Chapter 13 Oscillators and mixers

13.2 Microwave oscillators

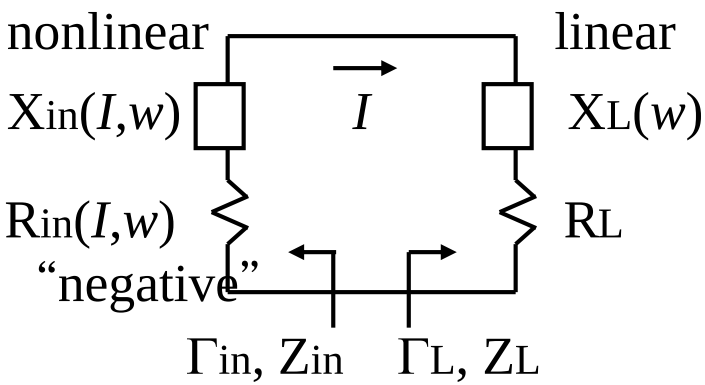
one-port negative resistance oscillator, transistor oscillator, DRO (dielectric resonator oscillator)

13.5 Mixers

single-ended mixer, balanced mixer, FET mixers

13.2 Microwave oscillators

- one-port negative resistance oscillators



@ steady state

$$\text{KVL} \rightarrow (Z_L + Z_{in})I = 0$$

$$I \neq 0 \rightarrow R_L + R_{in} = 0,\ X_L + X_{in} = 0$$

$$\text{passive load} \rightarrow R_{in} < 0$$

<u>Discussion</u>

1. oscillator concept

   noise $\rightarrow$ circuit unstable $R_{in}(I,w)+R_L(w) < 0$

   $\rightarrow$ feedback and amplify near w_o

   $\rightarrow$ at steady state $R_{in}(I_o,w_o)+R_L = 0$, $X_{in}(I_o,w_o)+X_L(w_o) = 0$

   $\rightarrow$ oscillation at w_o with output power $P_o = 1/2 I_o^2 R$

2. $Z_{in}+Z_L = 0 \rightarrow \Gamma_{in}\Gamma_L = 1$

$$\because \Gamma_L = \frac{Z_L - Z_o}{Z_L + Z_o} = \frac{-Z_{in} - Z_o}{-Z_{in} + Z_o} = \frac{Z_{in} + Z_o}{Z_{in} - Z_o} = \frac{1}{\Gamma_{in}}$$

3. A high-Q tuning circuit enhances the oscillation stability using perturbation analysis

$$Z_T(I,s) \equiv Z_L(s) + Z_{in}(I,s) = 0, s \equiv \alpha + jw$$

$$Z_T(I,s) = \cancelto{0}{Z_T(I_o,s_o)} + \left.\frac{\partial Z_T}{\partial s}\right|_{so,Io} \delta s + \left.\frac{\partial Z_T}{\partial I}\right|_{so,Io} \delta I = 0$$

$$\rightarrow \delta s = \delta\alpha + j\delta w = -\left.\frac{\partial Z_T / \partial I}{\partial Z_T / \partial s}\right|_{so,Io} \delta I = -j \left.\frac{\partial Z_T / \partial I \partial Z^*_T / \partial w}{\left|\partial Z_T / \partial w\right|^2}\right|_{so,Io} \delta I$$

if $\delta I > 0$ occurs $\rightarrow$ $\delta\alpha < 0$ for a stable oscillation

$$\rightarrow \operatorname{Im}\left\{\frac{\partial Z_T}{\partial I}\frac{\partial Z^*_T}{\partial w}\right\} < 0, \text{ or } \operatorname{Im}\left\{\frac{\partial (R_T + jX_T)}{\partial I}\frac{\partial (R_T - jX_T)}{\partial w}\right\} < 0$$

$$\rightarrow \frac{\partial R_T}{\partial I}\frac{\partial X_T}{\partial w} - \frac{\partial X_T}{\partial I}\frac{\partial R_T}{\partial w} > 0$$

$$\because \frac{\partial R_L}{\partial I} = \frac{\partial X_L}{\partial I} = \frac{\partial R_L}{\partial w} = 0 \text{ for a passive load} \rightarrow \frac{\partial R_{in}}{\partial I}\frac{\partial X_T}{\partial w} - \frac{\partial X_{in}}{\partial I}\frac{\partial R_{in}}{\partial w} > 0$$

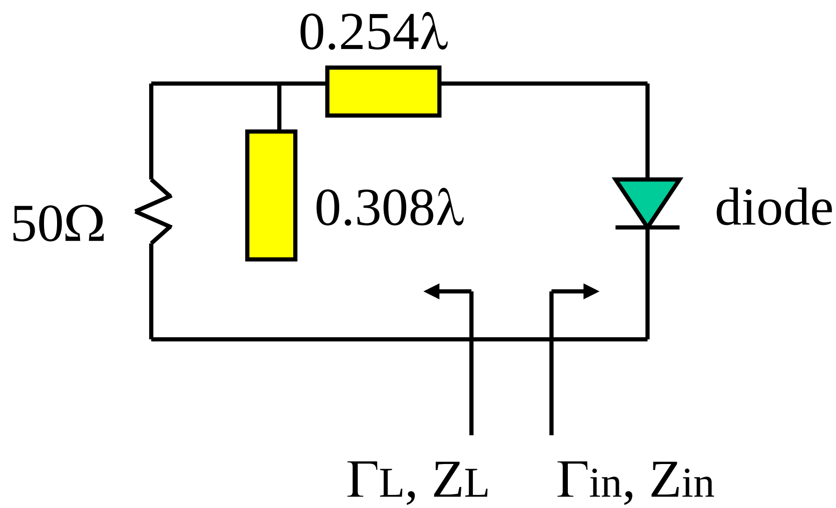
$$\Rightarrow \frac{\partial X_T}{\partial w} = \frac{\partial (X_L + X_{in})}{\partial w} >> 0$$

4. oscillator design consideration

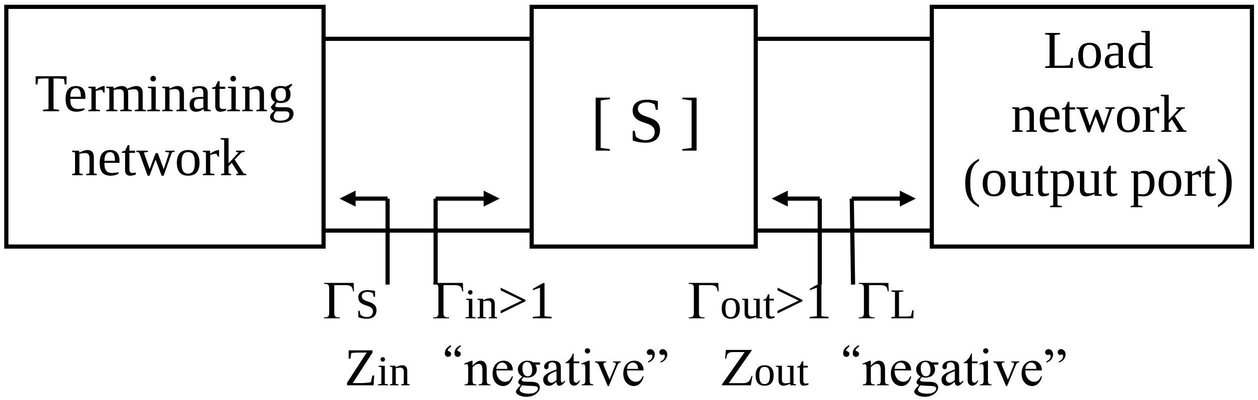
selection of device operation point for stable oscillation and good o/p power, large signal performance, phase noise, frequency pulling,…

