SBM and DBM diode-based mixers

SBM: Single Balanced Mixer= 2 SEM with couplers or baluns

DBM: Double Balanced Mixer = 2 SBM with couplers or baluns

Advantages

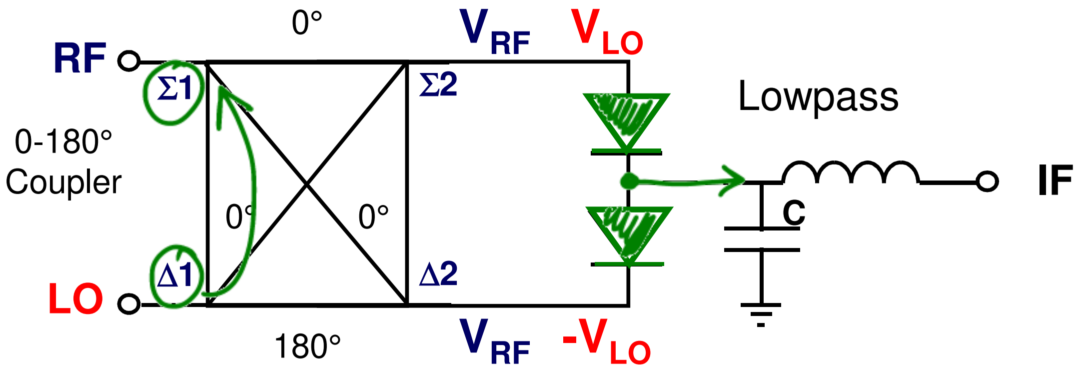
- Suppression of some spurs by out of phase recombination
- Good LO-RF Isolation and sometimes LO-IF isolation without filtering issues

Disadvantages

- Requirement of higher levels of LO power

Example of a diode-based SBM (LO at Δ port)

• Architecture with 180° coupler (LO @ Δ)



180° Coupler

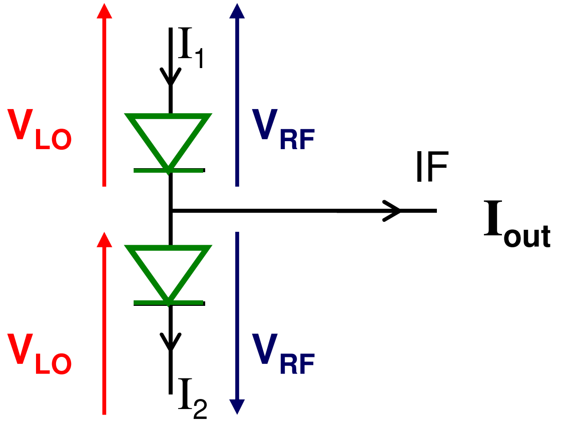
Input Matching $_{@LO/RF}$ ≈ Input Matching$_{@LO/RF}$ of coupler

Isolation LO-RF ≈ Isolation LO-RF of coupler

LO @ $\Sigma \rightarrow$ mix[EH(LO), *] rejected

LO @ $\Delta \rightarrow$ mix[* , EH(RF)] rejected

• Operation mode (LO @ Δ)



Diode current law

$$I(V) = F(V) = a.V + b.V^2 + c.V^3 + \dots$$

$$I_1 = F(V_{LO} + V_{RF})$$

$$I_2 = F(V_{LO} - V_{RF})$$

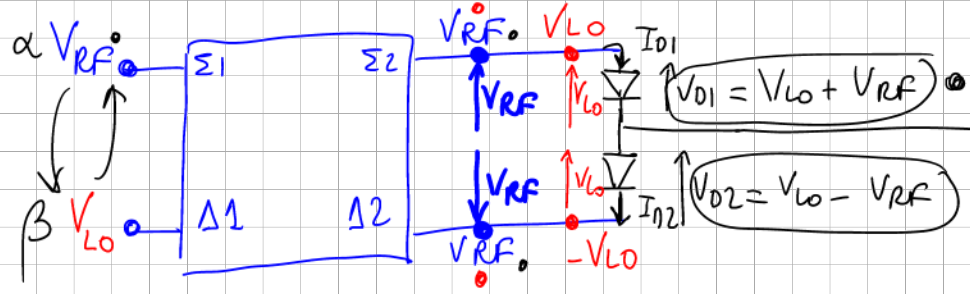
$$V_{LO}^p \,.\, V_{RF}^q \rightarrow \pm p.\omega_{LO} \pm q.\omega_{RF}$$

$$I_{OUT} = I_1 - I_2 = 0 \Leftrightarrow \omega = \pm m.\omega_{LO} \pm n.\omega_{RF}$$

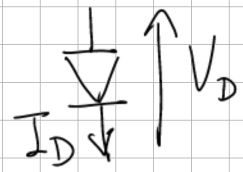
If **n is even** because $(V_{RF})^n = (-V_{RF})^n$

ω_{LO}, $2(\omega_{LO} - \omega_{RF})$, … suppressed @ IF port →(LO-IF Isolation) …

n=0 n=2



$$\boxed{I_{OUT} = I_{D1} - I_{D2}}$$



$$\cancel{I_D = \exp(V_D)}$$

$$I_D = f_{NL}(V_D) = aV_D + bV_D^2 + cV_D^3 + \dots$$

$$I_{D1} = a(\cancel{V_{LO}} + V_{RF}) + b(\cancel{V_{LO}} + V_{RF})^2 + \underbrace{c\,(V_{LO} + V_{RF})^3}$$

$$I_{D2} = a(\cancel{} - \quad) + b(\cancel{} - \quad) + c\,(\quad - \quad)$$

$$I_{OUT} = I_{D1} - I_{D2}$$

$$= 2aV_{RF} + \underbrace{4b\,V_{LO}V_{RF}} + 2c\,V_{RF}^{③} + \underbrace{6c\,V_{LO}^2 V_{RF}^1}$$

ω_{RF} — spurs

ω_{IF}, ω_Σ

ω_{RF}, $3\omega_{RF}$

ω_{RF}, $2\omega_{LO} + \omega_{RF}$, $2\omega_{LO} - \omega_{RF}$

$$(a+b)^3 = \cancel{a^3} + b^3 + 3a^2b + \cancel{3ab^2}$$

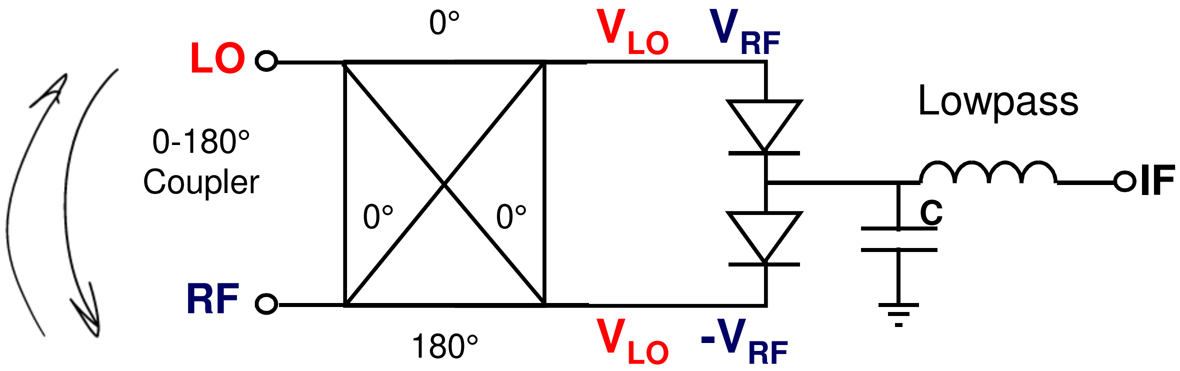
$$-\ (a-b)^3 = \cancel{a^3} - b^3 - 3a^2b + \cancel{3ab^2}$$

