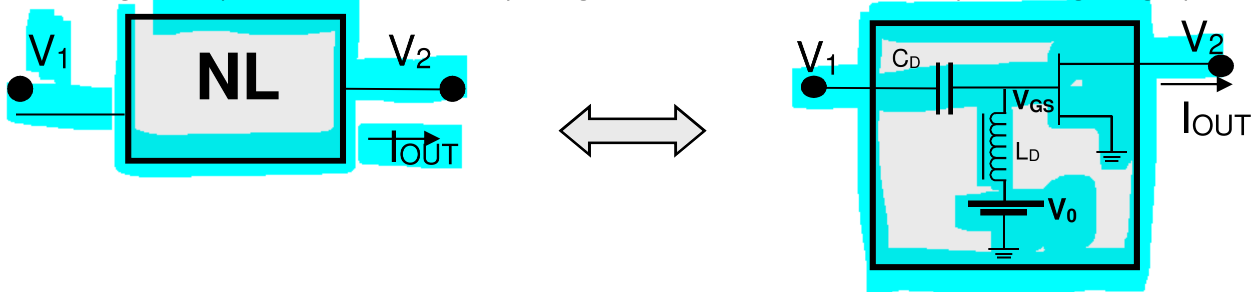
Tutorial (SEM cold-FET Mixer)

The following cold-FET mixer (biased @ V_{DS0}=0 V) is used to design a SEM up-converter where the LO signal V_1 is applied to the gate, which is biased @ ($V_{GS0}= V_0$) while the IF input signal is applied to the drain using a low-pass filter and the output signal is extracted at the drain port using a high-pass filter.



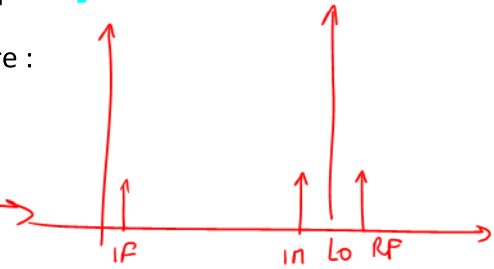
The nonlinear operation of the cold-FET (NL) is expressed by the 2 following equations that give the output current I_{OUT} as a function of input and output control voltages V_1 and V_2:

$$V_{GS} = V_0 + V_1 \qquad \text{(eq1)}$$ where V_0 is a constant (gate bias voltage)

$$I_{OUT} = p\,V_2 - q\,V_2\,V_{GS}^2 + r\,V_1 \qquad \text{(eq2)}$$ where p , q and r are constants

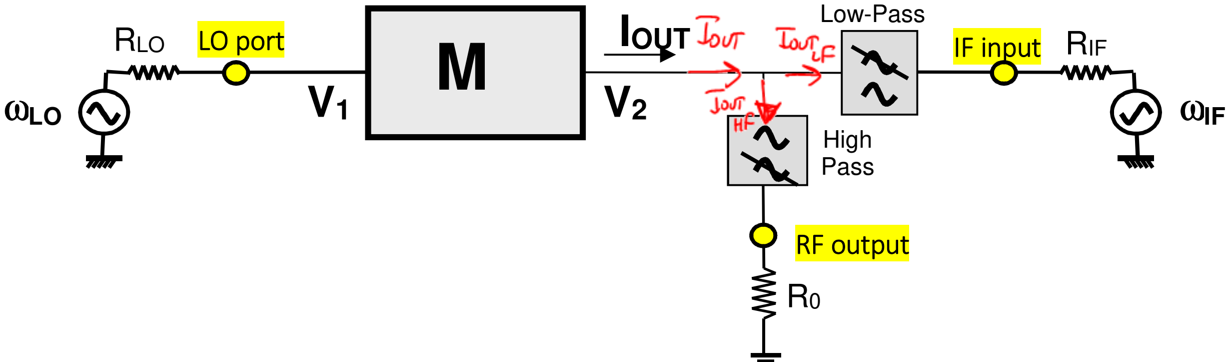
The SEM cold-FET mixer is shown below and the main frequencies are :

f_{LO}= 9 GHz , f_{IF}= 0.5 GHz et $f_{RF} = f_{LO} + f_{IF} =$ 9.5 GHz ($\omega_{RF} = \omega_{LO} + \omega_{IF}$).