5. Ex.13.2 a diode with $\Gamma_{in}=1.25\angle 40^{\circ}$ @6GHz

$Z_{in}=-44+j123\Omega$, $\rightarrow Z_L=44-j123\Omega$



• transistor oscillator



1. Select transistor configuration to enhance its instability
2. Select Γ_L to produce large value of negative R_{in}
3. Choose $R_S = -R_{in}/3$, $X_S = -X_{in}$

<u>Discussion</u>

1. at steady state $\Gamma_{in}\Gamma_S = 1 \rightarrow \Gamma_{out}\Gamma_L = 1$

$$\frac{1}{\Gamma_S} = \Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \rightarrow \Gamma_L = \frac{1 - S_{11}\Gamma_S}{S_{22} - \Delta\Gamma_S}, \Delta = S_{11}S_{22} - S_{12}S_{21}$$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} = \frac{S_{22} - \Delta\Gamma_S}{1 - S_{11}\Gamma_S} \Rightarrow \Gamma_L\Gamma_{out} = 1$$

2. Ex13.3 FET (CE) @4GHz

$$S_{11}=0.72\angle-116°, S_{12}=0.03\angle57°, S_{21}=2.6\angle76°, S_{22}=0.73\angle-54°$$

(CG) with a 5nH inductor

$$S'_{11}=2.18\angle-35°, S'_{12}=1.26\angle18°, S'_{21}=2.75\angle96°, S'_{22}=0.52\angle155°$$

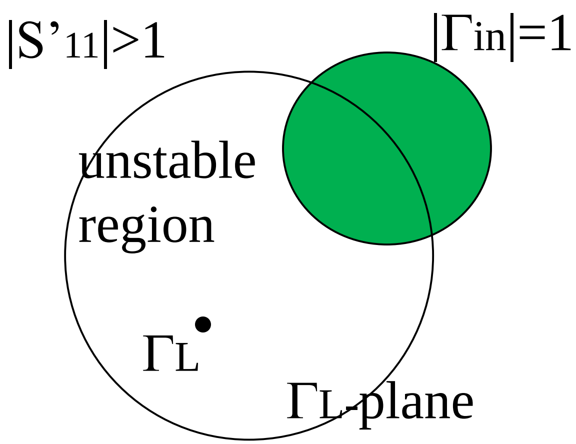
o/p stability circle

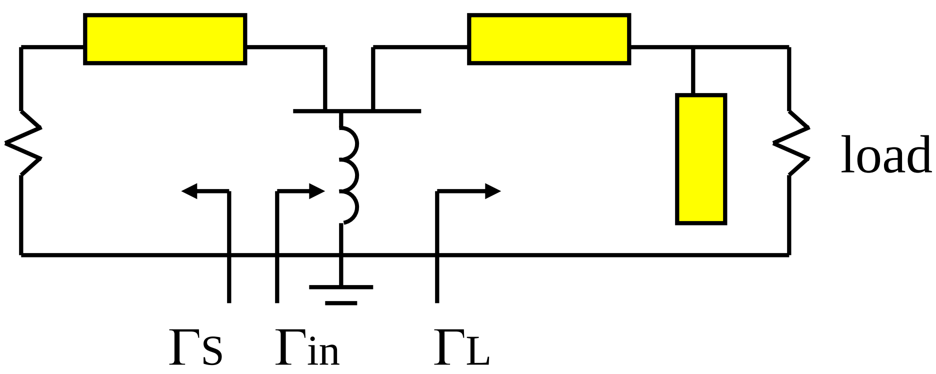
$$C_L=1.08\angle33°, R_L=0.665$$

select

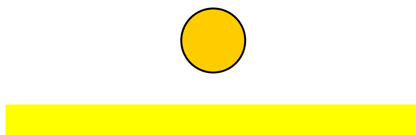
$$\Gamma_L=0.59\angle-104° \rightarrow \text{a large } \Gamma_{in}=3.96\angle-2.4°$$

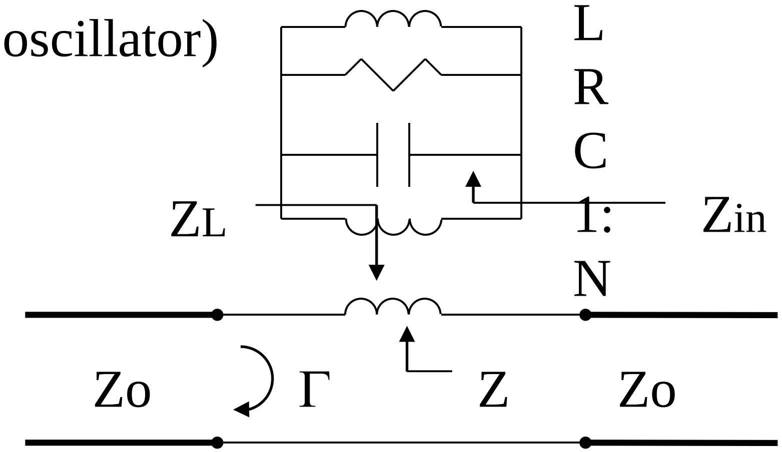
$$Z_{in}=-84-j1.9\Omega \rightarrow Z_S=-\frac{R_{in}}{3}-jX_{in}=28+j1.9\Omega$$





• DRO (dielectric resonator oscillator)





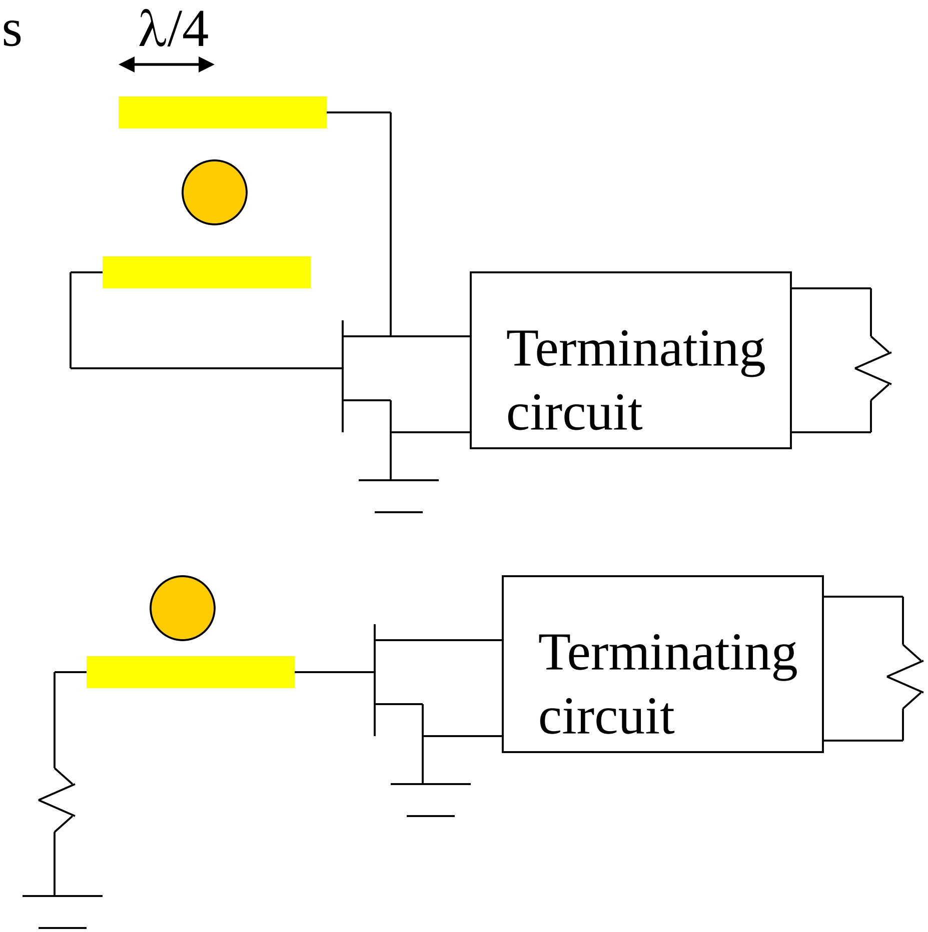
$$Z(w) = N^2 Z_{in}(w) = \frac{N^2 R}{1 + j2Q_U \Delta w / w_o}$$