$ISO_{LO-RF} =$

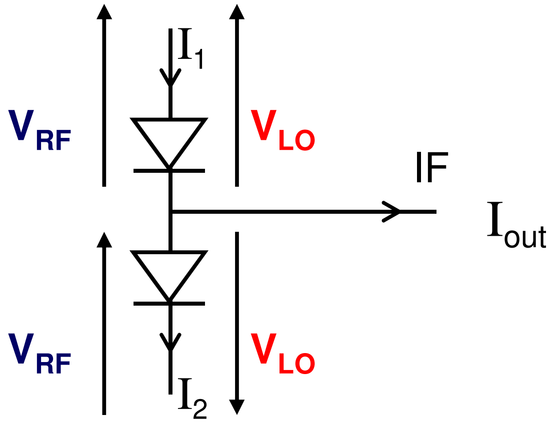
$ISO_{LO-IF} = \infty$

Diode-based SBM : LO and RF ports are reversed (LO at Σ port)

• Architecture with 180° coupler (LO @ Σ)



• If LO and RF are reversed



$$I(V) = F(V) = a.V + b.V^2 + c.V^3 + \ldots$$

$$I_1 = F\,(V_{RF} + V_{LO})$$

$$I_2 = F\,(V_{RF} - V_{LO})$$

$$V_{LO}^{p}\ .\ V_{RF}^{q} \rightarrow p\omega_{LO} \pm\ q\omega_{RF}$$

$$I_{OUT} = I_1 - I_2 = 0 \;\Leftrightarrow\; \omega = \pm\, m.\omega_{LO} \pm\ n.\omega_{RF}$$

If **m is even** because $(V_{LO})^m = (-V_{LO})^m$

ω_{RF} , $2(\omega_{LO} - \omega_{RF})$, … suppressed @IF port →(RF-IF Isolation) …

m=0 m=2

Less critical

Diode-based SEM

- Properties are linked to the architecture (Baluns, Couplers, …)
- Conversion losses of SBM are higher than conversion losses of SEM

  (Coupler losses, Non ideal phase shift and amplitude balance …)

- SBM enable to suppress critical spurs and enhance isolations

Diode-based SBM are more efficient than diode-based SEM

Diode-based DBM

A diode-based DBM

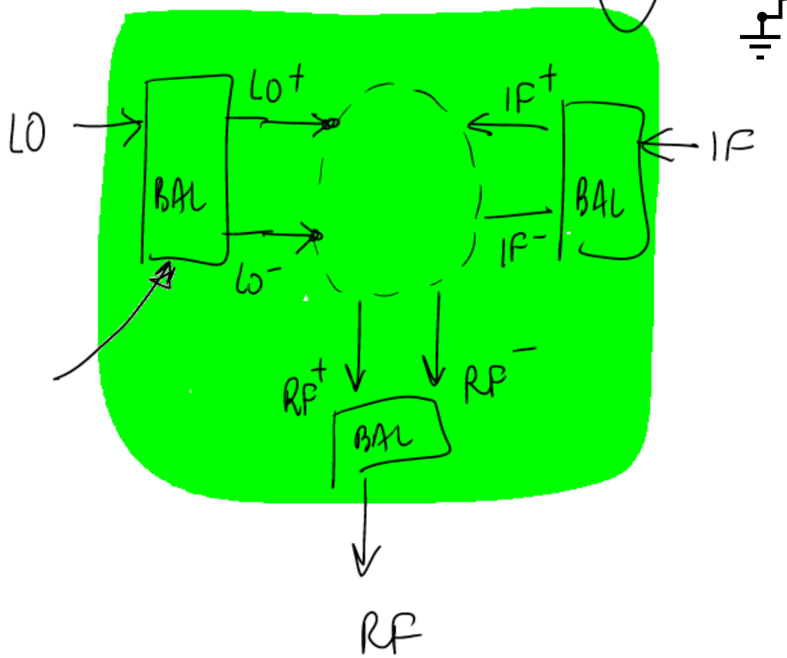
integrates 2 pairs of diodes

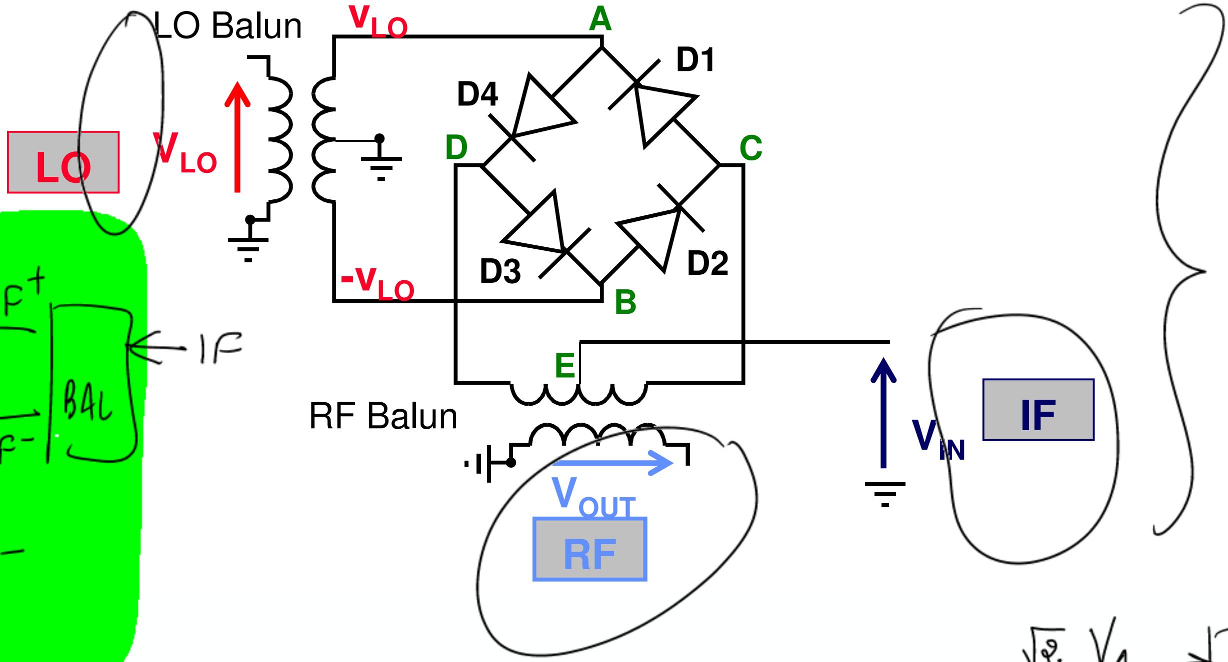
Diode-based DBM are preferred to SBM

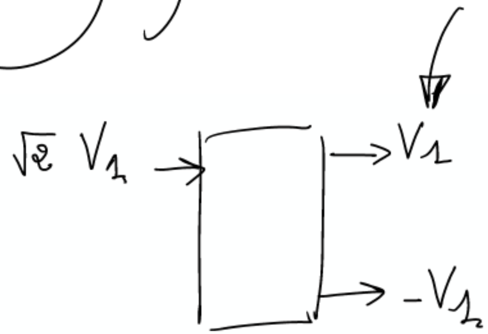
if the isolation requirements are more critical than the conversion loss specifications

