ECE 513- Lecture 24

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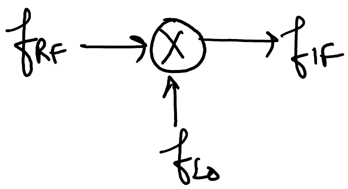
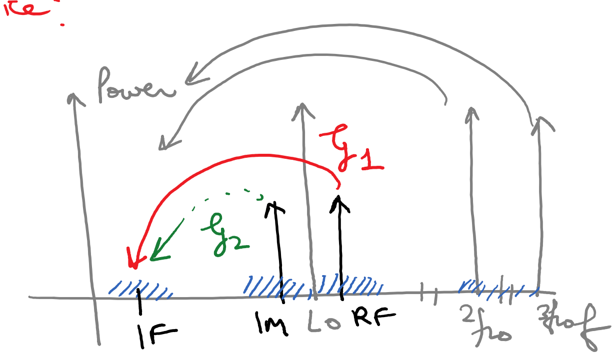
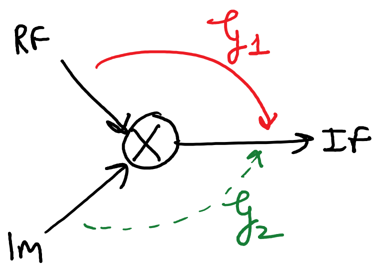
Modeling Mixer as a Three-Port Device:





$$g_c = \frac{V_{IM}}{V_{RF}} = \begin{cases} \frac{\beta}{2} R_L V_{LO} & \text{for FET Mixer} \\ \frac{1}{\pi} & \text{for passive switch based mixer} \end{cases}$$

* Simplistic model where we treat large Lo signal as a "DC bias voltage"



↳ Crude model that ignores other responses besides the RF and IM frequencies that are downconverted to the IF port

* The mixer can now be modeled by a three-port Y, S or Z matrix

S-matrix

$$\begin{bmatrix} b_{RF} \\ b_{IF} \\ b_{IM} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix} \begin{bmatrix} a_{RF} \\ a_{IF} \\ a_{IM} \end{bmatrix}$$

If the mixer is matched at all ports (no reflection), then

$$\begin{bmatrix} 0 & S_{12} & S_{13} \end{bmatrix}$$

$$S = \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

* In an upconverter $G_1 = |S_{12}|^2$ and $G_2 = |S_{23}|^2$ are the power conversion gains from IF to RF and IF to IM

* Ideally, there should be no conversion from IM to RF $\Rightarrow S_{13} = 0$

Mixer Noise:

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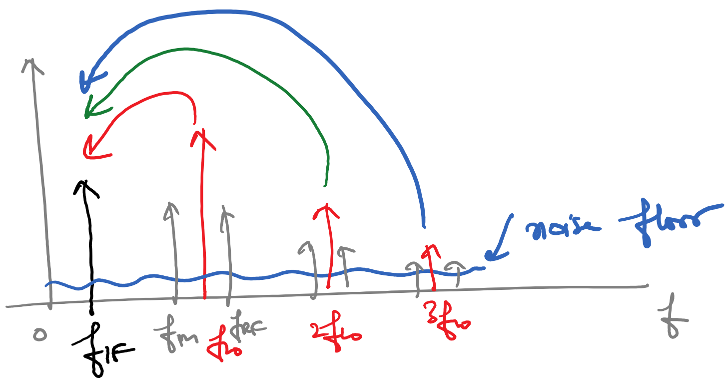
* Concern in downconverters, not upconverters

* Can be difficult to model mixer noise
  because we have infinite number of responses from
  $(n f_{LO} \pm m \cdot f_{RF})$ to f_{IF}
  → Show up at IF as spurs and add to noise floor (if not filtered out)

* In narrowband RX most of the noise sources are filtered out, but in broadband RX more than the two response (RF & IM) can contribute to noise at IF.



* PSS
  ↳ harmonic balance (HB)

* In general, for broadband mixers, the output noise consists of noise generated within the mixer, as well as the noise of the terminations (Z_s or Z_L) at each response, downconverted to IF frequency.

