Chapter 12 Oscillators and mixers

12.1 RF oscillators
- CE BJT oscillator, CG FET oscillator

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

12.3 Oscillator phase noise

12.4 Frequency multipliers
- transistor multiplier

12.5 Overview of microwave sources

12.6 Mixers
- single-ended mixer, balanced mixer, FET mixers

12.1 RF oscillators

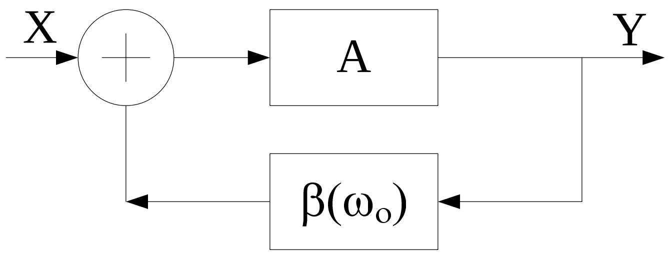
- Feedback for oscillation

  noise $\rightarrow$ trigger an unstable circuit

  $\rightarrow$ feedback the output signal and then the active device amplifies the signal near w_o

  $\rightarrow$ nonlinear active device at steady state

  $\rightarrow$ oscillation at w_o with certain output power



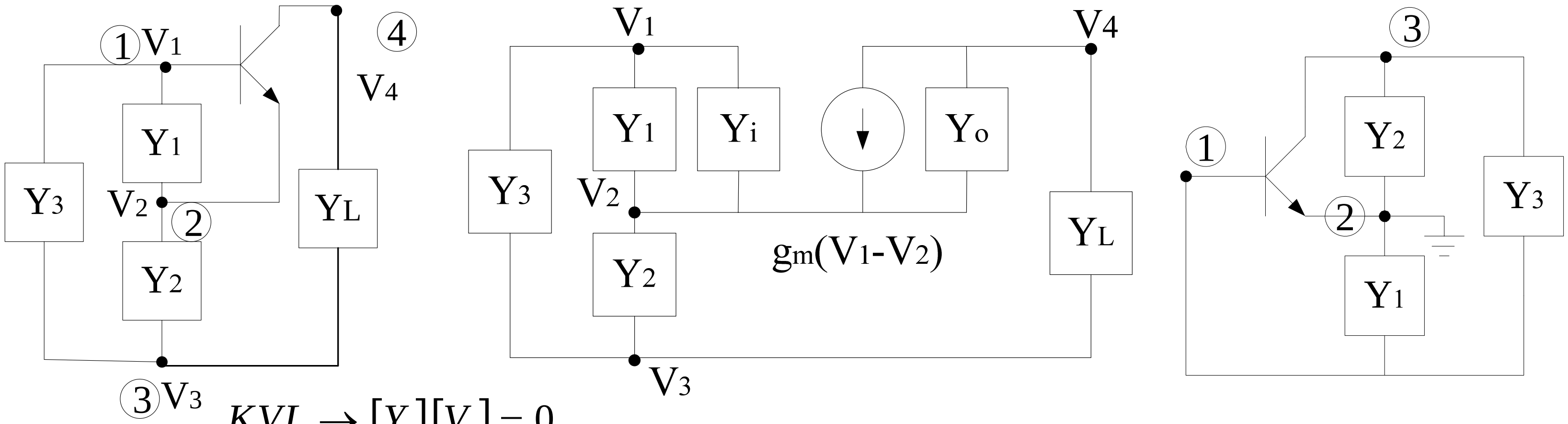
$$Y = A(X + \beta Y) \rightarrow \text{closed-loop gain } \frac{Y}{X} = \frac{A}{1 - \beta(w_o)A}$$

