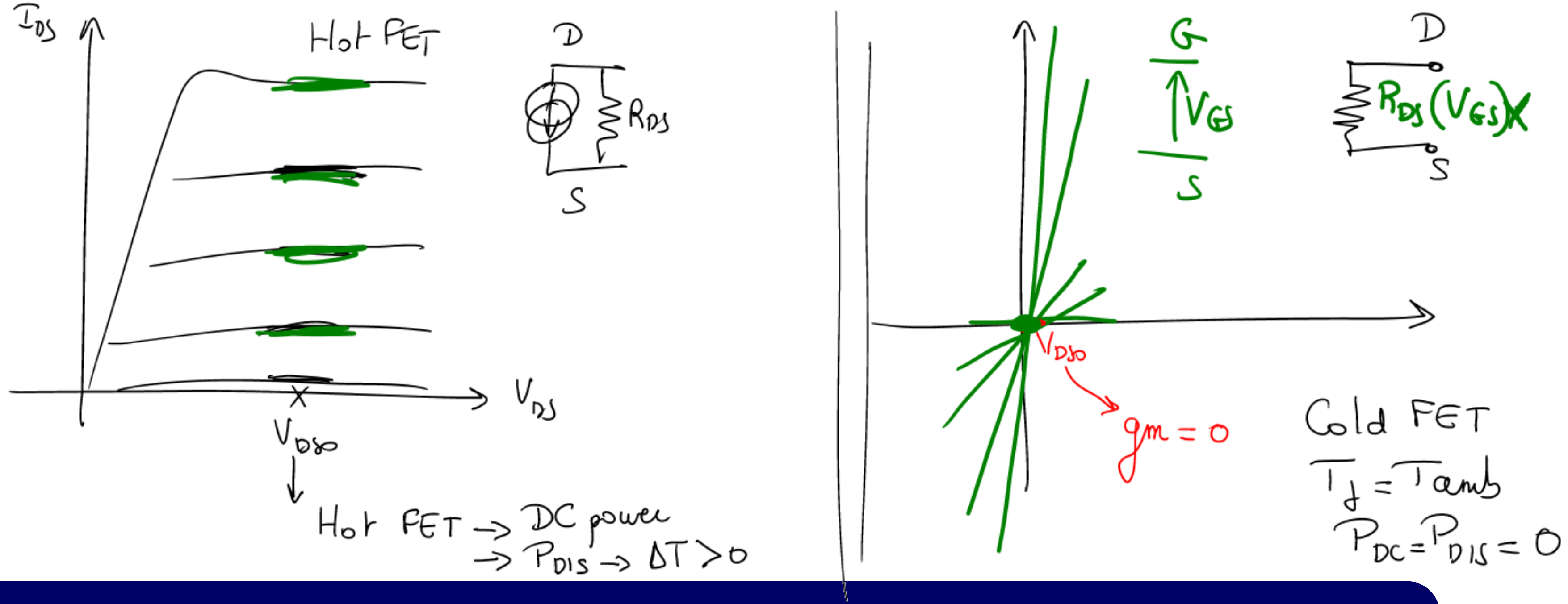
Outline

- **Introduction**
- **Theory of frequency conversion** → ⊗ NL switches (sign)
- **Characteristic performances of mixers**
- **Active mixers**
  - ➔ Single Ended (SEM) → Gate Mixer / Drain Mixer
  - ➔ Gilbert Cell → DBDM Double Balanced Differential Mixer
- **Passive Mixers**
  - ➔ Diodes → SEM / SBM / DBM
  - ➔ Cold FETs → SEM / SBM
- **IRM: Image Reject Mixers**



Passive "Resistive" Mixers

Multiplication: Resistive Mixers

- **Principle :** Implementing a multiplication by using the Ohm's law

$$V = R.I \quad \text{or} \quad I = G.V$$

$$V_{out}(t)=R(t).I_{in}(t) \quad \text{or} \quad I_{out}(t)=G(t).V_{in}(t)$$

- **Varying nonlinear conductance G(t)** = nonlinear element driven by a large signal @ LO