Example of diode-based DBM : Ring oscillator

• Architecture





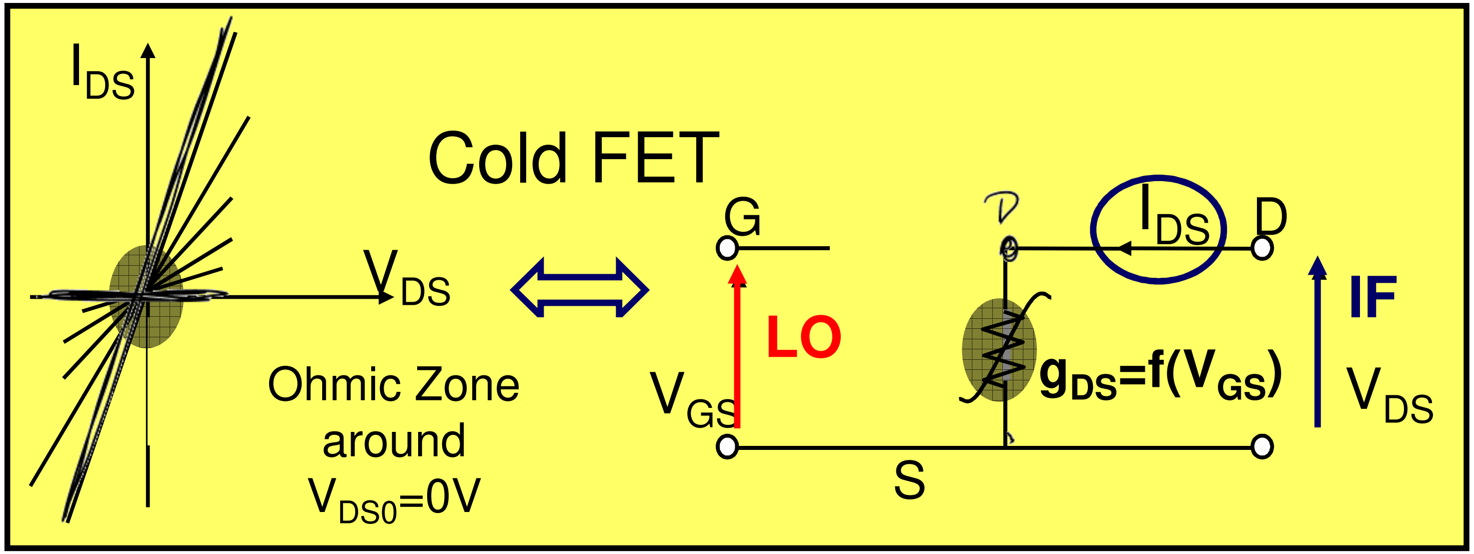


Cold-FET mixers : Principle

Main advantages : High linearity and No Consumption

Principle of cold-FET resistive mixers

$V = R I$



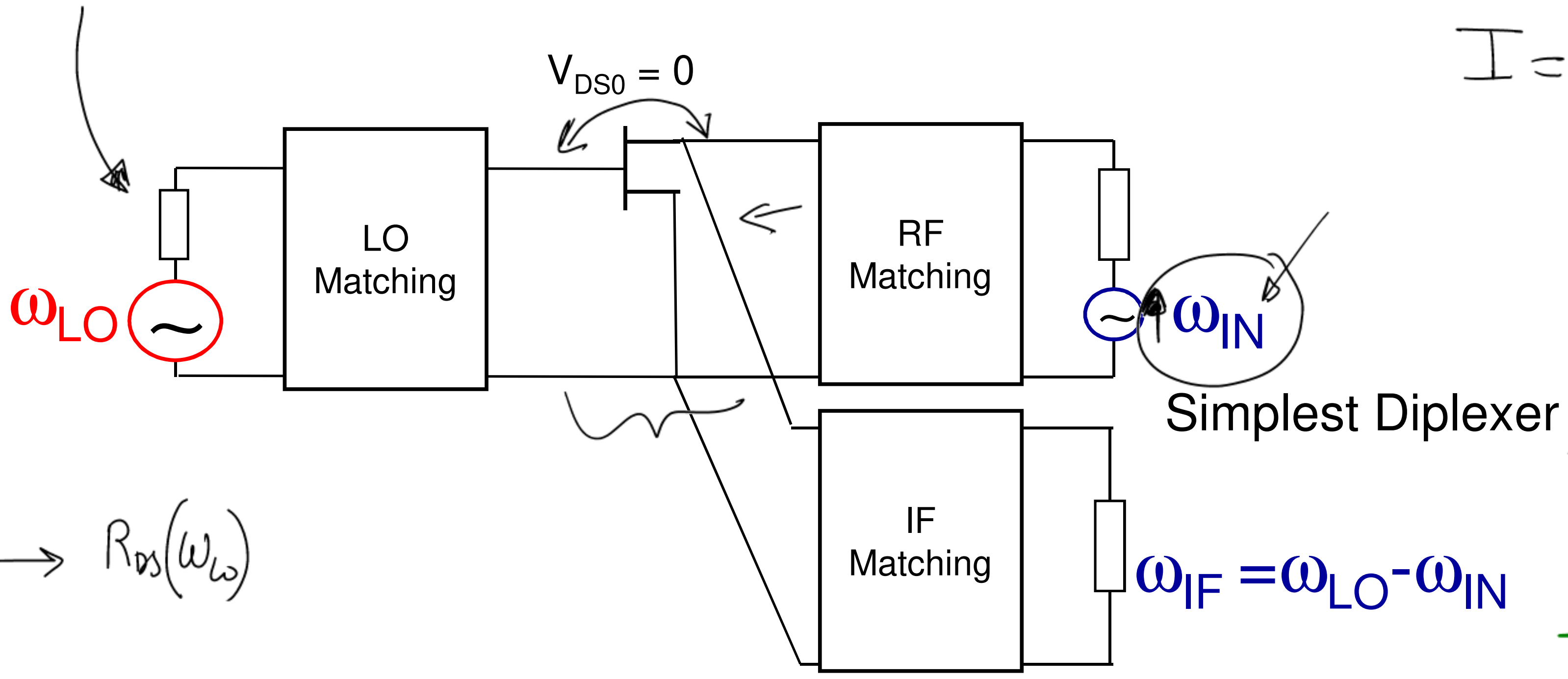
<u>Not biased Drain</u> → Transconductance gm is zero @ V_{DS0}=0