$$g = \frac{Q_U}{Q_e} = \frac{\dfrac{R}{w_o L}}{\dfrac{R_L / N^2}{w_o L}} = \frac{\dfrac{R}{w_o L}}{\dfrac{2Z_o / N^2}{w_o L}} = \frac{N^2 R}{2Z_o}$$

$$\Gamma = \frac{Z_o + N^2 R - Z_o}{Z_o + N^2 R + Z_o} = \frac{N^2 R}{2Z_o + N^2 R} = \frac{g}{1+g} \rightarrow g = \frac{\Gamma}{1-\Gamma}$$

Discussion

1. DRO examples



2. Ex13.4 BJT @2.4GHz

$$S_{11}=1.8\angle 130°, S_{12}=0.4\angle 45°, S_{21}=3.8\angle 36°, S_{22}=0.7\angle -63°$$

DR Qu=1000

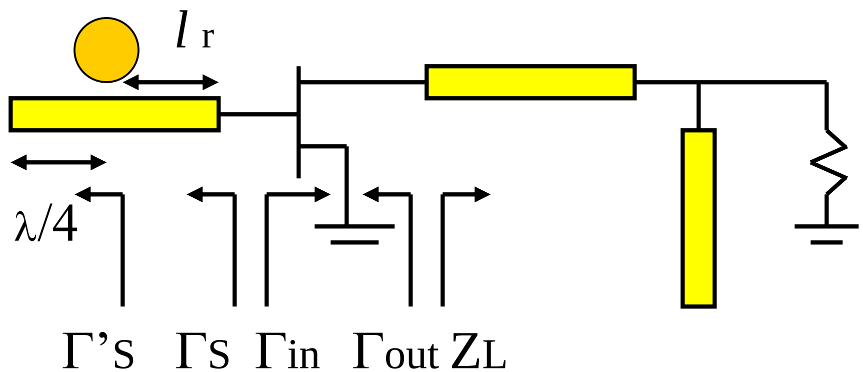
select Γ_S ($\rightarrow S_{11}\Gamma_S \sim 1$) to give a large Γ_{out} $\quad \Gamma_{out}=S_{22}+\frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$

$$\Gamma_S=0.6\angle -130° \rightarrow \text{a large } \Gamma_{out}=10.7\angle 132°, Z_{out}=-43.7+j6.1\Omega$$

$$\rightarrow Z_L=-\frac{R_{out}}{3}-jX_{out}=14.6-j6.1\Omega$$

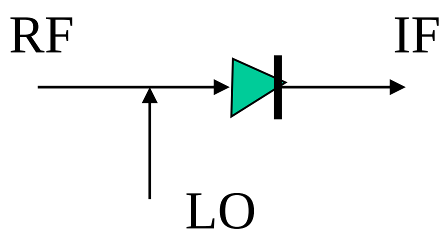
$$\Gamma_S^{'}=\Gamma_S e^{j2\beta l_r}=0.6\angle 180° \rightarrow l_r=0.431\lambda$$

$$Z_S^{'}=12.5\Omega \rightarrow g=\frac{N^2R}{Z_o}=\frac{12.5}{50}=0.25$$

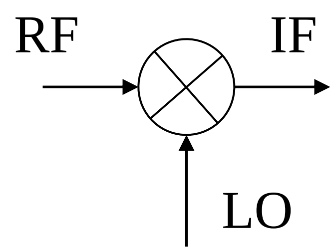


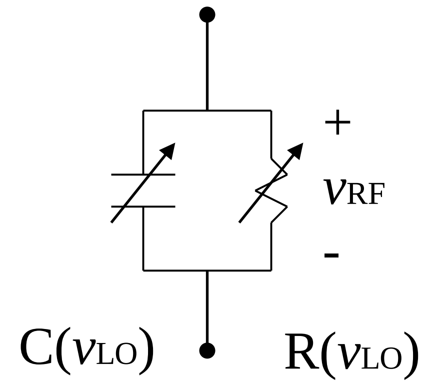
13.5 Mixers

- single-ended mixer



down converter

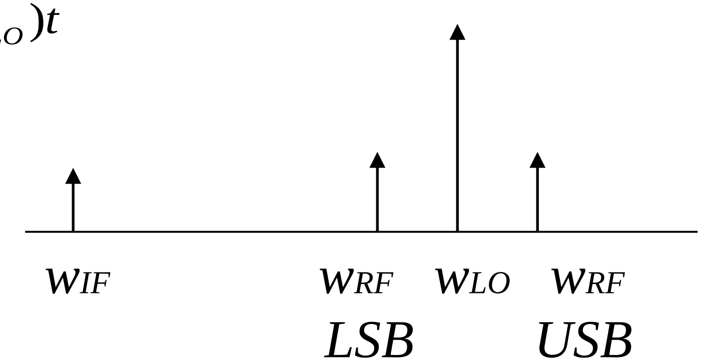




$$i(t) = \frac{(v_{RF} + v_{LO})^2}{2} G'_d = \frac{G'_d}{2} (a \cos w_{rf} t + b \cos w_{LO} t)^2$$