→ Obtain a time varying conductance and its required frequency spectrum

- **Expansion of G(t) in Fourier transform:**

$$\underbrace{G(t) = G_0 + G_1.\cos(\omega_{LO}.t)}_{\text{Ideal term}} \underbrace{+ G_2.\cos(2\omega_{LO}.t) + G_3.\cos(3\omega_{LO}.t) + \ldots}_{\text{Spurs for a fundamental mixer}}$$

Ideal term

Spurs for a fundamental mixer (*However 2nd harmonic can be used for subharmonic mixers*)

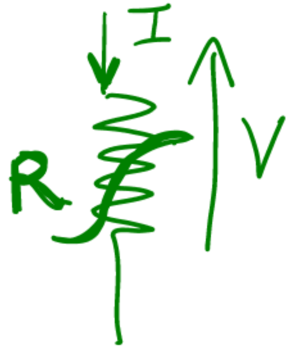
- The mixing is obtained by applying a low signal $\mathbf{V_{RF}}$ at the input of the time varying conductance to create the required converted current at IF

$$\underset{\omega_{IF}}{\underset{\uparrow}{I_S(t)}} = \underset{\omega_{LO}}{\underset{\uparrow}{G(t)}} \;.\; \underset{\omega_{RF}}{\underset{\uparrow}{V_{RF}(t)}}$$