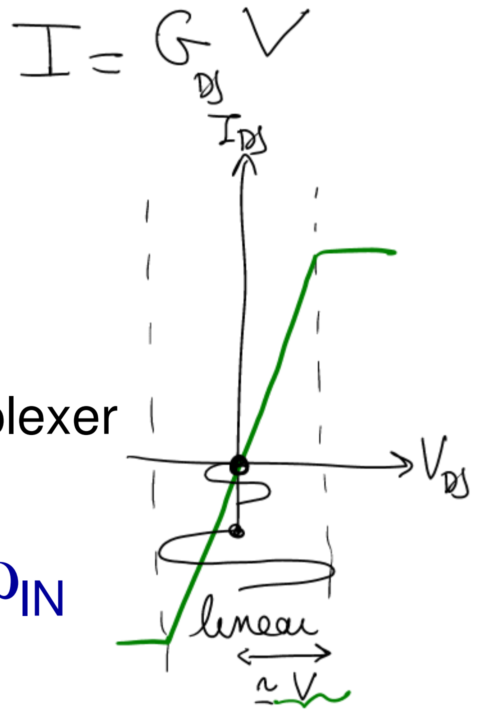
→ Resistive Nonlinearity R_{DS} (V_{GS}) between drain and source

Cold → $V_{DS0} = 0$ → $P_{DC} \# V_{DS0} \cdot I_{DS0} = 0$ → $P_{DIS} = 0$ → $T = T_{amb}$

→ ohmic zone $\begin{cases} gm = 0 \text{ (no gain)} \\ R_{DS}(V_{GS}) \end{cases}$

Cold-FET advantages

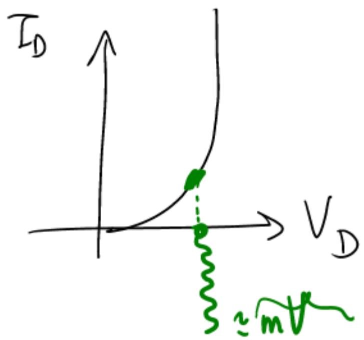




$V_{GS}(\omega_{LO}) \longrightarrow R_{DS}(\omega_{LO})$

→ <u>Simplified design constraints</u>

- better LO-RF isolation due to the intrinsic G-D isolation of FETs (depends on Cgd and ω)
- limited interactions between matching circuits (LO @ gate port and $\omega_{RF} >> \omega_{IF}$ @ drain port)
- higher linear voltage swing of RF signal from 0 to knee voltage → higher linearity
- mixer that can be efficiently used in SEM configuiration



→ <u>Other solutions</u>: SBM and DBM cold-FET mixers

Comparison (Diode / Cold FET)

- <u>Conversion losses</u>

  → L_C(Diode Mixers) < L_C(Cold-FET mixers) because R_{MIN}(Diode)<R_{MIN} (Cold-FET)

- <u>Linearity/Saturation</u>

  - Linearity of diode-based mixer is limited to very low level of RF signal (exponential current)

  - Linearity of cold-FET mixer is limited to moderate level of RF signal (ohmic zone)

    → Higher linearity of cold-FET and higher output power

- <u>Isolations</u>

  - Diodes do not have intrinsic isolation → can only used in complex balanced architectures

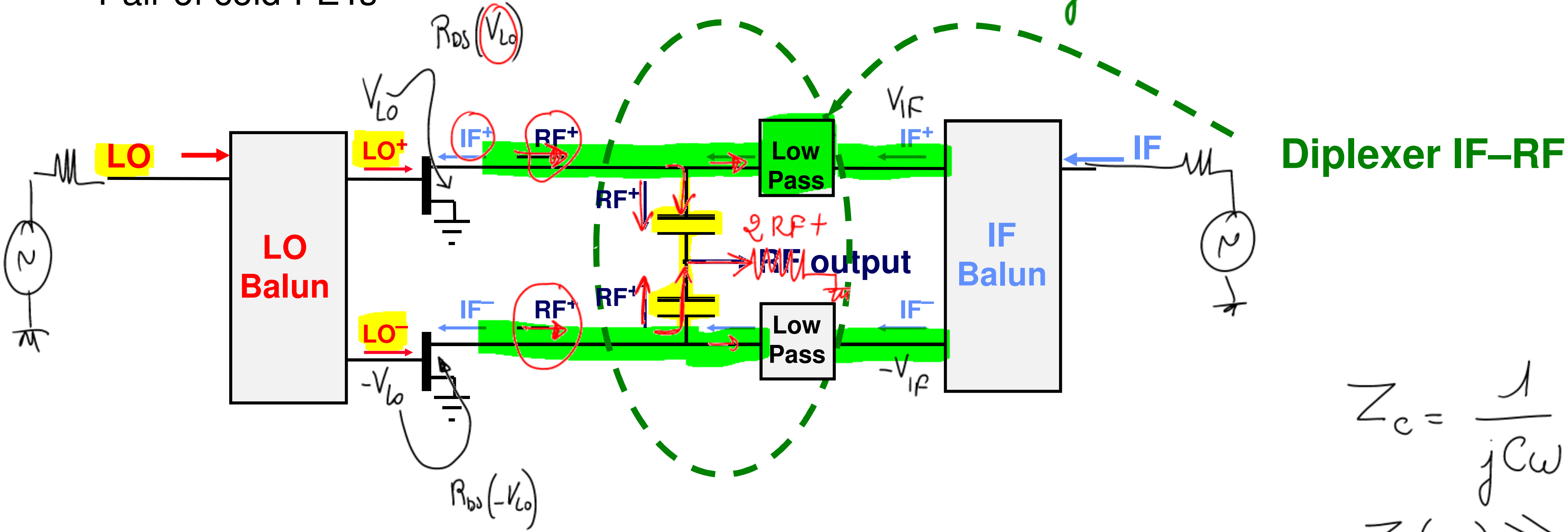
  - Cold-FETs have the intrinsic G-D isolation → can be used as SEM or balanced topologies

