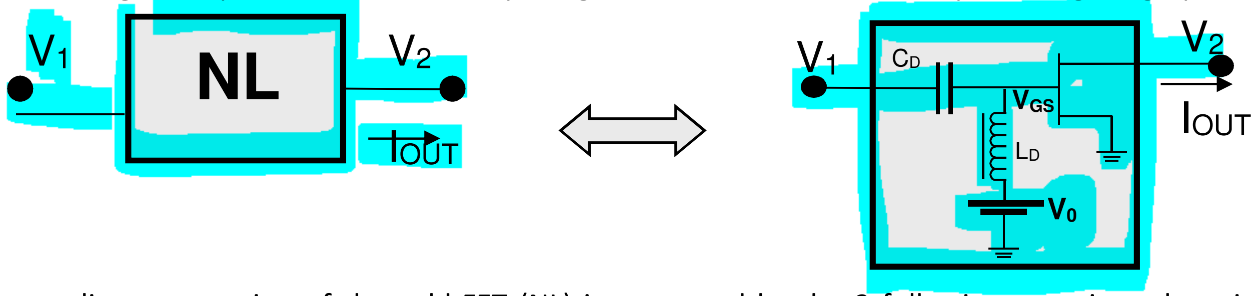
Tutorial (SEM cold-FET Mixer)

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.



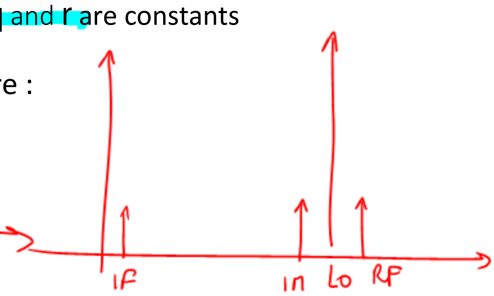
The nonlinear operation of the cold-FET (NL) is expressed by the 2 following equations that give the output current I_{OUT} as a function of input and output control voltages V_1 and V_2:

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

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

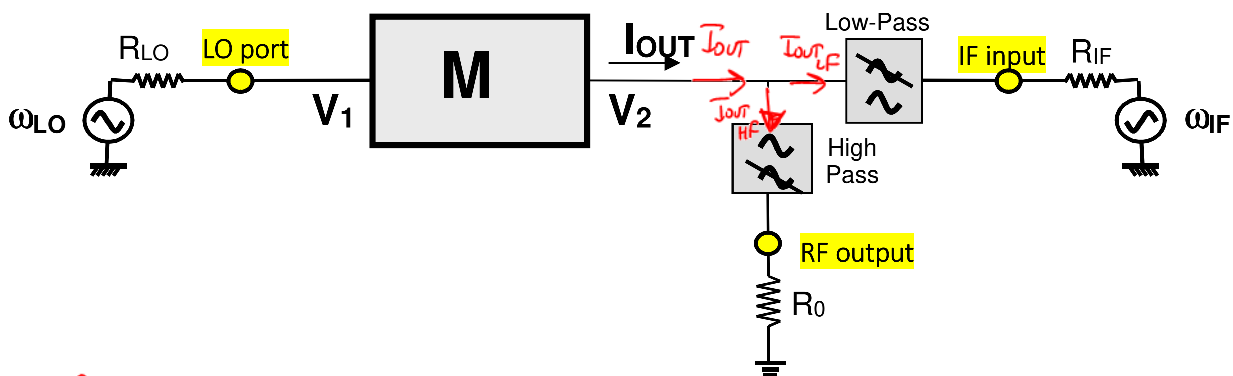
The SEM cold-FET mixer is shown below and the main frequencies are :

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)**

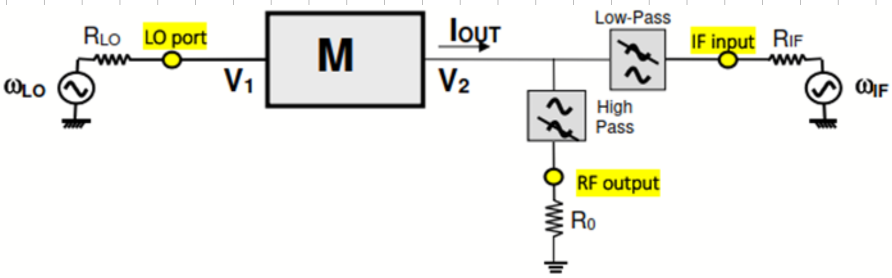


1) Using equations 1 to 4, express the output current I_{OUT} as a function of signal magnitudes (V_{LO}, V_{IF}), nonlinearity constants (p, q, r), gate bias V_0 and the mixing frequencies. The following notations can be used for mixing frequencies: $\omega_{IM}=(\omega_{LO} - \omega_{IF})$; $\omega_1=(2\omega_{LO}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

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



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

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

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

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

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

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: $\omega_{IM}=(\omega_{LO} - \omega_{IF})$; $\omega_1=(2\omega_{LO} - \omega_{IF})$; $\omega_2=(2\omega_{LO}+\omega_{IF})$

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

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

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

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

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

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