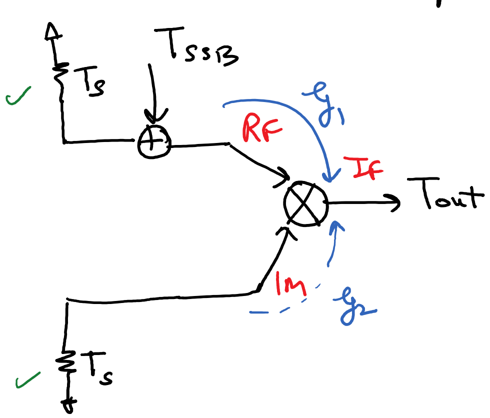
(noise temperature $4kT_eR_s$)

$$T_{out} = T_m + \sum_{n=1}^{\infty} g_n \cdot T_s$$

- T_s → termination noise temp ($Z = 50\,\Omega$)
- g_n → conversion gain at the n-th response
- T_m → output noise produced at the mixer only due to the internal noise sources in the mixer.

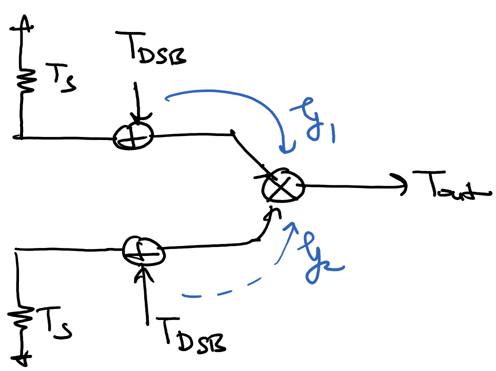
* We employ three-port mode
  ↳ assume that the Lo port doesn't contribute to noise at IF.

Mixer Single-side band (SSB) noise temp



↳ the noise generated inside the mixer is referred to the RF port only.

Mixer Double-side band (DSB) Noise temp



↳ mixer noise is referred to both RF and IM ports.

Output noise temp:

$$T_{out} = (T_s + T_{SSB})\, g_1 + T_s \cdot g_2$$

from here we derive

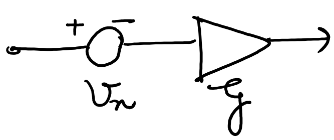
$$T_{SSB} = \frac{T_{out} - T_s(g_1 + g_2)}{g_1} = \frac{T_{out}}{g_1} - T_s\left(1 + \frac{g_2}{g_1}\right) \longrightarrow (1)$$

Similarly,

$$T_{DSB} = \frac{T_{out}}{g_1 + g_2} - T_s \longrightarrow (2)$$

more useful for automotive RADARs where information in both RF and IM band is processed.

* Circuit Noise is always refered to the input to take gain out of the comparison



$$\overline{v_{n,out}^2} = g \cdot \overline{v_n^2} = |A_v|^2\, \overline{v_n^2}$$

report $\overline{v_n^2} = \dfrac{\overline{v_{n,out}^2}}{|A_v|^2}$

Noise figure:

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Total available noise at the mixer output

$$N_o = kT\Delta f\,(G_1 + G_2) + N_a$$

* Assuming that the signals at RF and IM frequencies have the same amplitude, V_{RF},

$$V_{i_{DSB}} = \underbrace{V_{RF}\cos((\omega_{LO} - \omega_{IF})t)}_{IM} + \underbrace{V_{RF}\cos((\omega_{LO} + \omega_{IF})t)}_{RF}$$

* After downconversion of both RF and IM bands to IF, the output power at IF port is

$$S_{oIF} = (G_1 + G_2)\frac{V_{RF}^2}{2}$$

Using the SNR ratio definition of noise factor

$$F_{DSB} = \frac{SNR_{iDSB}}{SNR_o} = \frac{V_{RF}^2\,[(G_1 + G_2)kT\Delta f + N_a]}{(G_1 + G_2)\,V_{RF}^2\,kT\Delta f} = 1 + \frac{N_a}{kT\Delta f\,(G_1 + G_2)}$$

$$F_{SSB} = \frac{SNR_{iSSB}}{SNR_o} = \frac{V_{RF}^2\,[(G_1 + G_2)kT\Delta f + N_a]}{G_1 \cdot V_{RF}^2 \cdot kT\Delta f} = \left(1 + \frac{G_1}{G_2}\right)\left[1 + \frac{N_a}{1 + kT\Delta f\,(G_1 + G_2)}\right]$$

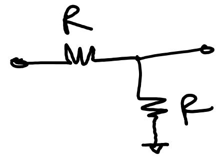
* If the mixer doesn't have an image rejection filter or an image-reject topology, and if $G_1 = G_2 = 0$, then

$$NF_{SSB} = NF_{DSB} + 3\,dB$$

* In an image reject mixer, $G_2 = 0 \Rightarrow NF_{SSB} = NF_{DSB}$

* If the mixer is ideal an contributes $N_a = 0$
then $F_{SSB} = 2 \Rightarrow$ 3dB and equals mixer's conversion loss.