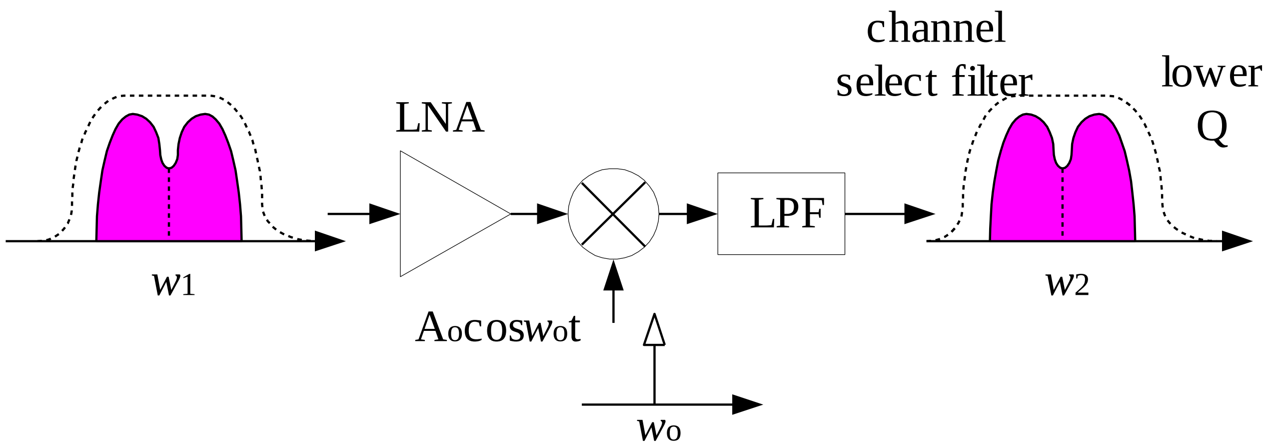
$$v_{IF}(t) \propto \cos(w_{rf} - w_{LO})t$$

linear time-varying components



Discussion

1. heterodyne receiver

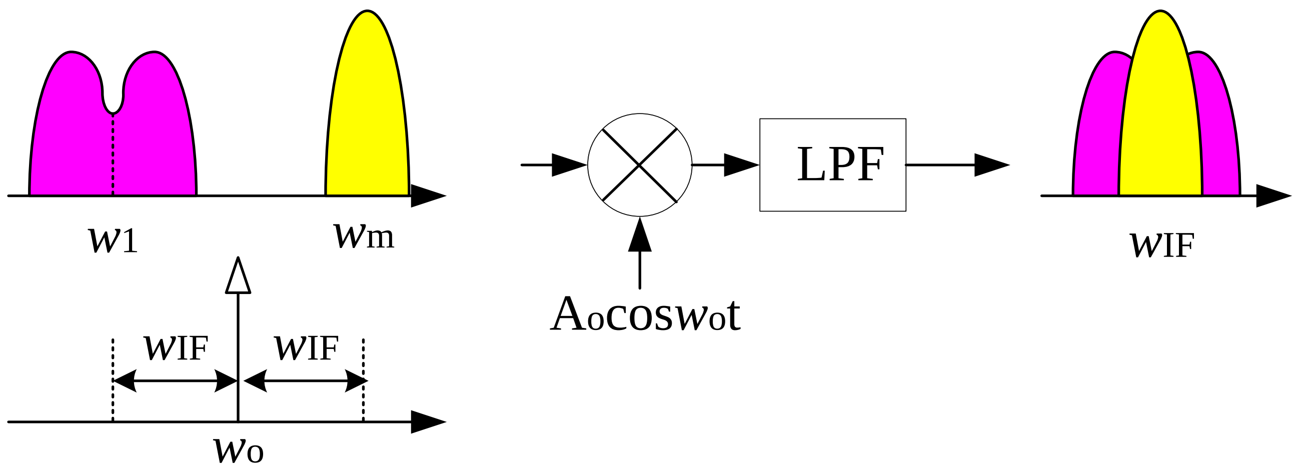


Relax the Q required of the channel-select filter.

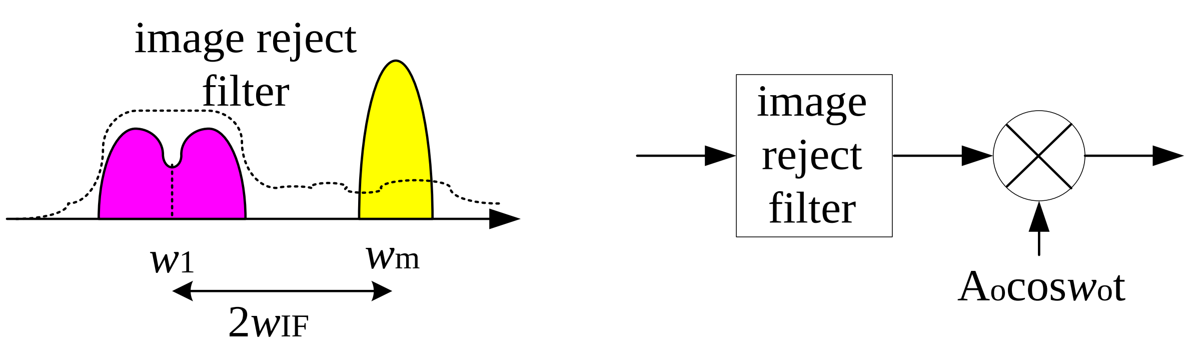
Down-conversion mixer typically has high noise, it's then preceded by a LNA.

2. problem of heterodyne receiver

Image signal degrades the receiver sensitivity.



One can use an image-reject filter, but it introduces losses.