The two control voltages V_1 and V_2 of the FET mixer are :

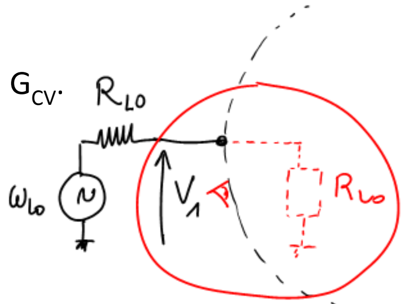
- LO voltage at gate port : $V_1 = V_{LO}\cos(\omega_{LO} t)$ (eq3)
- IF voltage at drain port : $V_2 = V_{IF}\cos(\omega_{IF} t)$ (eq4)



1) Using equations 1 to 4, express the output current I_{OUT} as a function of signal magnitudes (V_{LO}, V_{IF}), nonlinearity constants (p, q, r), gate bias V_0 and the mixing frequencies. The following notations can be used for mixing frequencies: $\omega_{IM}=(\omega_{LO} - \omega_{IF})$; $\omega_1=(2\omega_{LO} - \omega_{IF})$; $\omega_2=(2\omega_{LO}+\omega_{IF})$

2) The high-pass filter is designed to reject frequencies lower than 5GHz while the low-pass frequency is designed to cut frequencies greater than 5GHz. Therefore, what are the mixing frequencies at the RF output port?

3) Determine the expression of the voltage conversion gain G_{CV}.



4) If the LO port is assumed to be matched to R_{LO},
   a) express the LO power applied at the LO port
   b) express the LO power at the RF output port
   c) express in dB the LO-to-RF isolation
   d) what is the LO-to-IF isolation ?
   e) express the equivalent impedance Z_{IN} seen by the IF generator @ ω_{IF} at the IF input port

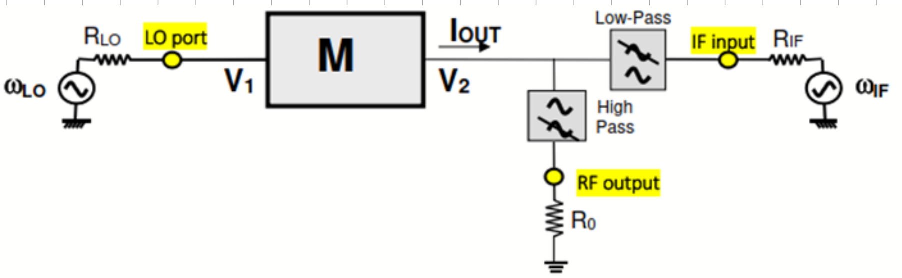
$V_1 = V_{LO}\cos(\omega_{LO} t)$ (eq3)

$V_2 = V_{IF}\cos(\omega_{IF} t)$ (eq4)

$\cos^2(x) = \frac{1}{2} + \frac{1}{2}\cos(2x)$

$V_{GS} = V_0 + V_1$ (eq1)

$I_{OUT} = p\,V_2 - q\,V_2\,V_{GS}^2 + r\,V_1$ (eq2)



1) Using equations 1 to 4, express the output current I_{OUT} as a function of signal magnitudes (V_{LO}, V_{IF}), nonlinearity constants (p, q, r), gate bias V_0 and the mixing frequencies. The following notations can be used for mixing frequencies: $\omega_{IM}=(\omega_{LO} - \omega_{IF})$; $\omega_1=(2\omega_{LO} - \omega_{IF})$; $\omega_2=(2\omega_{LO}+\omega_{IF})$