A: forward path gain, βA: loop gain

βA=1: oscillation condition

<u>Discussion</u>

1. Hartley and Colpitts (CE) oscillators from feedback point of view



$$KVL \rightarrow [Y][V] = 0$$

$$\begin{bmatrix} Y_1+Y_3+Y_i & -(Y_1+Y_i) & -Y_3 & 0 \\ -(Y_1+Y_i+g_m) & Y_1+Y_2+Y_i+g_m+Y_o & -Y_2 & -Y_o \\ -Y_3 & -Y_2 & Y_2+Y_3+Y_L & -Y_L \\ g_m & -(g_m+Y_o) & -Y_L & Y_o+Y_L \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = 0$$

if $V_2 = 0(CE), V_3 = V_4, Y_o = 0$

$$\rightarrow \begin{cases} (Y_1+Y_3+Y_i)V_1 - Y_3V_3 = 0 \\ -Y_3V_1 + (Y_2+Y_3)V_3 = 0 \\ g_mV_1 + Y_oV_3 = 0 \end{cases} \rightarrow \begin{bmatrix} Y_1+Y_3+Y_i & -Y_3 \\ g_m - Y_3 & Y_2+Y_3 \end{bmatrix} \begin{bmatrix} V_1 \\ V_3 \end{bmatrix} = 0$$

$$\det\begin{vmatrix} Y_1+Y_3+Y_i & -Y_3 \\ g_m-Y_3 & Y_2+Y_3 \end{vmatrix} = (Y_2+Y_3)(Y_1+Y_3+Y_i)+Y_3(g_m-Y_3)=0$$

$$\text{if } \begin{matrix} Y_i=G_i \\ Y_1=jB_1, Y_2=jB_2, Y_3=jB_3 \end{matrix} \rightarrow \begin{cases} B_1B_2+B_2B_3+B_1B_3=0 \rightarrow \text{one C, two L or vice versa. (1)} \\ (g_m+G_i)B_3+B_2G_i=0 \rightarrow \text{one C, one L......................(2)} \end{cases}$$

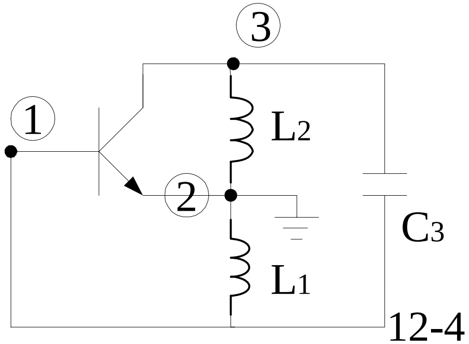
$$(2)\rightarrow (1+\frac{g_m}{G_i})B_3+B_2=0 \rightarrow (1+h_{fe})X_2=-X_3,\ h_{fe}=\frac{g_m}{G_i}$$

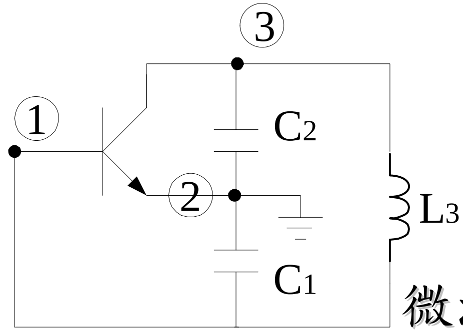
$$(1)\rightarrow X_1+X_2+X_3=0 \rightarrow X_1+X_2-(1+h_{fe})X_2=0 \rightarrow X_1=h_{fe}X_2 : \text{osc. cond.}$$

$\rightarrow X_1$ and X_2 of the same kind, X_3 be the different kind

$$X_1+X_2+X_3=0 \rightarrow \begin{cases} wL_1+wL_2-\dfrac{1}{wC_3}=0 \rightarrow w_o=\sqrt{\dfrac{1}{C_3(L_1+L_2)}} \\ \dfrac{1}{wC_1}+\dfrac{1}{wC_2}-wL_3=0 \rightarrow w_o=\sqrt{\dfrac{1}{L_3}\dfrac{C_1+C_2}{C_1C_2}} \end{cases}$$