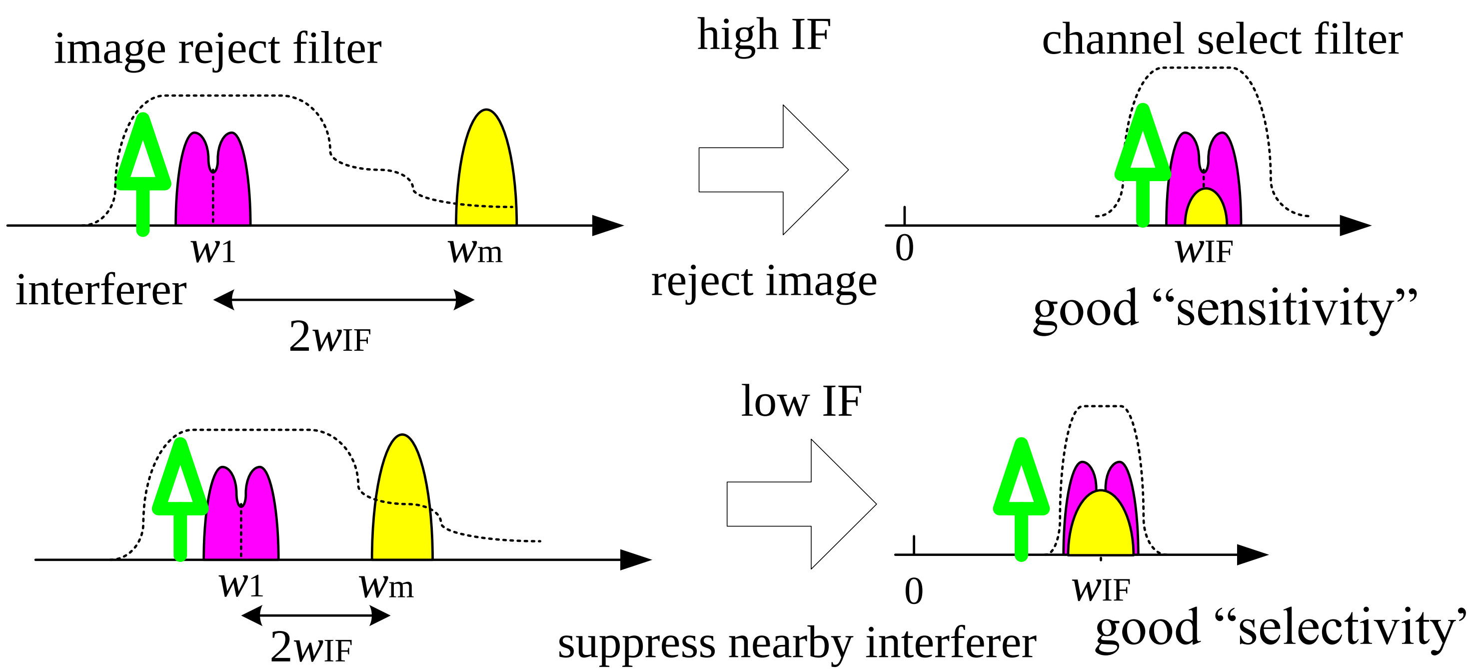
3. choice of IF depends on

the amount of image noise

the spacing between the desired band and the image

the loss of image-reject filter

→ trade-off between sensitivity and selectivity

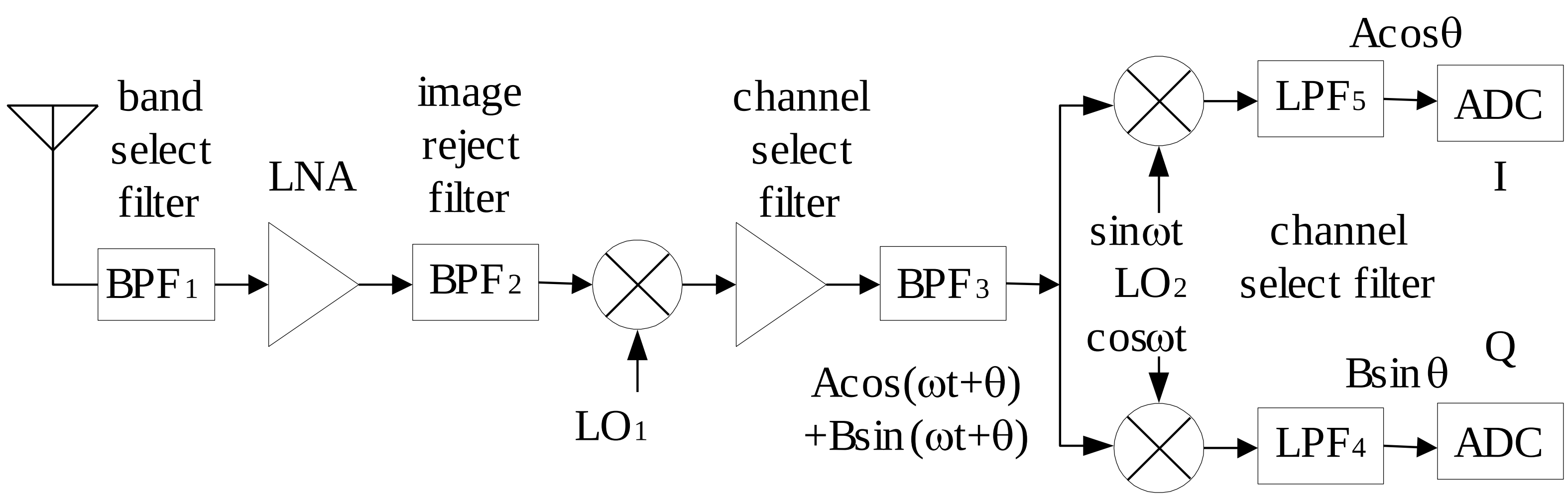


4. dual-IF hetrodyne receiver

Partial channel selection at progressively lower center frequencies

Relax the Q required of each filter

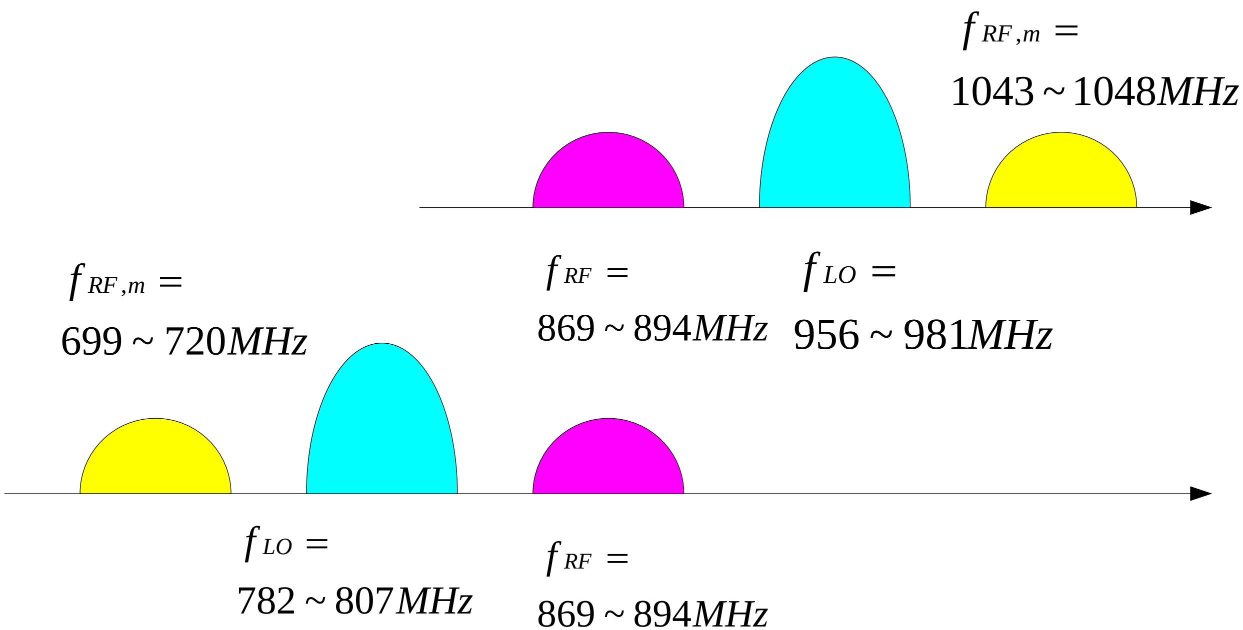
Frequency planning, NF, IP3 and gain calculation are important



5. Ex 13.7 IS-54 digital cell telephone $f_{RF} = 869 \sim 894 GHz,$

$f_{IF} = 87 MHz$

$$f_{LO} = f_{RF} \pm f_{IF} = (869 \sim 894) \pm 87 = \begin{cases} 956 \sim 981 MHz \\ 782 \sim 807 MHz \end{cases}$$



6. mixer characteristics

conversion loss $$L_c(dB) = 10\log\frac{\text{available RF input power}}{\text{IF output power}}$$

DSB noise figure = SSB noise figure / 2

SSB $T = (T_o + T_{SSB})G_r + T_oG_i \rightarrow T_{SSB} = \dfrac{T - T_o(G_r + G_i)}{G_r}$

DSB $T = (T_o + T_{DSB})(G_r + G_i) \rightarrow T_{DSB} = \dfrac{T - T_o(G_r + G_i)}{G_r + G_i}$

LO/RF isolation

7. single-ended diode mixer

relative high noise figure, high conversion loss, high-order nonlinearities, no isolation between LO and RF, large output current at LO frequency