Cold-FET SBM

Cold-FET SBM

Single Balanced

- Example of SBM with LO and IF baluns (emission)
  - Pair of cold-FETs



$$Z_c = \frac{1}{jC\omega}$$

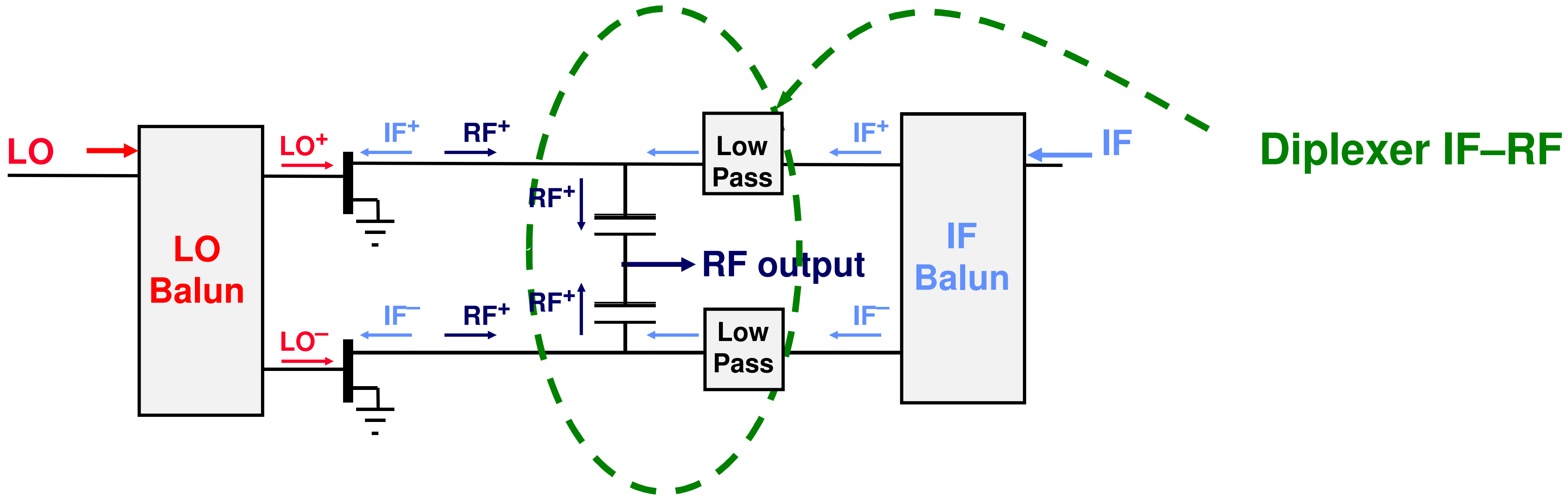
$$Z_c(\omega_{IF}) \gg$$

$$I_{DS} = \underbrace{G_{DS}}_{LO} \; \underbrace{V_{DS}}_{IF}$$

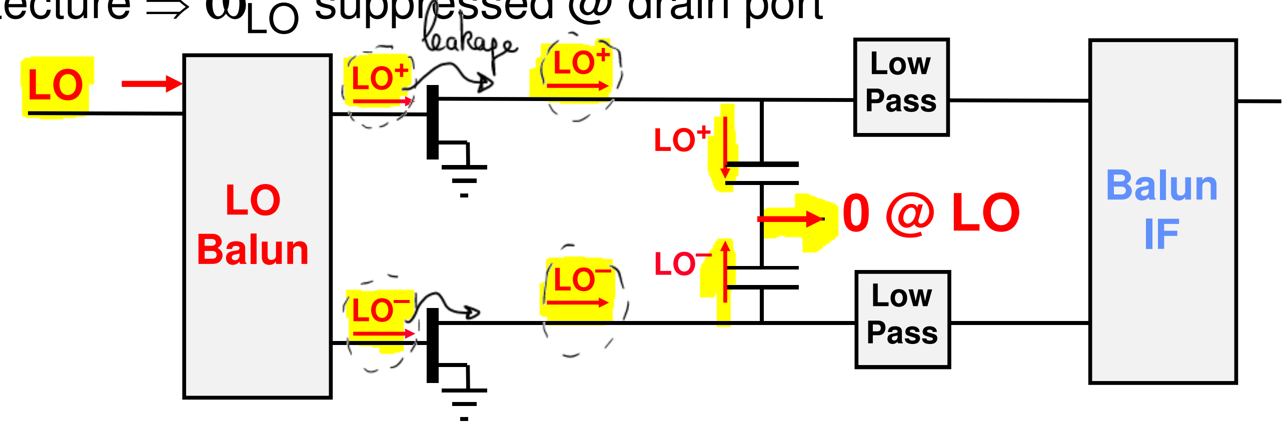
Cold-FET SBM

- Example of SBM with LO and IF baluns (emission)

  - Pair of cold-FETs



  - Balanced architecture $\Rightarrow \omega_{LO}$ suppressed @ drain port



Isolation LO_RF

Cold-FET DBM

Ring mixer

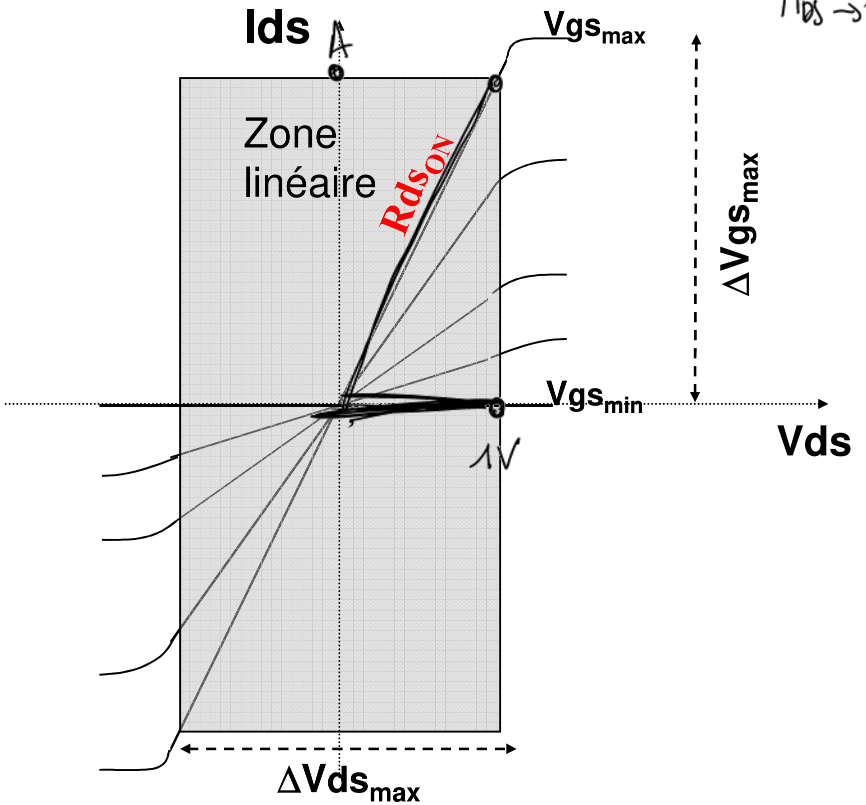
4 Cold-FETs + 3 Baluns (RF, IF, LO)

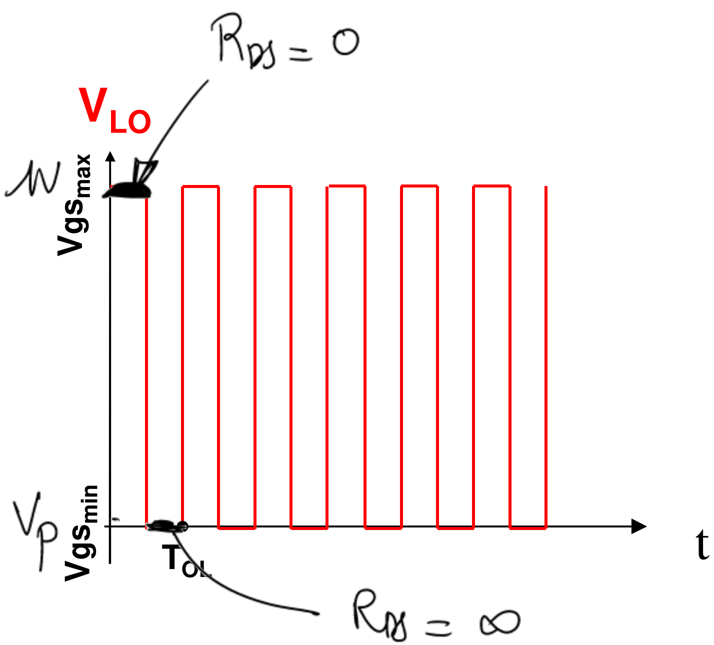
Switch mode of Cold-FET

DBM

The Cold-FET is switched between R_{DSON} (minimum value of R_{DS}) and ∞ (maximum value of R_{DS})