$\Rightarrow$ Nf of a lossy circuit is equal to its loss in dB.



$\Rightarrow$ Nf = 3dB

loss = 3dB

Conversion Gain:

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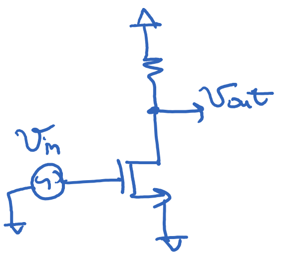
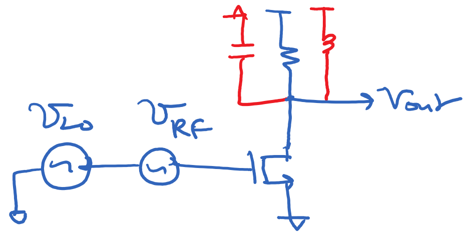
* Small signal power gain from RF port to IF port (DN)
  IF → RF (UP)



$A_v = -g_m R_D$



$\omega_{IF} = \omega_{LO} - \omega_{RF}$

~~$\omega_{LO} + \omega_{RF}$~~ filtered out

$|G_c| = \frac{V_{out}}{V_{RF}} \leq \frac{1}{2} g_m R_D$

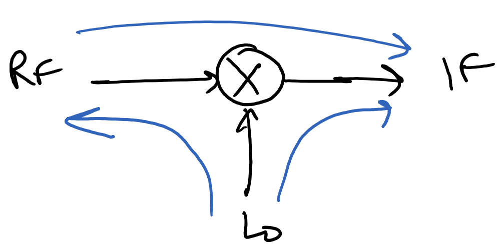
* Conversion gain of a mixer will always be smaller than the gain of the corresponding amplifier realized with the same transistor topology

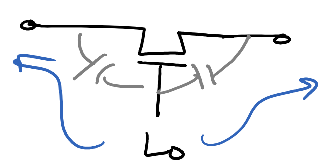
(Passive)
* Resistive mixers → diodes, switches → these exhibit conversion loss

* Active mixers → transistors → Gilbert's Mixer
  ↳ conversion gain

* Linearity:

* Isolation:





Isolation between ports → measured in dB

* Lo → IF → IS$_{Lo \to RF}$
* Lo → RF → IS$_{Lo \to RF}$
* IF → Lo → IS$_{IF \to Lo}$

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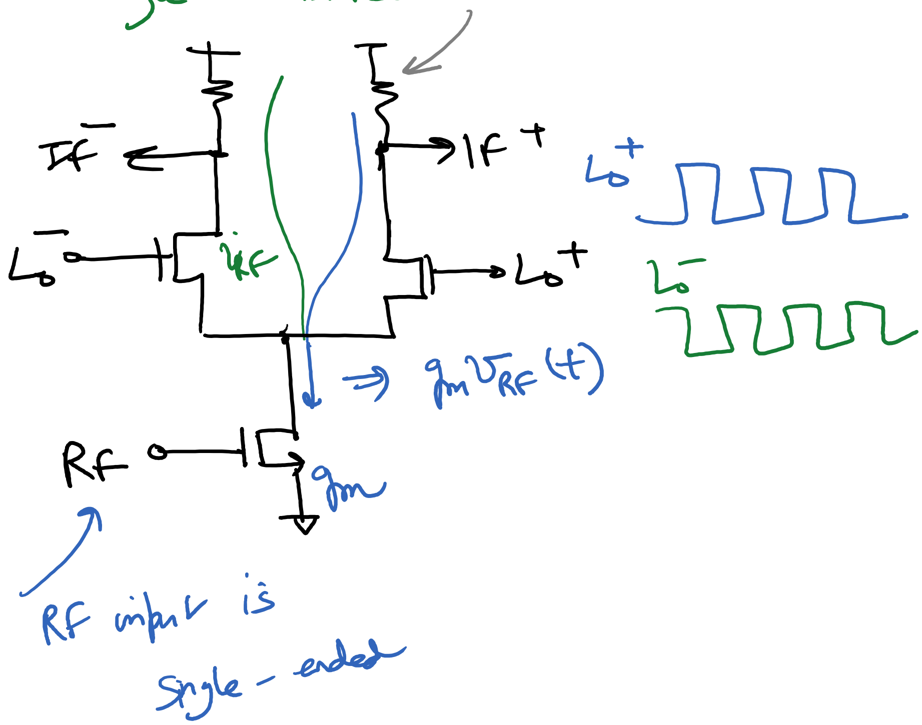
Single-balanced