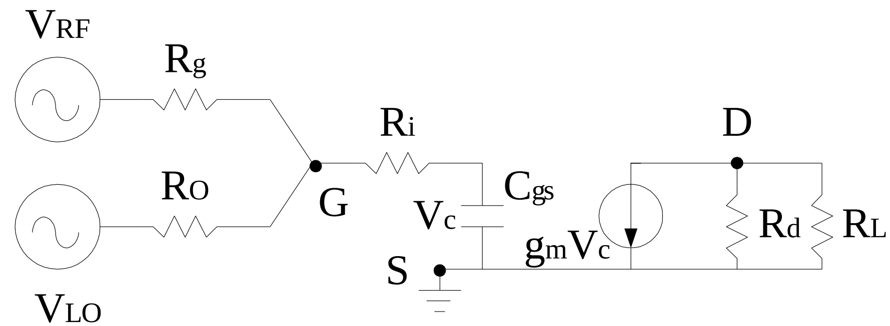
8. single-ended FET mixer

Gate-bias is near the pinch-off region, LO signal then switches FET between high and low transconductance states to give mixing function.

$$v_c^{RF} = V_c^{RF} \cos w_{RF} t$$

$$V_c^{RF} = V_{RF} \frac{1/jw_{RF}C_{gs}}{Z_g + R_i + 1/jw_{RF}C_{gs}}$$

$$= \frac{V_{RF}}{1 + jw_{RF}C_{gs}(R_i + Z_g)}$$



$$g_m(t)v_c^{RF}, g_m(t) = g_o + 2\sum_{n=0}^{\infty} g_n \cos nw_o t \rightarrow g_1 V_c^{RF} \cos w_{IF} t$$

$$V_D^{IF} = -g_1 V_c^{RF} \frac{R_d Z_L}{R_d + Z_L} = \frac{-g_1 V_{RF}}{1 + jw_{RF}C_{gs}(R_i + Z_g)} \frac{R_d Z_L}{R_d + Z_L}$$

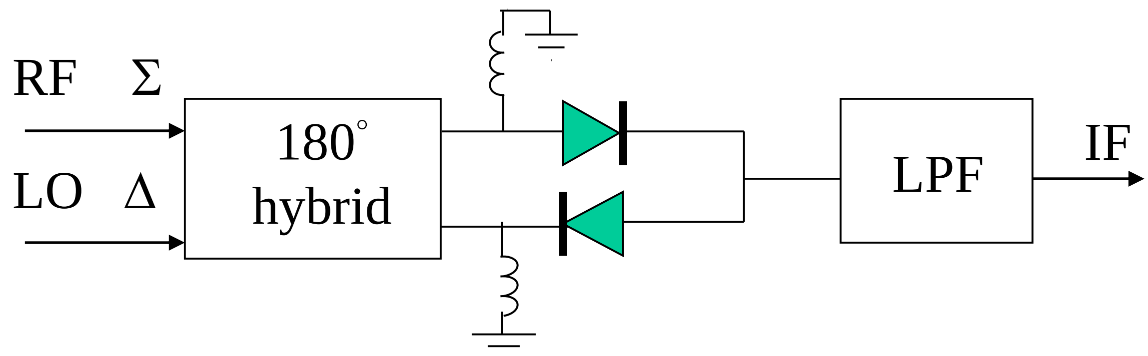
$$G_c = \frac{P_{IF,ava}}{P_{RF,ava}} = \frac{\left|V_D^{IF}\right|^2 R_L / \left|Z_L\right|^2}{\left|V_{RF}\right|^2 / 4R_g} = \frac{4R_g R_L}{\left|Z_L\right|^2}\left|\frac{V_D^{IF}}{V_{RF}}\right|^2 \underset{R_L = R_d}{\overset{R_g = R_i}{\Longrightarrow}} G_c = \frac{g_1^2 R_d}{4w_{RF}^2 C_{gs}^2 R_i}$$

9. Ex13.8 A single-ended FET mixer $R_d = 300\Omega, R_i = 10\Omega, C_{gs} = 0.3pF$

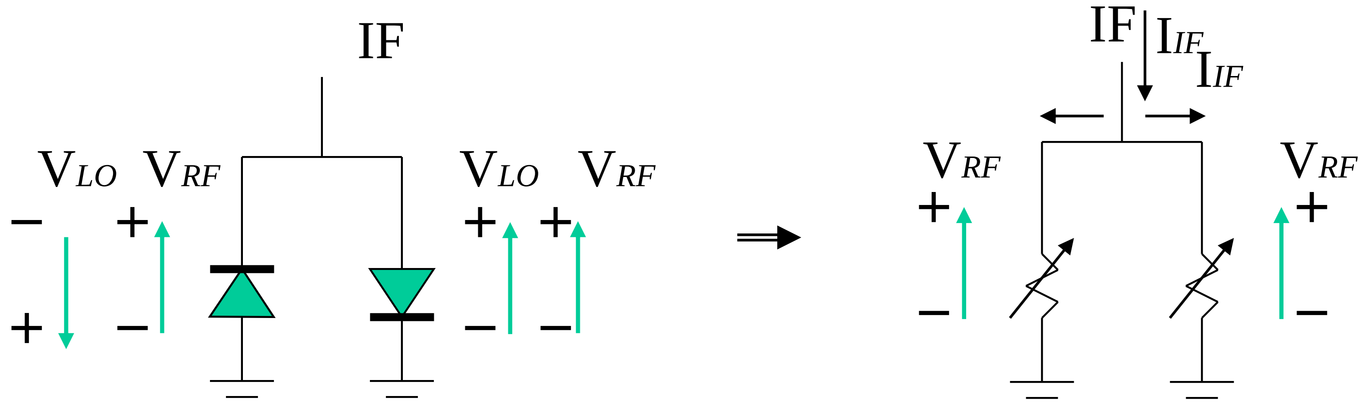
$$g_1 = 10mS \rightarrow G_c = \frac{g_1^2 R_d}{4w_{RF}^2 C_{gs}^2 R_i} = 36.6 = 15.6dB$$