$R_{DS} \to 0$

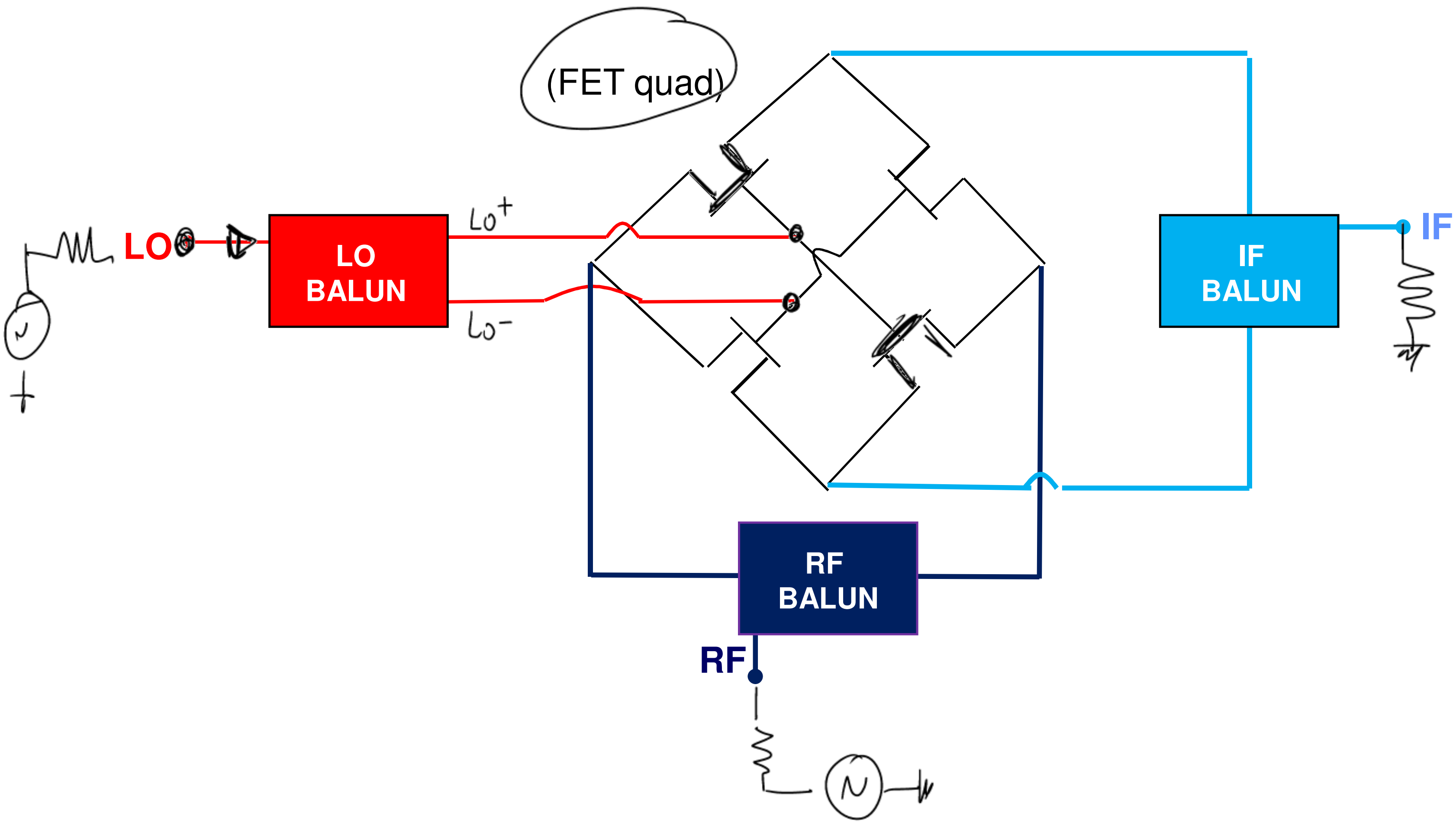




If the transistor size is increased → $(I_{DSMAX} \uparrow)$ → $(R_{DSON} \downarrow)$ → (Conversion losses ↓)

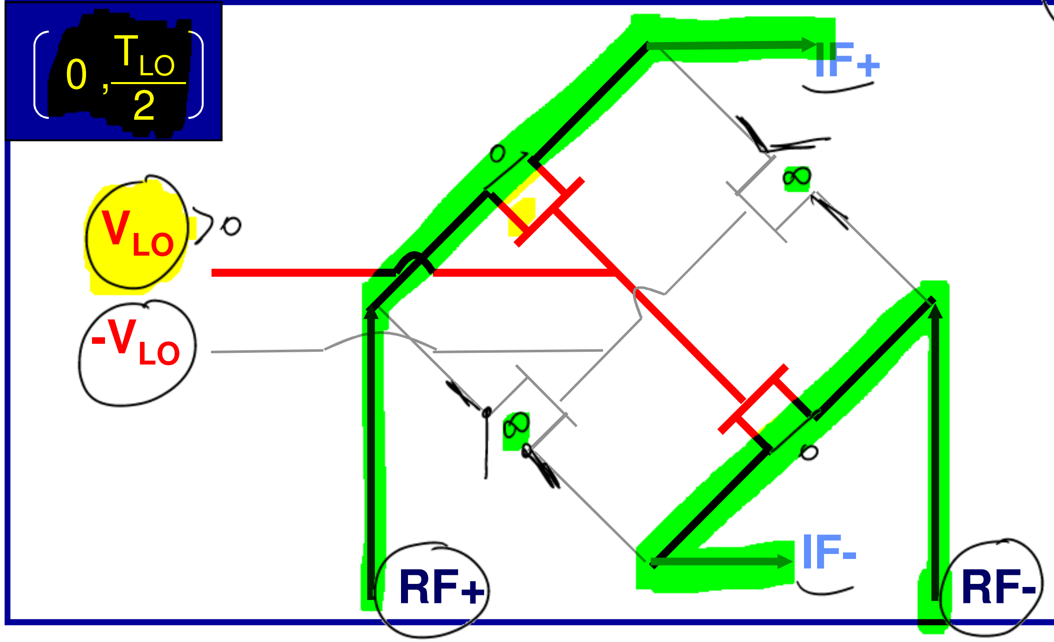
However → $(C_{GS} \uparrow)$ → (Frequency limitation ↑)

Cold-FET « Switch Mode Mixer » : Ring DBM



Operating principle of the ring Cold-FET DBM

$$V_{OUT} = V_{IN} \times \mathrm{Sign}(V_{LO}) \rightarrow (2k+1)\,\omega_{LO} \pm \omega_{IN}$$