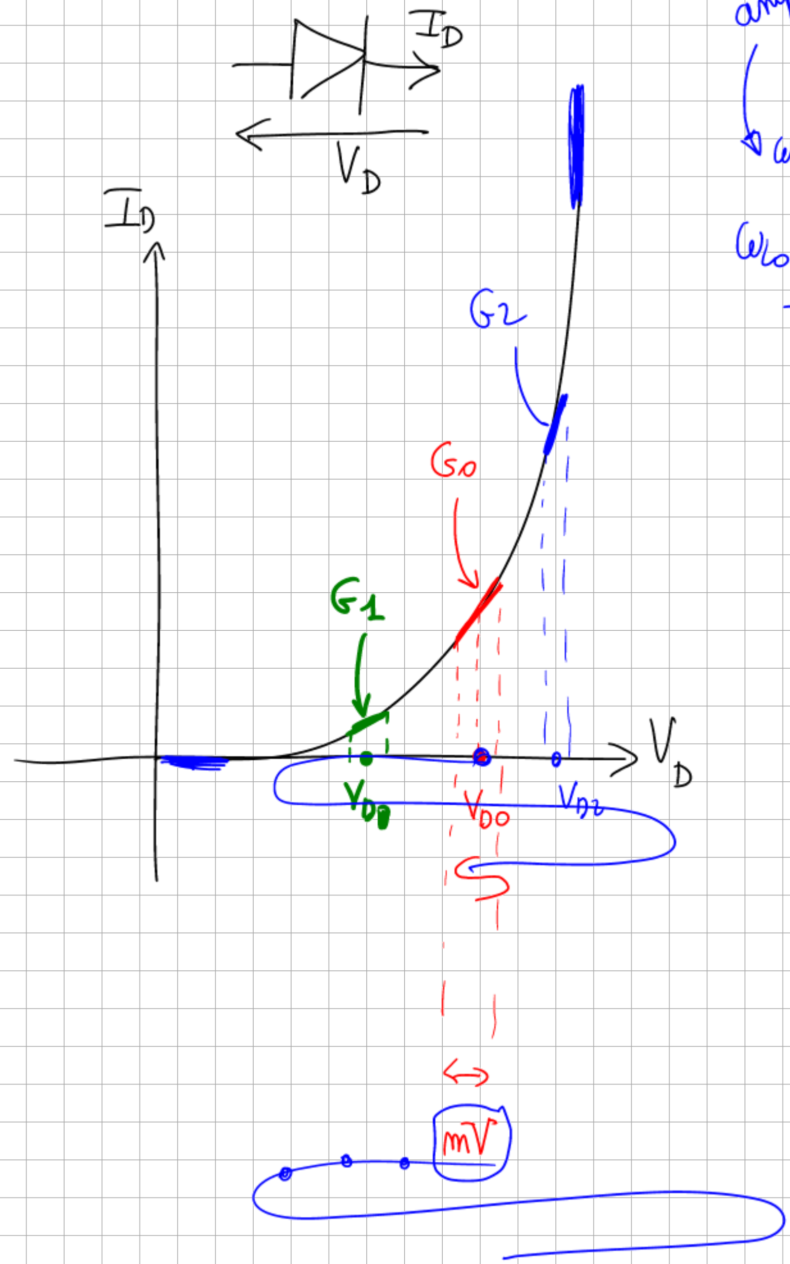
Ohm law

$V = R \times I$

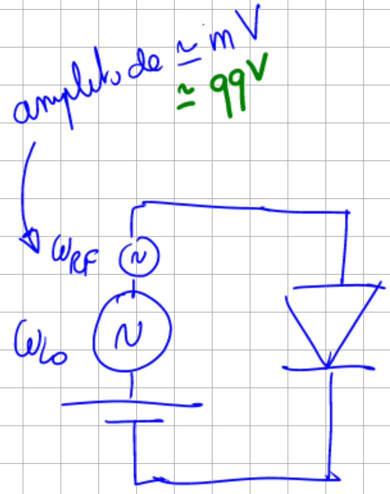
$I = G \times V$



$G = \frac{1}{R}$

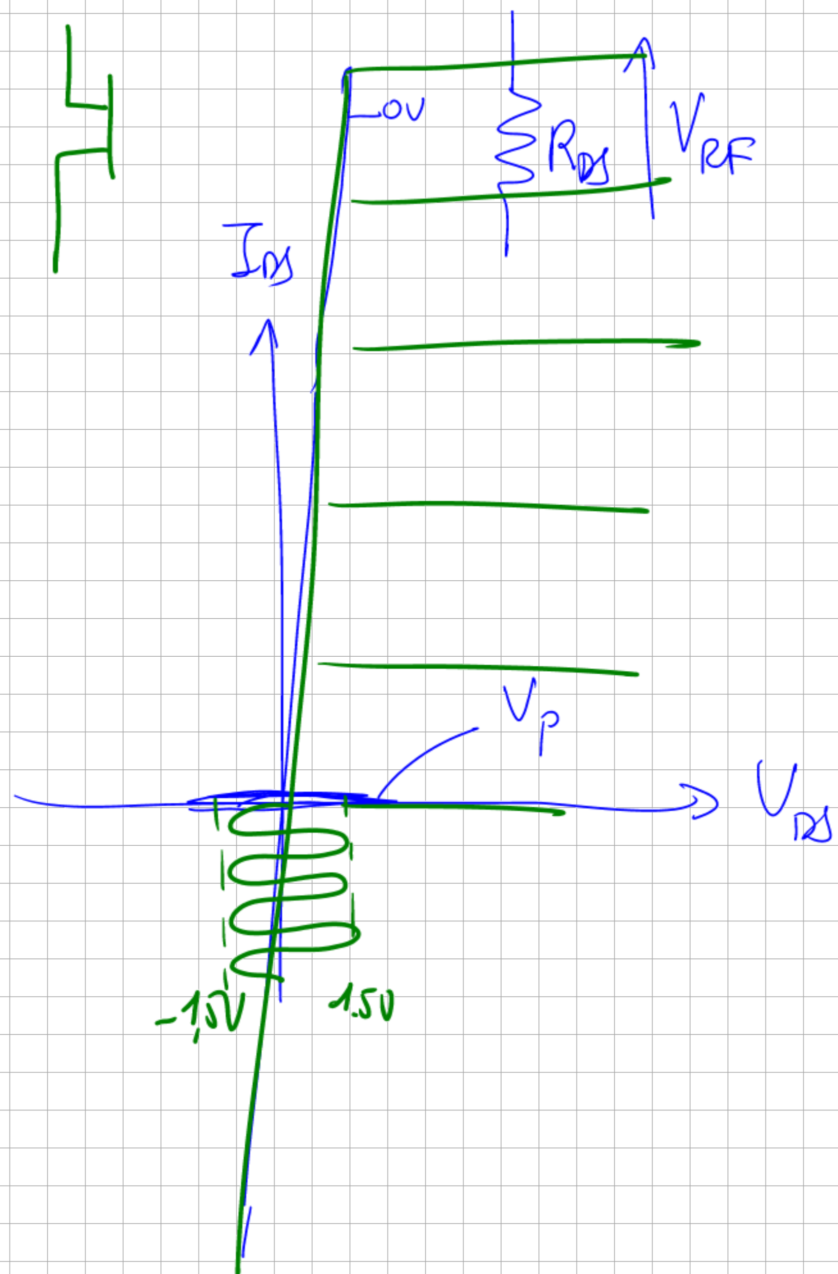


I_D
V_D
I_D
G2
G0
G1
V_D
V_D1
V_D0
V_D2
mV



amplitude ≃ mV
≃ 99V