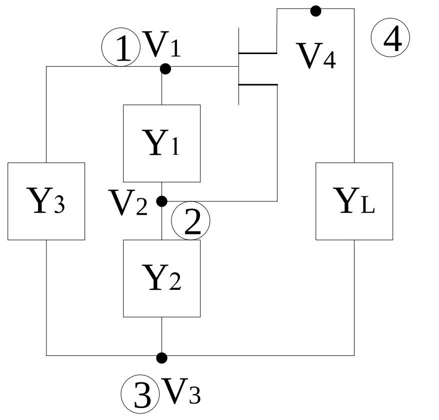
Hartley oscillator

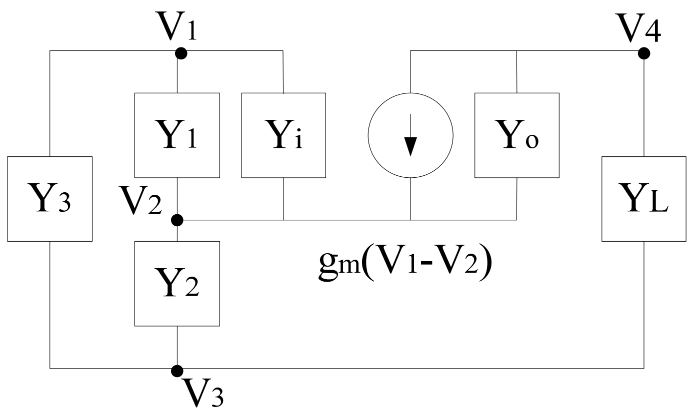




Colpitts oscillator

2. Hartley and Colpitts (CG) oscillators from feedback point of view





$$KVL \rightarrow [Y][V] = 0$$

$$\begin{bmatrix} Y_1 + Y_3 + Y_i & -(Y_1 + Y_i) & -Y_3 & 0 \\ -(Y_1 + Y_i + g_m) & Y_1 + Y_2 + Y_i + g_m + Y_o & -Y_2 & -Y_o \\ -Y_3 & -Y_2 & Y_2 + Y_3 + Y_L & -Y_L \\ g_m & -(g_m + Y_o) & -Y_L & Y_o + Y_L \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} = 0$$

if $V_1 = 0(CG), V_3 = V_4, Y_i = 0$

$$\rightarrow \begin{cases} (Y_1 + Y_2 + g_m + Y_o)V_2 - Y_2 V_3 = 0 \\ -Y_2 V_2 + (Y_2 + Y_3)V_3 = 0 \\ -(g_m + Y_o)V_2 + Y_o V_3 = 0 \end{cases} \rightarrow \begin{bmatrix} Y_1 + Y_2 + g_m + Y_o & -(Y_3 + Y_o) \\ -(g_m + Y_o + Y_2) & Y_2 + Y_3 + Y_o \end{bmatrix} \begin{bmatrix} V_2 \\ V_3 \end{bmatrix} = 0$$

$$\det\begin{vmatrix} Y_1+Y_2+g_m+Y_o & -(Y_3+Y_o) \\ -(g_m+Y_o+Y_2) & Y_2+Y_3+Y_o \end{vmatrix}=0$$

if $\begin{matrix} Y_o=G_o \\ Y_1=jB_1, Y_2=jB_2, Y_3=jB_3 \end{matrix} \rightarrow \begin{cases} B_1B_2+B_2B_3+B_1B_3=0 \rightarrow \text{one C, two L or vice versa. (1)} \\ (g_m+G_o)B_3+B_1G_o=0 \rightarrow \text{one C, one L.......................(2)} \end{cases}$

$$(2) \rightarrow (1+\frac{g_m}{G_o})B_3+B_1=0 \rightarrow (1+\frac{g_m}{G_o})X_1=-X_3$$

$$(1) \rightarrow X_1+X_2+X_3=0 \rightarrow X_1+X_2-(1+\frac{g_m}{G_o})X_1=0 \rightarrow X_2=\frac{g_m}{G_o}X_1\text{: osc. cond.}$$

$\rightarrow X_1$ and X_2 of the same kind, X_3 be the different kind

$$X_1+X_2+X_3=0 \rightarrow \begin{cases} wL_1+wL_2-\frac{1}{wC_3}=0 \rightarrow w_o=\sqrt{\frac{1}{C_3(L_1+L_2)}}\text{ : Hartley} \\ \frac{1}{wC_1}+\frac{1}{wC_2}-wL_3=0 \rightarrow w_o=\sqrt{\frac{1}{L_3}\frac{C_1+C_2}{C_1C_2}}\text{ : Colpitts} \end{cases}$$

3. Ex.12.1 Design a 50MHz Colpitts oscillator using CE transistor with $\beta = g_m/G_i = 30$, $R_i = 1/G_i = 1200\Omega$, and $L_3 = 0.1uH$, Q=100, What is the minimum Q of the inductor for oscillation