10. single-balanced mixer

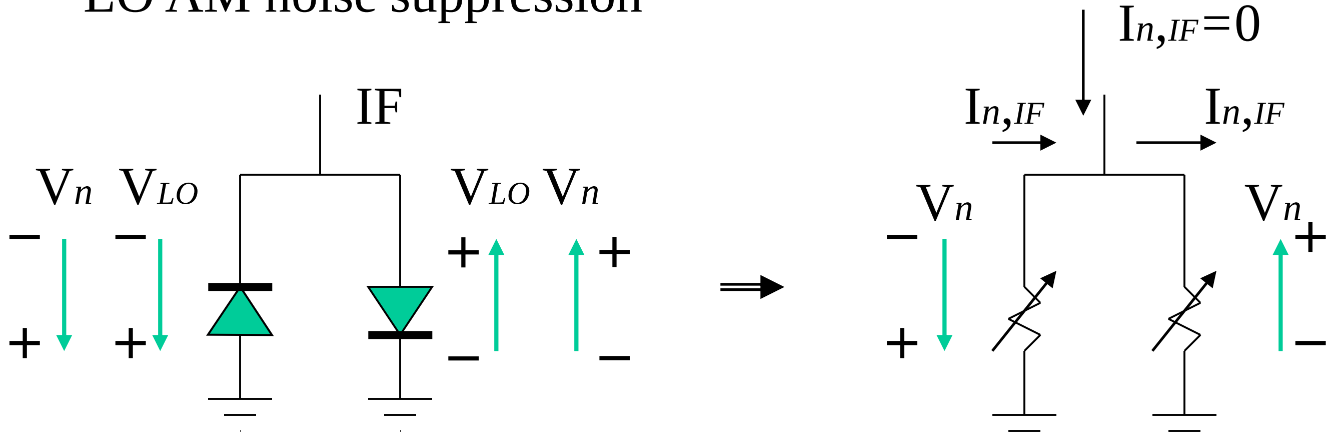
good
RF/LO
isolation



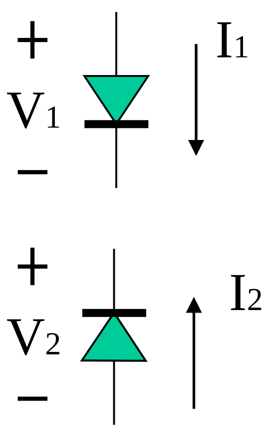
phasor representation



LO AM noise suppression



LO even-harmonic suppression

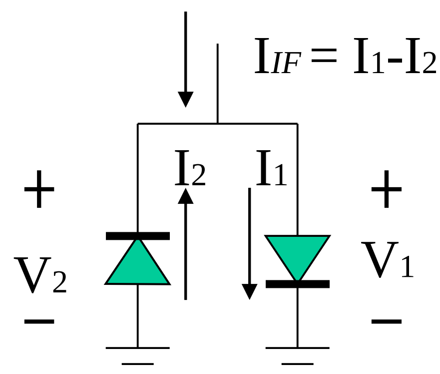


$$I_1 = aV_1 + bV_1^2 + cV_1^3 + dV_1^4$$

$$I_2 = -aV_2 + bV_2^2 - cV_2^3 + dV_2^4$$

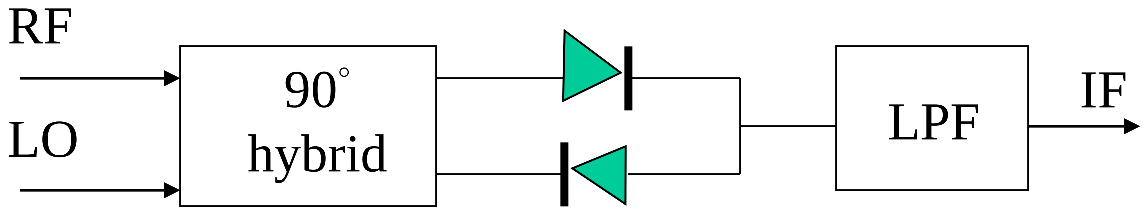
$$v_1 = -v_{LO}\cos w_{LO}t + v_{RF}\cos w_{RF}t$$

$$v_2 = v_{LO}\cos w_{LO}t + v_{RF}\cos w_{RF}t$$

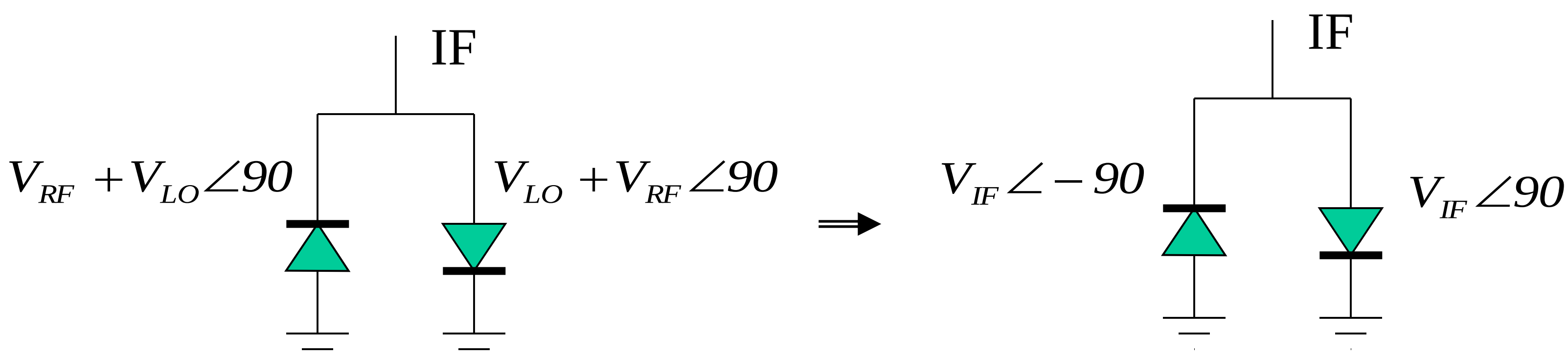


good
RF VSWR

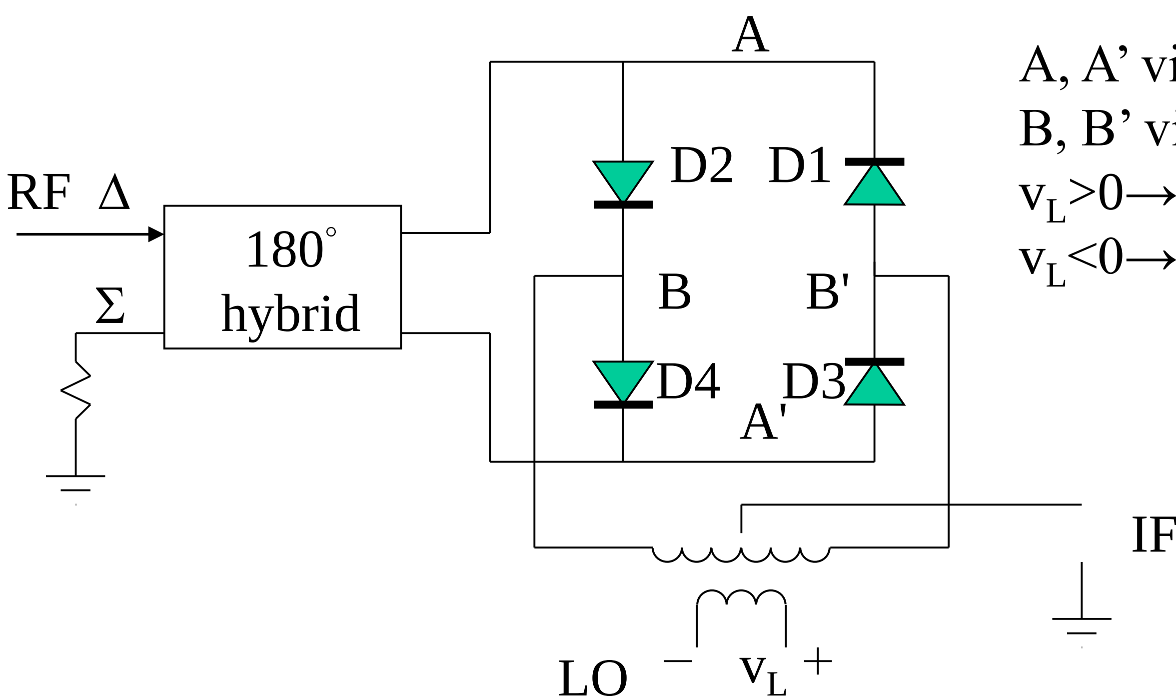
poor RF/LO
isolation



$$\frac{-1}{\sqrt{2}}\begin{bmatrix}0 & j & 1 & 0\\ j & 0 & 0 & 1\\ 1 & 0 & 0 & j\\ 0 & 1 & j & 0\end{bmatrix}\begin{bmatrix}1\\0\\0\\0\end{bmatrix}=\frac{-1}{\sqrt{2}}\begin{bmatrix}0\\j\\1\\0\end{bmatrix},\quad \begin{bmatrix}0 & j & 1 & 0\\ j & 0 & 0 & 1\\ 1 & 0 & 0 & j\\ 0 & 1 & j & 0\end{bmatrix}\begin{bmatrix}0\\j\Gamma\\\Gamma\\0\end{bmatrix}=\begin{bmatrix}0\\0\\0\\j2\Gamma\end{bmatrix}$$