ω_RF
ω_LO

LO



0V
R_DS
V_RF
I_DS
V_P
V_DS
-1,5V
1,5V

Principle of Diode Mixers

Minimum of conversion losses for passive mixers

- **Ideal case of a diode mixer :**

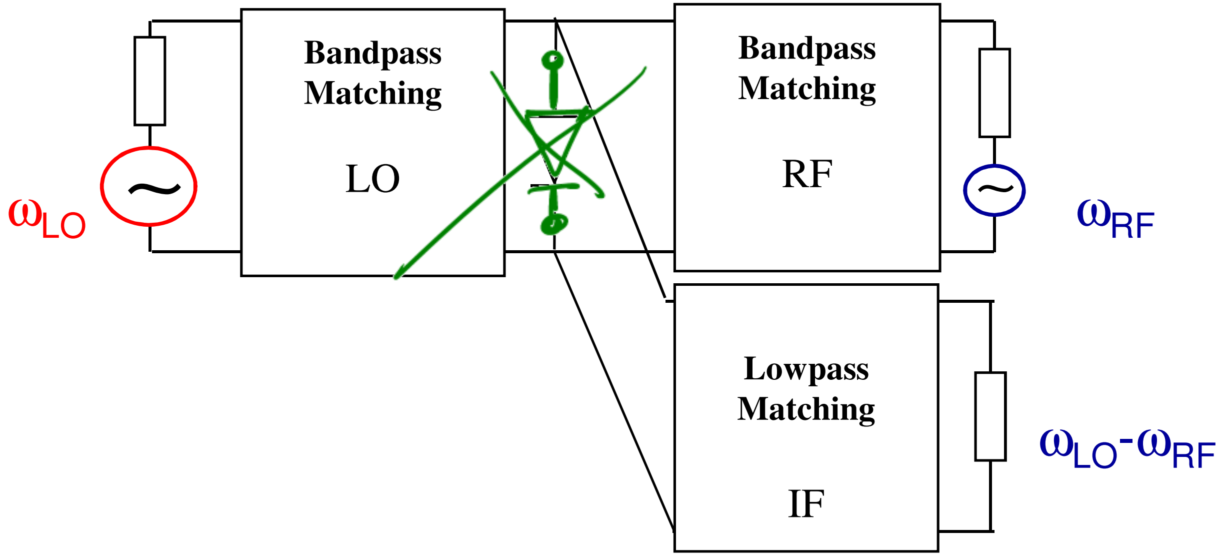
$$\rightarrow Lc_{MIN} \cong 4 \text{ dB}$$