For a lossy inductor $Z_3 = R + jwL_3$

$$\det\begin{vmatrix} Y_1 + Y_3 + Y_i & -Y_3 \\ g_m - Y_3 & Y_2 + Y_3 \end{vmatrix} = (Y_2 + Y_3)(Y_1 + Y_3 + Y_i) + Y_3(g_m - Y_3) = 0$$

$$\rightarrow Y_1Y_2 + Y_2Y_3 + Y_2Y_i + Y_1Y_3 + Y_3Y_i + g_mY_3 = 0$$

if $Y_i = G_i, Y_1 = jwC_1, Y_2 = jwC_2 \rightarrow$

$$w_o = \sqrt{\frac{1}{L_3}\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{G_iR}{C_1}\right)} = \sqrt{\frac{1}{L_3}\left(\frac{1}{C_1'} + \frac{1}{C_2}\right)}, C_1' = \frac{C_1}{1 + RG_i}$$

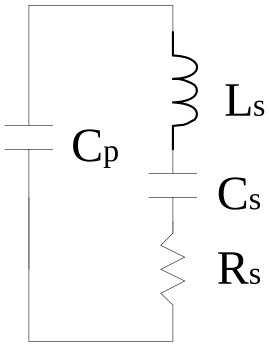
$$\frac{R}{G_i} = \frac{1 + g_m/G_i}{w_o^2C_1C_2} - \frac{L_3}{C_1}$$

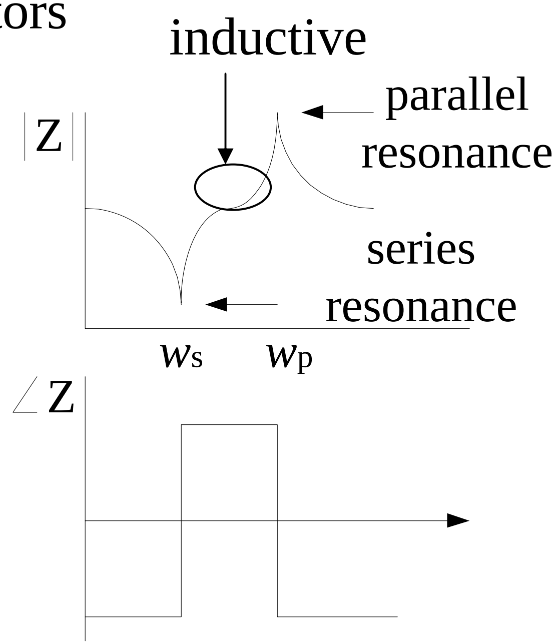
$$\frac{C_1'C_2}{C_1' + C_2} = \frac{1}{w_o^2L_3} = 100\,pF \rightarrow C_1' = C_2 = 200\,pF$$

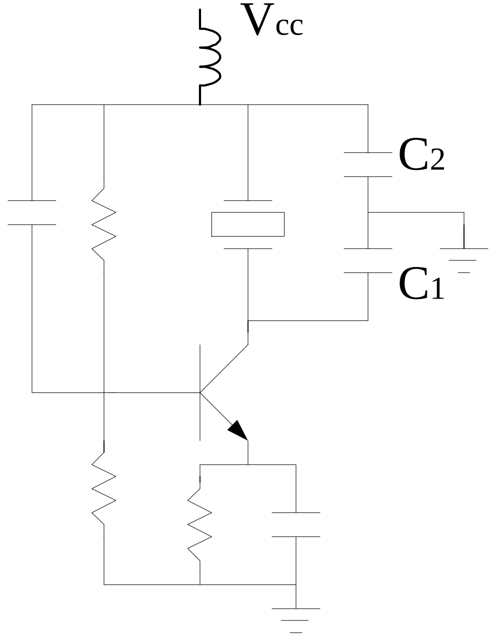
for inductor $Q = \dfrac{wL_3}{R} \rightarrow R = \dfrac{w_oL_3}{Q} = 0.31\Omega, C_1 = C_1'(1 + RG_i) \approx 200\,pF$

from osc. cond $\dfrac{R}{G_i} = \dfrac{1 + g_m/G_i}{w_o^2C_1C_2} - \dfrac{L_3}{C_1} \rightarrow R_{\max} = 6.13\Omega \rightarrow Q_{\min} = 5.1$