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

$$V_2 \times V_{GS}^2 = V_2\left(V_0 + V_1\right)^2 = V_2\left(V_0^2 + V_1^2 + 2V_0V_1\right)$$

$$V_1^2 = V_{LO}^2\cos^2(\omega_{LO}t)$$

$$= V_{IF}\cos(\omega_{IF}t)\left[V_0^2 + \underbrace{\frac{1}{2}V_{LO}^2 + \frac{1}{2}V_{LO}^2\cos(2\omega_{LO}t)}_{V_1^2} + 2V_0V_{LO}\cos(\omega_{LO}t)\right]$$

$$= \left(V_0^2 + \frac{V_{LO}^2}{2}\right)V_{IF}\cos(\omega_{IF}t) + V_0V_{LO}V_{IF}\left[\cos(\omega_{RF}t) + \cos(\omega_{IM}t)\right] + \frac{1}{4}V_{LO}^2V_{IF}\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right]$$

$$I_{OUT} = \underbrace{\left[p - q\left(V_0^2 + \frac{V_{LO}^2}{2}\right)\right]V_{IF}\cos(\omega_{IF}t)}_{I_{OUT_{LF}}}\underbrace{- qV_0V_{LO}V_{IF}\left[\cos(\omega_{RF}t) + \cos(\omega_{IM}t)\right] - \frac{q}{4}V_{LO}^2V_{IF}\left[\cos(\omega_1 t) + \cos(\omega_2 t)\right] + rV_{LO}\cos(\omega_{LO}t)}_{I_{OUT_{HF}}}$$

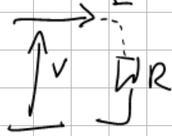
$$I_{OUT} = \left[p - q\left(V_0^2 + \frac{V_{LO}^2}{2}\right)\right] V_{IF}\cos(\omega_{IF}t) - \underbrace{qV_0V_{LO}V_{IF}}\left[\cos(\omega_{RF}t)+\cos(\omega_{IM}t)\right] - \frac{q}{4}V_{LO}^2V_{IF}\left[\cos(\omega_1 t)+\cos(\omega_2 t)\right] + rV_{LO}\cos(\omega_{LO}t)$$

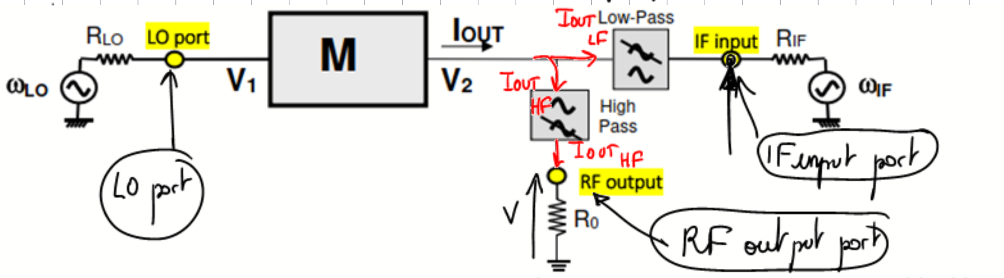
Y

*

$I_{OUT}(t) \longrightarrow$ phasors

$$P = \frac{1}{2}\,Re\left(V\,I^*\right) = \frac{1}{2}\frac{|V|^2}{R} = \frac{1}{2}R|I|^2$$





IF $\longrightarrow \otimes \longrightarrow$ RF

1) Using equations 1 to 4, express the output current I_{OUT} as a function of signal magnitudes (V_{LO}, V_{IF}), nonlinearity constants (p, q, r), gate bias V_0 and the mixing frequencies. The following notations can be used for mixing frequencies: $\omega_{IM}=(\omega_{LO} - \omega_{IF})$; $\omega_1=(2\omega_{LO} - \omega_{IF})$; $\omega_2=(2\omega_{LO}+\omega_{IF})$

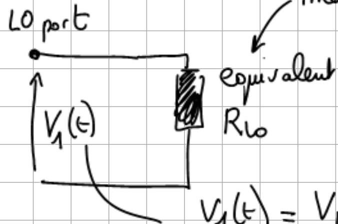
3) $$G_{CV} = \frac{V_{OUT}(\omega_{OUT})}{V_{IN}(\omega_{IF})} = \frac{V_{RF_{port}}(\omega_{RF})}{V_{IF_{port}}(\omega_{IF})} = \frac{R_0\, I_{OUT_{RF}}(\omega_{RF})}{V_{IF}} = \frac{R_0\left(-qV_0V_{LO}\cancel{V_{IF}}\right)}{\cancel{V_{IF}}}$$

$$\boxed{G_{CV} = -q\,R_0V_0V_{LO}}$$

2) Output frequencies @ RF port are: $(f_{LO}, f_{IM}, f_1, f_2)$ spurs and f_{RF}