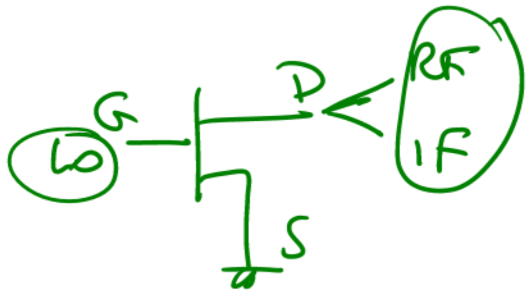
- **Actual case :**

$$Lc_{MIN} \approx 5 \text{ à } 6 \text{ dB}$$

$$Lc = f \left[\text{I-V}_{NL} , V_{LO}(t) , Z_L(\omega_{SPURS}) \right]$$

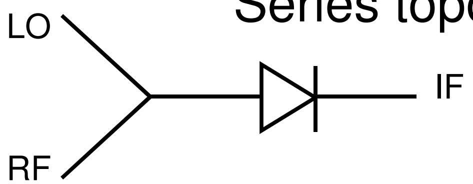
Diode-based SEM



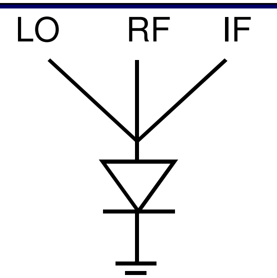


Critical matching constraints for single diode mixers

Series topology



Parallel topology



Advantages:

- Low Lc and P_{LO}

Disadvantages:

- No suppression of spurs
- Bandwidth and isolation are greatly limited by critical filtering issues
- Filter losses increase Lc $\rightarrow$ Very few diode-based SEM

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

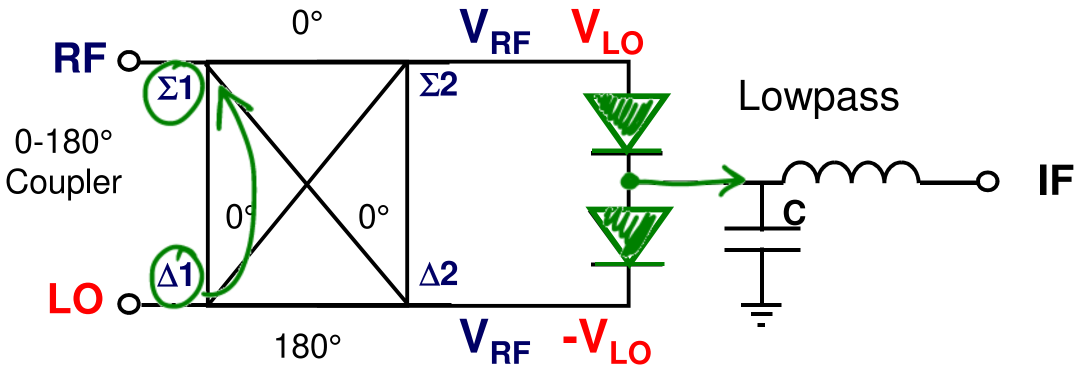
- Suppression of some spurs by out of phase recombination
- Good LO-RF Isolation and sometimes LO-IF isolation without filtering issues

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

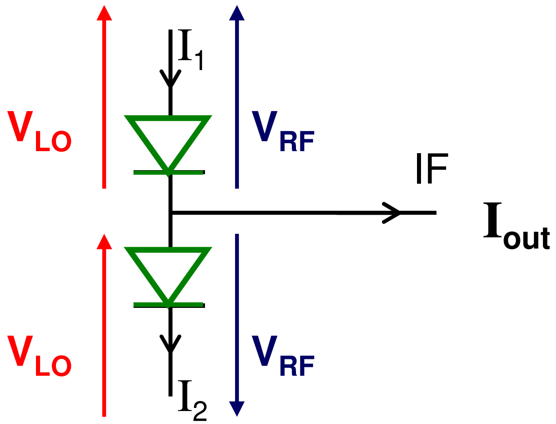
Input Matching $_{@LO/RF}$ ≈ Input Matching$_{@LO/RF}$ of coupler