4. Crystal oscillators







Pierce oscillator

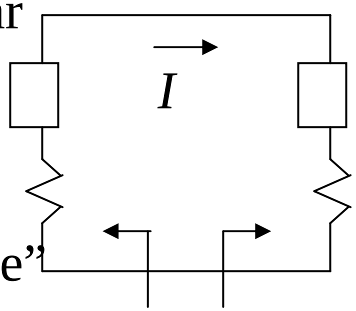
$$w_s = \frac{1}{\sqrt{L_s C_s}}, w_p = w_s \sqrt{1 + \frac{C_s}{C_p}}$$

$$\text{pull figure}: \Delta w = w_p - w_s = w_s \left(\sqrt{1 + \frac{C_s}{C_p}} - 1\right)$$

$$\approx \frac{C_s}{2C_p} w_s \text{ : inductive element}$$

12.2 Microwave oscillators

• one-port negative resistance oscillators



@ steady state

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

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

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 $\rightarrow$ for a stable oscillation $\delta\alpha < 0$

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

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

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

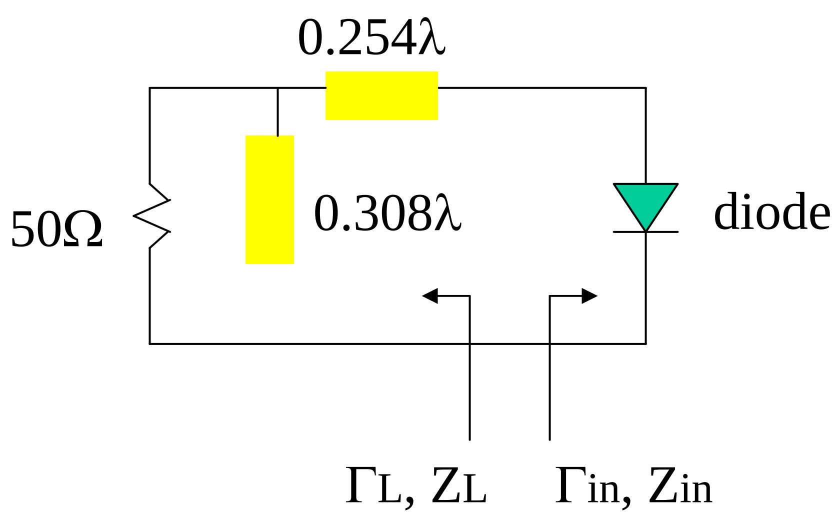
$$\Rightarrow \frac{\partial X_T}{\partial w} = \frac{\partial(X_L + X_{in})}{\partial w} >> 0$$

4. oscillator design consideration

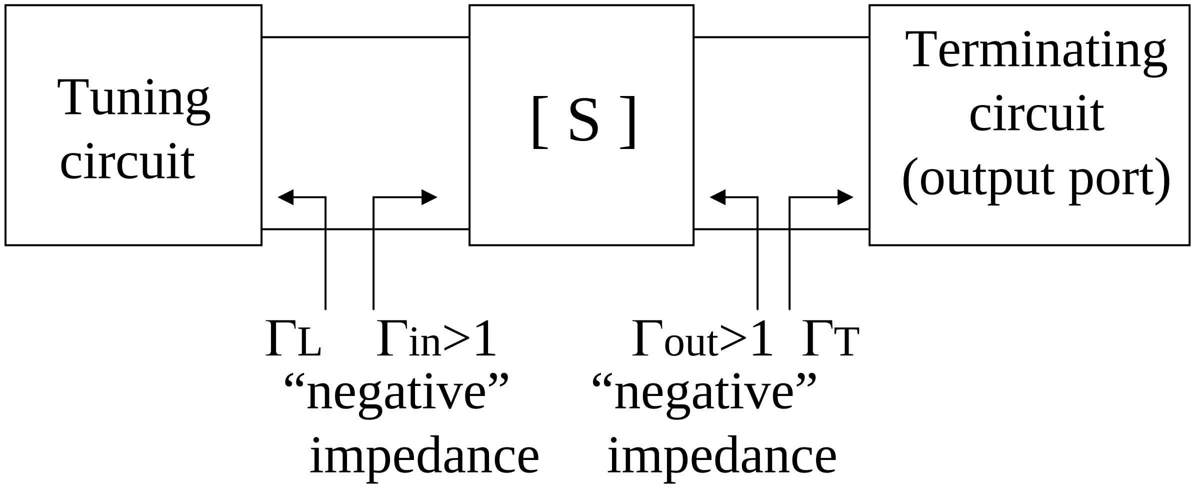
selection of device operation point for stable oscillation and good o/p power, large signal performance, phase noise, frequency pulling,…