11. double-balanced mixer



A, A' virtual ground for LO

B, B' virtual ground for RF

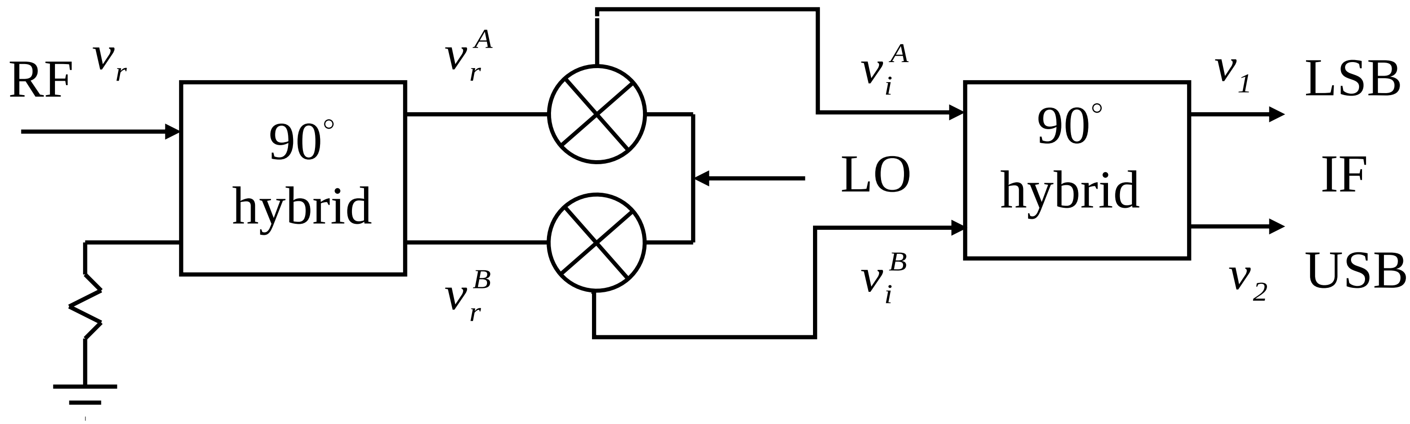
$v_L > 0 \rightarrow$ D1, D2 on

$v_L < 0 \rightarrow$ D3, D4 on

good RF/LO isolation

LO and RF even-harmonics suppressed

12. image-reject mixer



$$v_r = USB + LSB \quad USB = v_u\angle(w_o + w_i)t \quad LSB = v_L\angle(w_o - w_i)t$$

$$v_r^A = USB\angle(w_o + w_i)t - 90 + LSB\angle(w_o - w_i)t - 90$$

$$v_r^B = USB\angle(w_o + w_i)t + LSB\angle(w_o - w_i)t$$

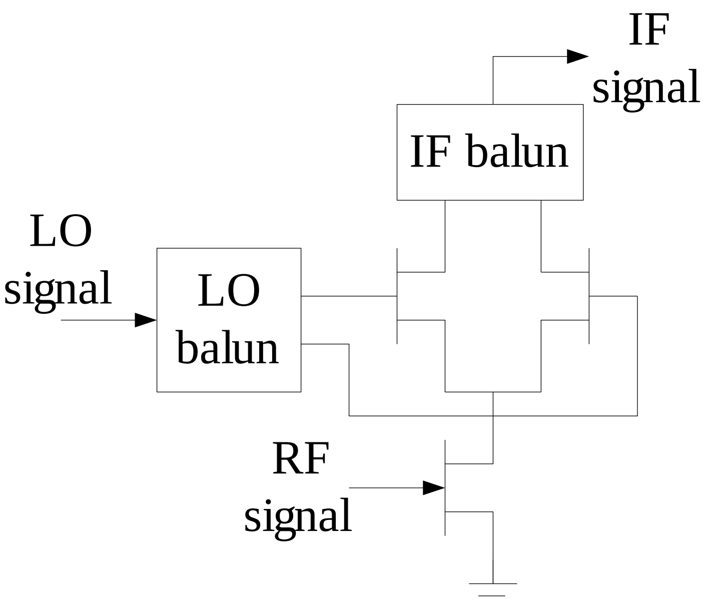
$$v_i^A = USB\angle w_i t - 90 + LSB\angle - w_i t - 90 = USB\angle w_i t - 90 + LSB\angle w_i t + 90$$

$$v_i^B = USB\angle w_i t + LSB\angle - w_i t = USB\angle w_i t + LSB\angle w_i t$$

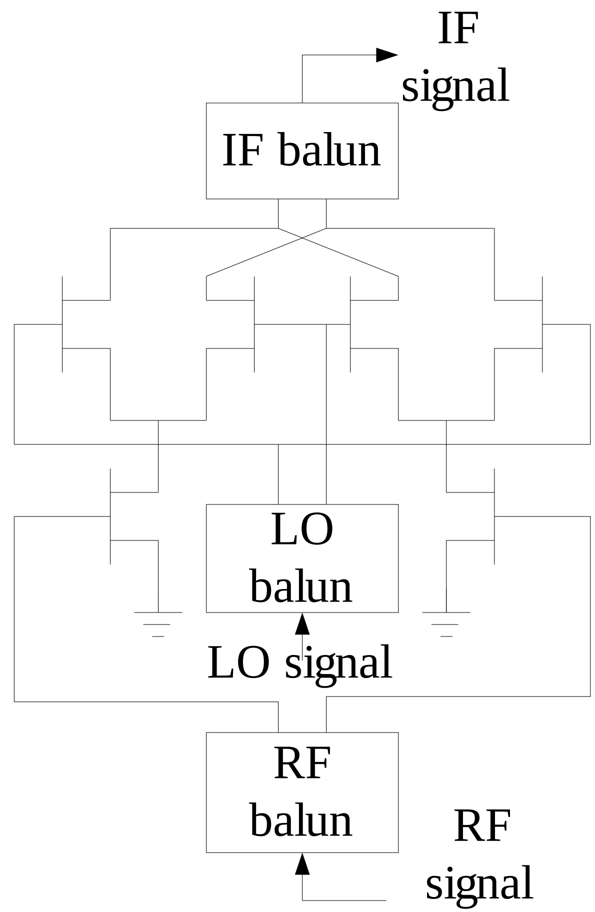
$$v_1 = v_i^A\angle - 90 + v_i^B = 2LSB\angle w_i t$$

$$v_2 = v_i^A + v_i^B\angle - 90 = 2USB\angle w_i t$$

13. differential mixer



Gilbert cell mixer



ADS examples: Ch13_prj