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

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

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

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

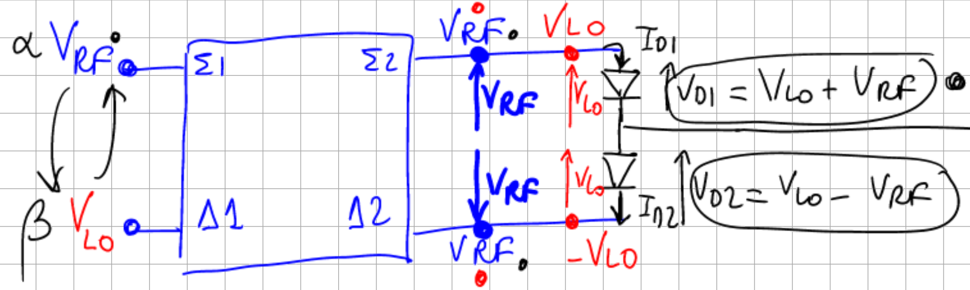
$V_{LO}^{\,p} \,.\, V_{RF}^{\,q} \rightarrow \pm\, p.\omega_{LO} \pm\, q.\omega_{RF}$

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

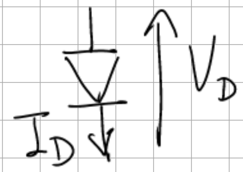
If **n is even** because $(V_{RF})^n = (-V_{RF})^n$

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

n=0 **n=2**



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



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

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

$$\begin{cases} I_{D1} = a(\cancel{V_{LO}} + V_{RF}) + b(\cancel{V_{LO}} + V_{RF})^2 + c\underbrace{(V_{LO} + V_{RF})^3} \\ I_{D2} = a(\cancel{} \; - \quad) + b(\cancel{} \; - \quad) + c(\quad - \quad) \end{cases}$$

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

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

ω_{RF} — spurs

ω_{IF}, ω_{Σ}

ω_{RF}, $3\omega_{RF}$

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

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

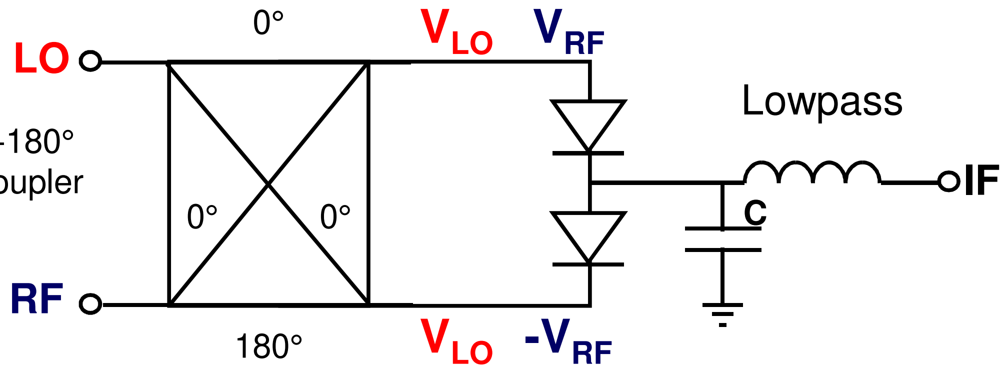
$-\;(a-b)^3 = \cancel{a^3} - b^3 - 3a^2b + \cancel{3ab^2}$

$ISO_{LO-RF} =$

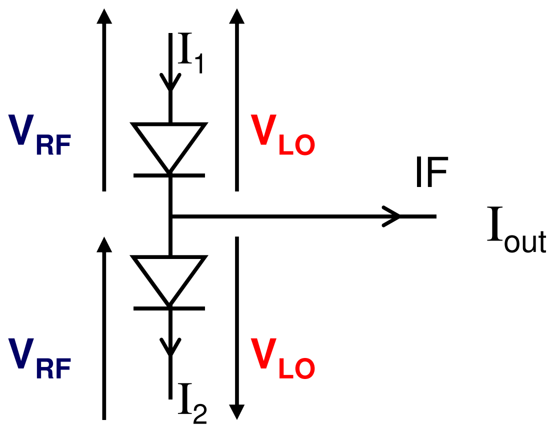
$ISO_{LO-IF} = \infty$

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



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

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

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

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

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

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