5. Ex.12.2 a diode with $\Gamma_{in}=1.25\angle 40^{\circ}$ @6GHz

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



- transistor oscillator



to start oscillation, select $R_L = -R_{in}/3$, $X_L = -X_{in}$

@ steady state $\Gamma_{in}\Gamma_L = 1 \rightarrow \Gamma_{out}\Gamma_T = 1$

<u>Discussion</u>

1. at steady state

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

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

2. Ex12.3 FET (CE) @4GHz

$$S_{11} = 0.72\angle -116°, S_{12} = 0.03\angle 57°, S_{21} = 2.6\angle 76°, S_{22} = 0.73\angle -54°$$

(CG) with a 5nH inductor

$$S'_{11} = 2.18\angle -35°, S'_{12} = 1.26\angle 18°, S'_{21} = 2.75\angle 96°, S'_{22} = 0.52\angle 155°$$

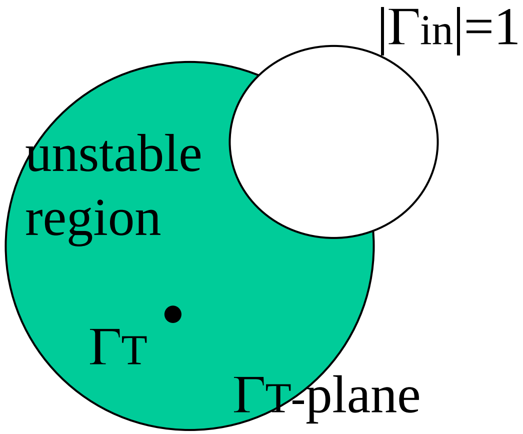
o/p stability circle

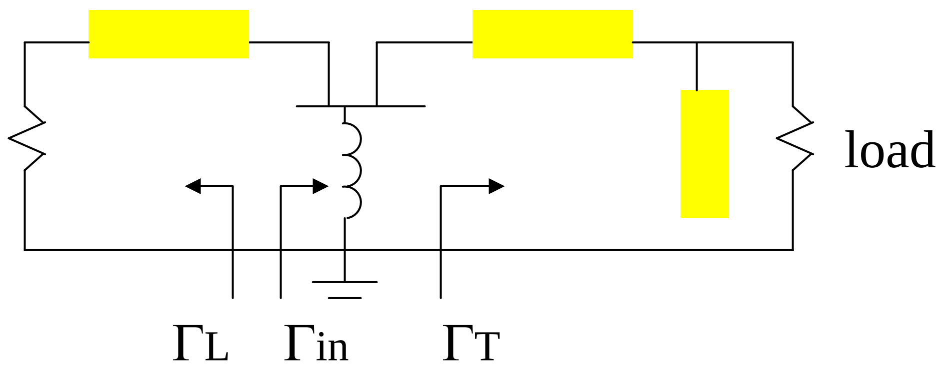
$$C_T = 1.08\angle 33°, R_T = 0.665$$

select

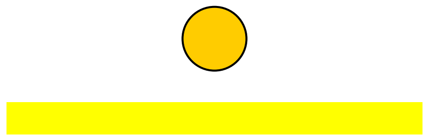
$$\Gamma_T = 0.59\angle -104° \rightarrow \text{large } \Gamma_{in} = 3.96\angle -2.4°$$