In the ideal case

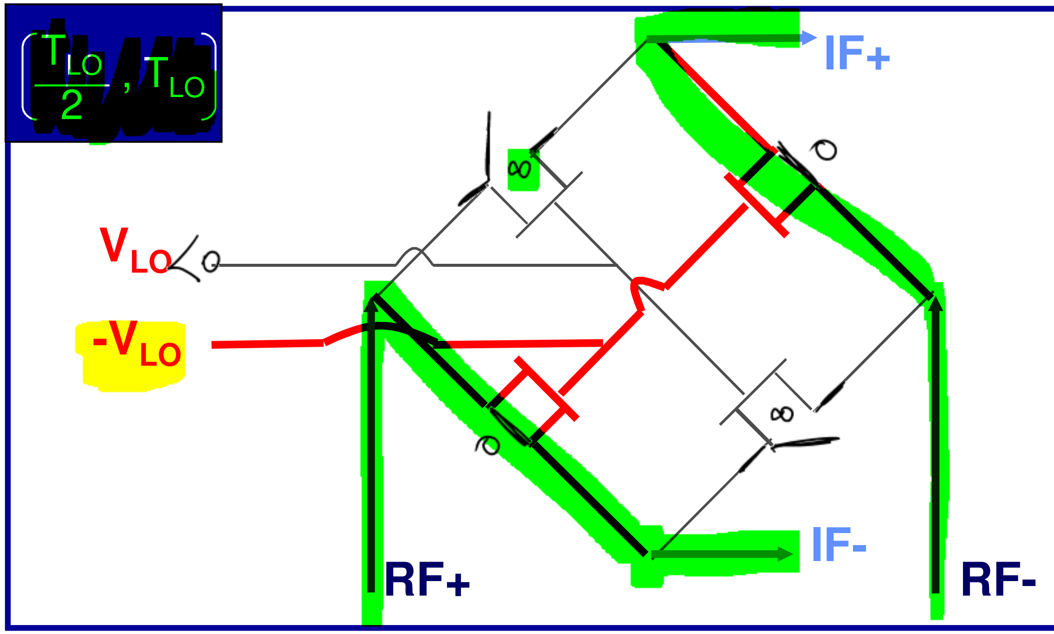
$Rds_{ON} = 0$ / $Rds_{OFF} = \infty$

$IF^+ \approx RF^+$

$IF^- \approx RF^-$

Input signal is copied

$$V_{OUT} = V_{RF} = +V_{RF} = +1 \times V_{RF} = \mathrm{Sign}(V_{LO}) \times V_{RF}$$