Double-balanced



Double-Balanced Gilbert Cell Mixer Topology (Active Mixer)

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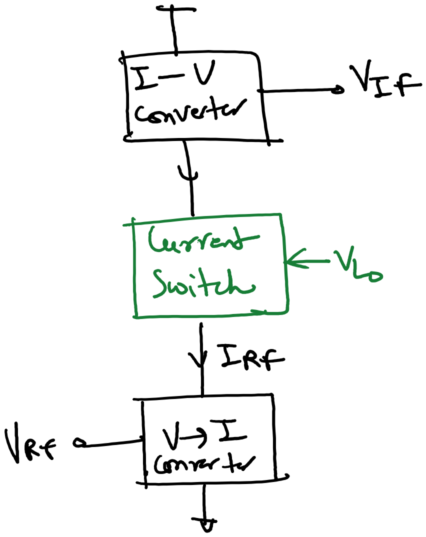

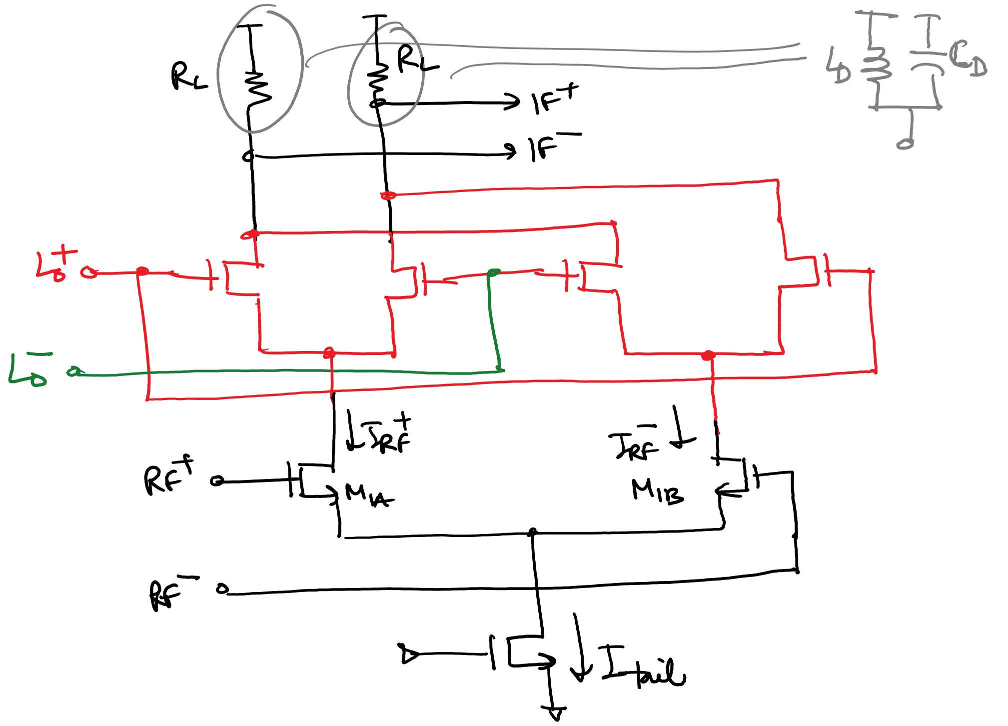

$$G_c = \frac{2}{\pi} g_{m1} R_L$$

	G_c
passive mixer	$1/\pi$
Double-balanced " "	$\frac{2}{\pi}$

→ $\frac{2}{\pi} \times g_{m1} R_L$