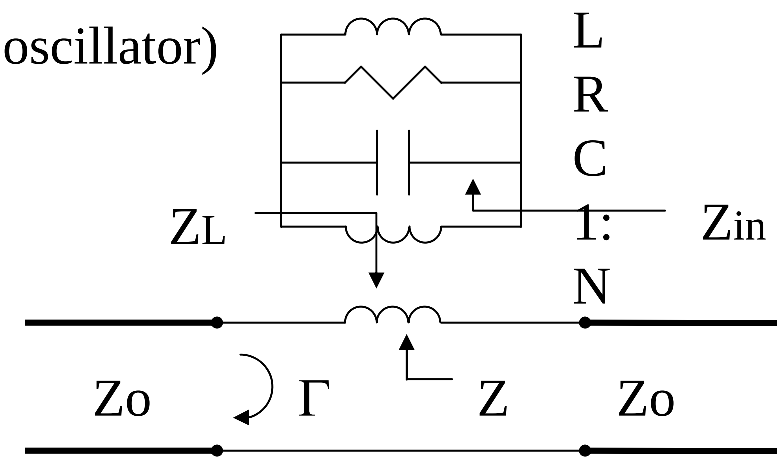
$$Z_{in} = -84 - j1.9\Omega \rightarrow Z_L = -\frac{R_{in}}{3} - jX_{in} = 28 + j1.9\Omega$$





• DRO (dielectric resonator oscillator)





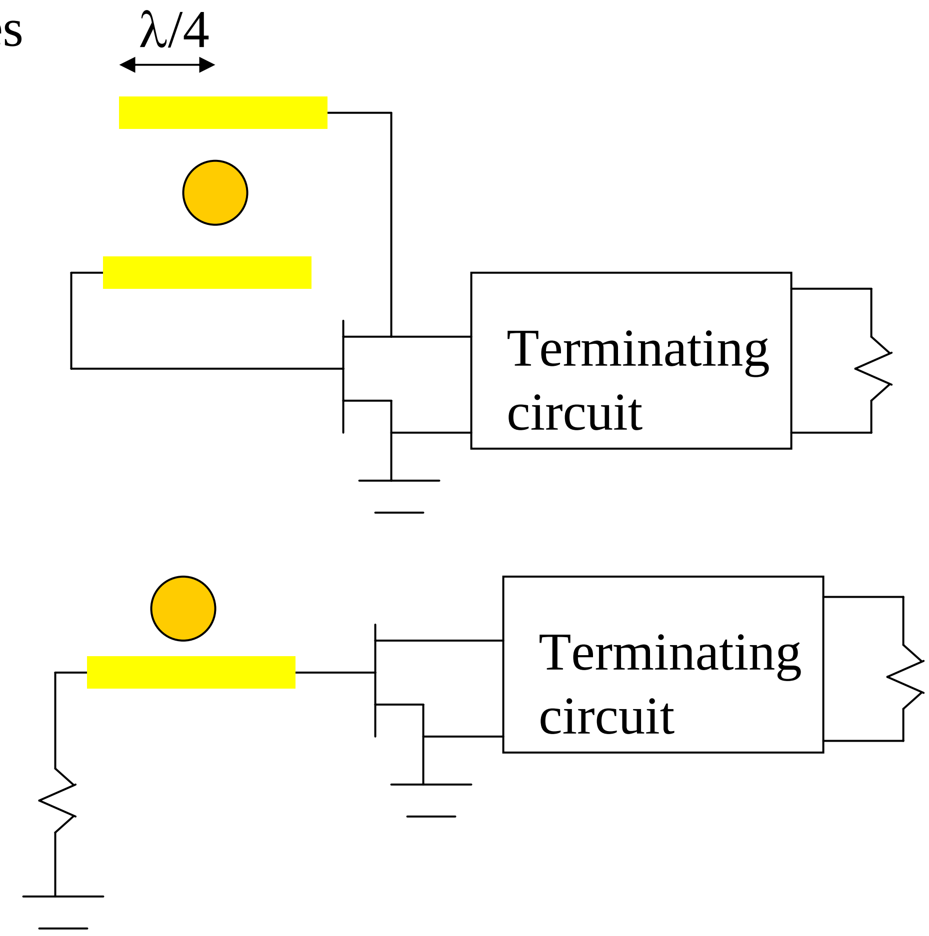
$$Z(w) = N^2 Z_{in}(w) = \frac{N^2 R}{1 + j2Q\Delta w / w_o}$$