$IF^+ \approx RF^-$

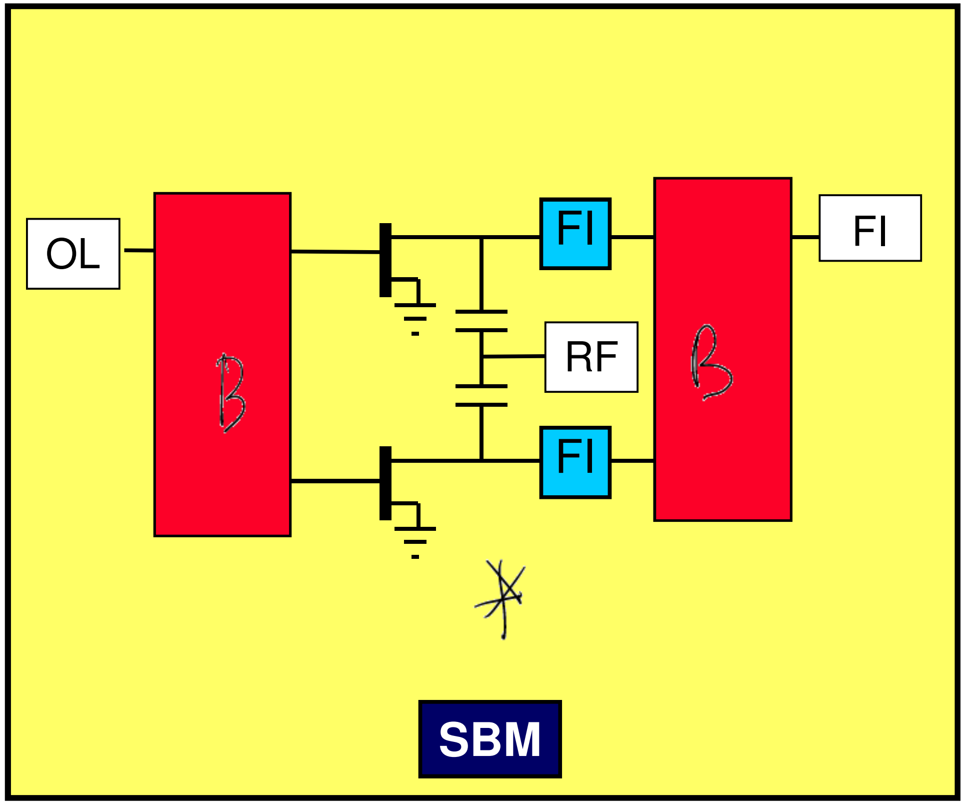
$IF^- \approx RF^+$

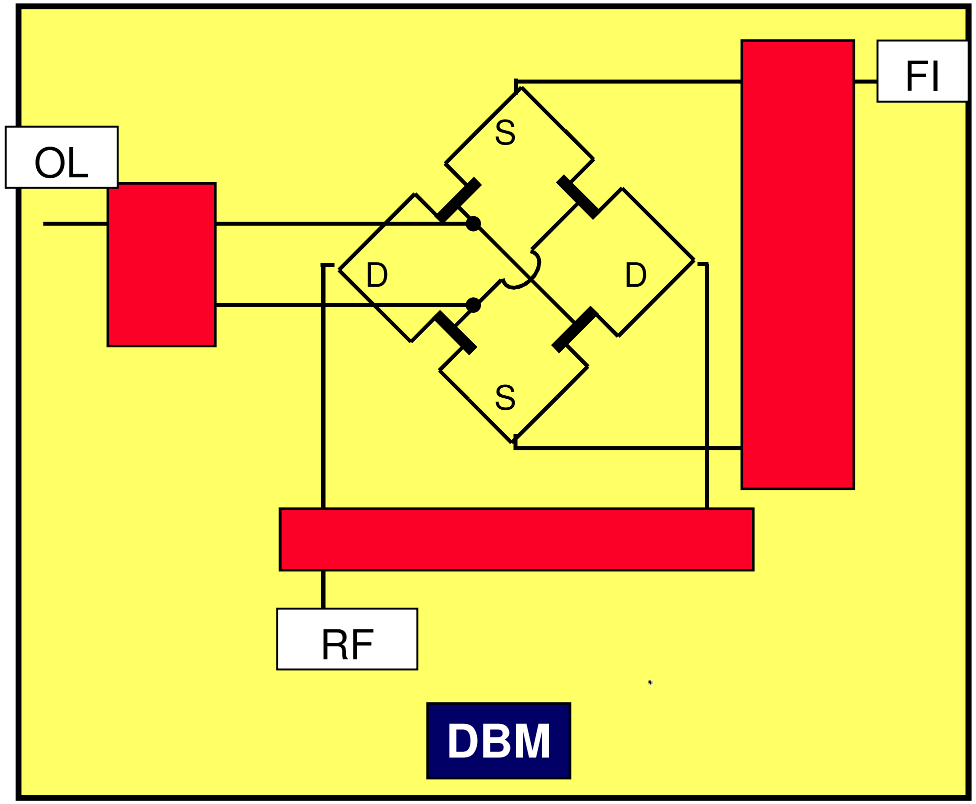
Input signal is reversed

$$V_{OUT} = -V_{RF} = -1 \times V_{RF} = \mathrm{Sign}(V_{LO}) \times V_{RF}$$

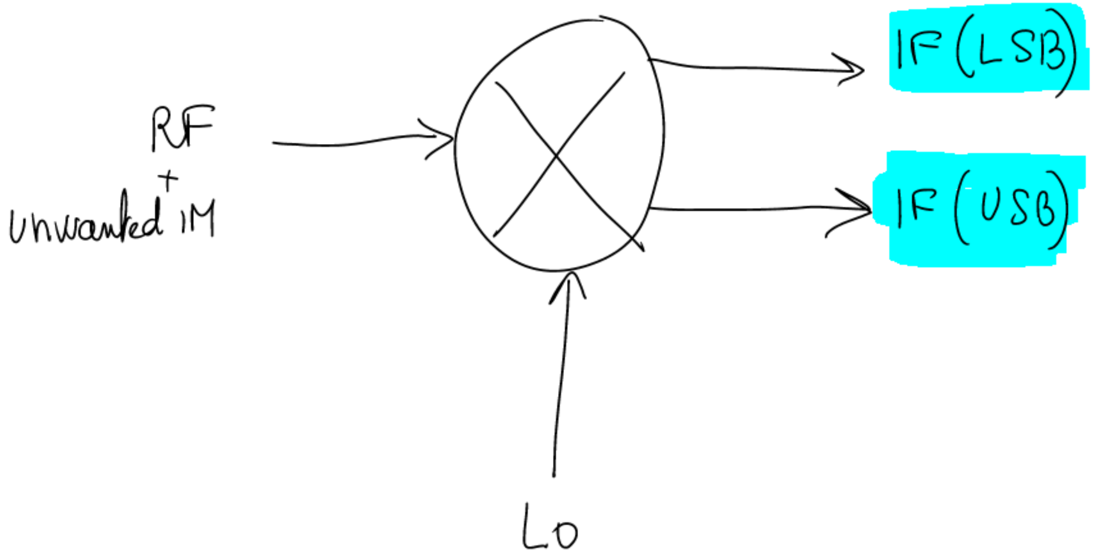
Main Cold-FET mixer architectures

- Cold-FET Mixers

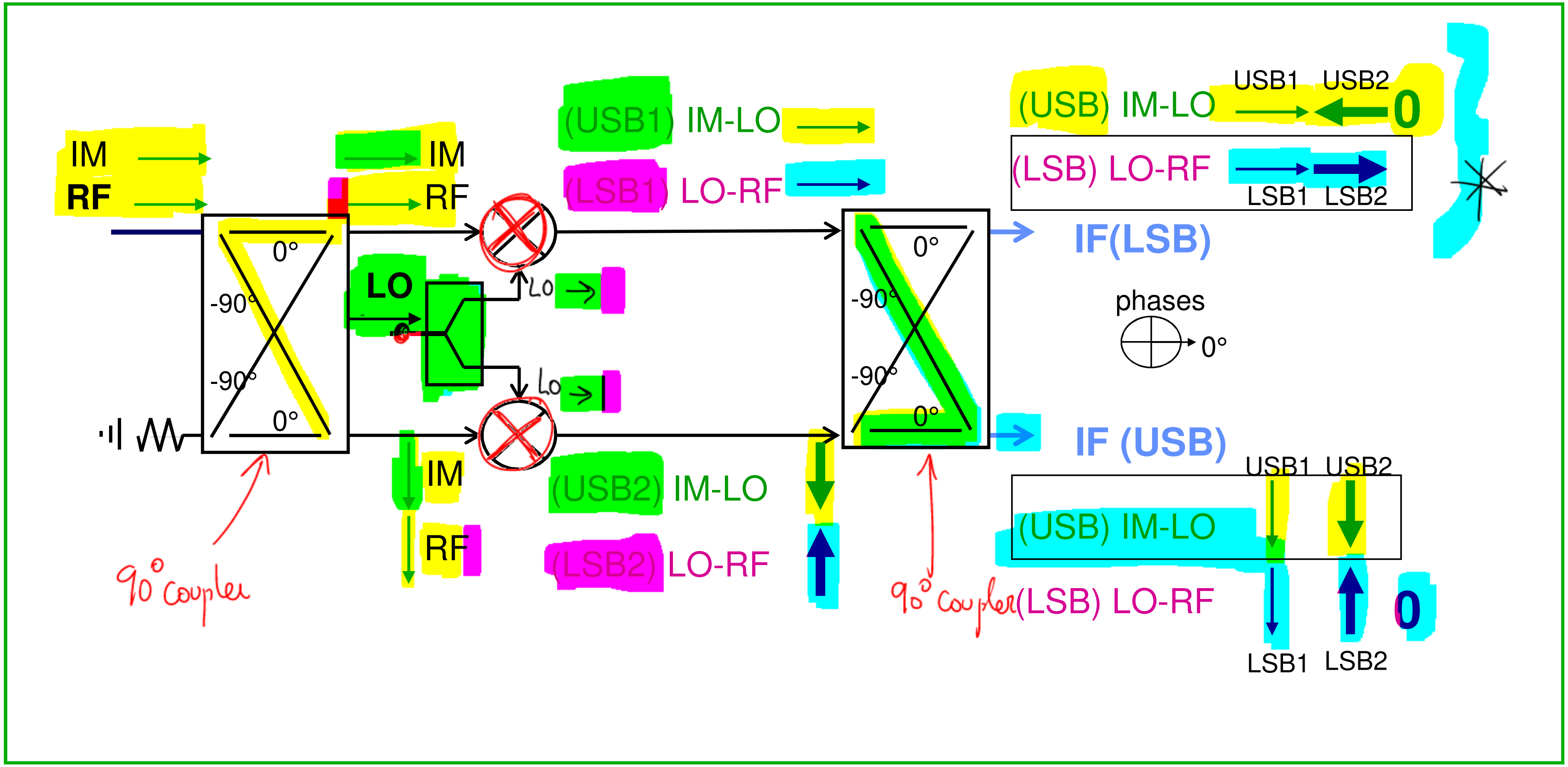




Example of IRM (Image Rejection Mixer)



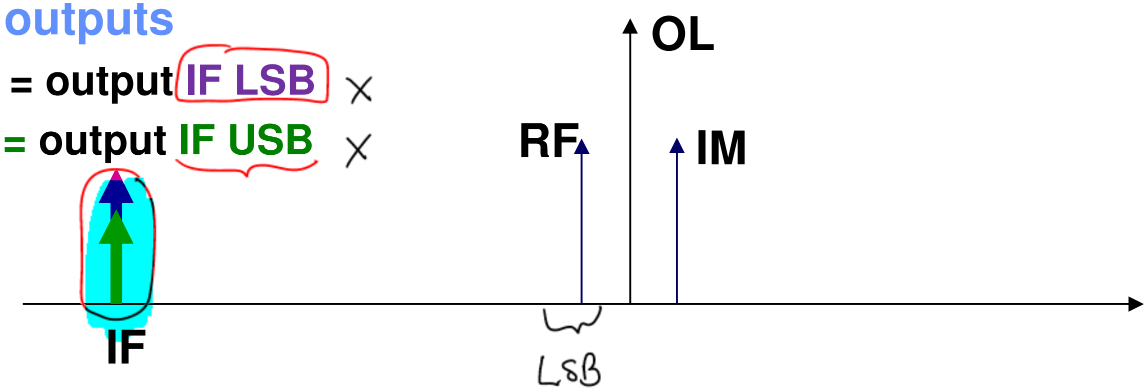
Example of IRM



IF outputs

= (LO-RF) = output IF LSB ×

= (IM-LO) = output IF USB ×



Mixer ⊗

$$(\omega_1+\omega_2)t+(\varphi_1+\varphi_2)$$
$$(\omega_1-\omega_2)t+(\varphi_1-\varphi_2)$$