4) a) $$\boxed{P_{LO_{port}}(\omega_{LO}) = \frac{1}{2}\frac{|V_{LO}|^2}{R_{LO}}}$$

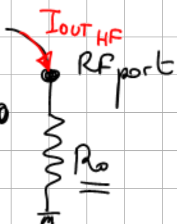
matched to R_{LO}



$V_1(t) = V_{LO}\cos(\omega_{LO}t)$

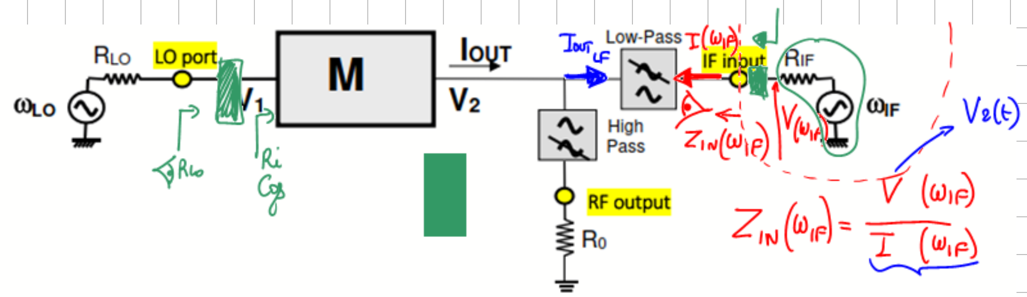
$\hookrightarrow V_1 = V_{LO}e^{j0} = V_{LO}$

b) $$\boxed{P_{RF_{port}}(\omega_{LO}) = \frac{1}{2}R_0\Big|\underbrace{I_{OUT}(\omega_{LO})}_{rV_{LO}}\Big|^2 = \frac{1}{2}R_0r^2V_{LO}^2}$$



c) $$ISo_{LO\to RF}(dB) = 10\log\left(\frac{P_{LO_{port}}(\omega_{LO})}{P_{RF_{port}}(\omega_{LO})}\right) = 10\log\left(\frac{\frac{1}{2}\frac{\cancel{V_{LO}^2}}{R_{LO}}}{\frac{1}{2}R_0r^2\cancel{V_{LO}^2}}\right) = \boxed{10\log\left(\frac{1}{R_0R_{LO}r^2}\right)}$$

d) $$Iso_{LO\to IF}(dB) = 10\log\left(\frac{P_{LO_{port}}(\omega_{LO})}{P_{IF_{port}}(\omega_{LO})}\right) = \infty$$ because of the ideal low-pass filter



1) Using equations 1 to 4, express the output current I_{OUT} as a function of signal magnitudes (V_{LO}, V_{IF}), nonlinearity constants (p, q, r), gate bias V_0 and the mixing frequencies. The following notations can be used for mixing frequencies: $\omega_{IM}=(\omega_{LO}-\omega_{IF})$; $\omega_1=(2\omega_{LO}-\omega_{IF})$; $\omega_2=(2\omega_{LO}+\omega_{IF})$

$$Z_{IN}(\omega_{IF}) = \frac{V_{IF}}{(-I_{OUT}(\omega_{IF}))} = \frac{\cancel{V_{IF}}}{-\left(p-q\left(V_0^2+\frac{V_{LO}^2}{2}\right)\right)\cancel{V_{IF}}} =$$

$$v(t) = V_1\cos(\omega_1 t+\theta_1) \rightarrow \underline{V} = V_1 e^{j\theta_1} = V_1\cos(\theta_1) + j\,V_1\sin(\theta_1)$$

$$\boxed{Z_{IN}(\omega_{IF}) = \frac{1}{q\left(V_0^2+\frac{V_{LO}^2}{2}\right)-p}} = R_{IF}$$

To power match the IF generator, $Z_{IN}(\omega_{IF}) = R_{IF}$