]

\[ V_{DS1, DS2, DS3} \]

\[ V_{OS} \rightarrow V_{OA} \]

One\textsuperscript{eff} has wider range - better linearity