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

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

Discussion

1. DRO examples



2. Ex12.4 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

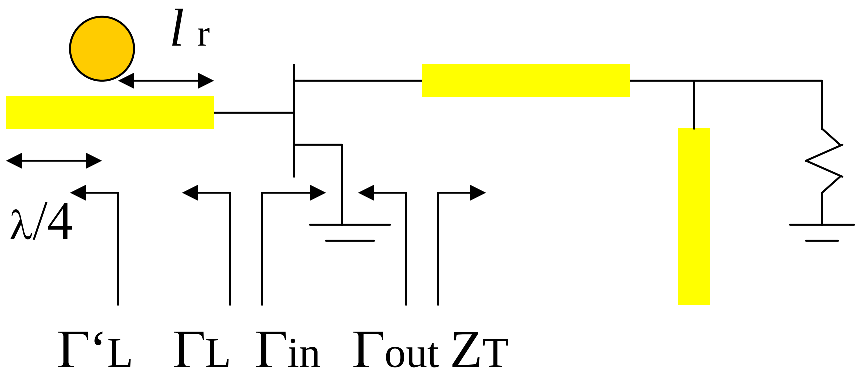
select Γ_L ($\rightarrow S_{11}\Gamma_L$~1) to give a large Γ_{out} $\quad \Gamma_{out} = S_{22} + \dfrac{S_{12}S_{21}\Gamma_L}{1 - S_{11}\Gamma_L}$

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

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

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

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



12.3 Oscillator phase noise

Discussion

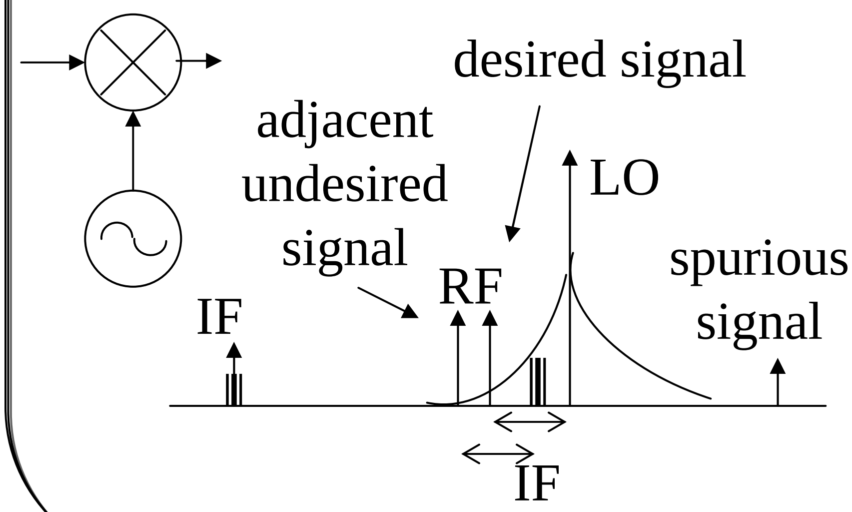
1. oscillator noises

spurious signals: spikes due to harmonics and intermodulation products

phase noise: a broad continuous distribution localized about the oscillation signal due to thermal noise

: dB relative to the carrier power per Hertz of bandwidth at a particular offset (dBc/Hz @ Hz offset)

2. LO phase noise effect: selectivity and snr



maximum allowable phase noise (*dBc/Hz*)

to achieve an adjacent channel rejection of *S*dB

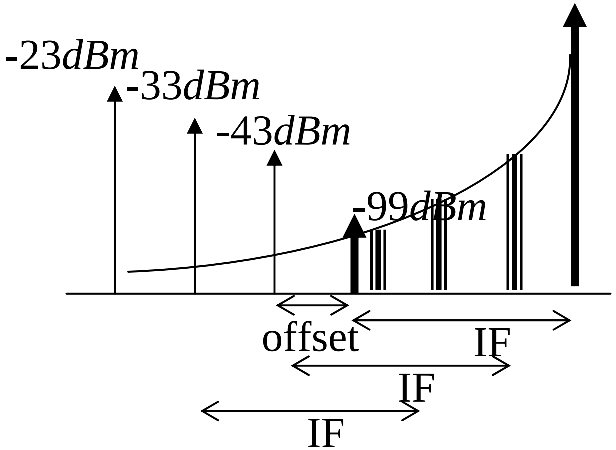
= C(desired signal level, *dBm*)

-S(adjacent channel rejection, *dB*)

-I(undesired signal level, *dBm*)

-10logB

3. Ex.12.5 GSM cellular standard requires 9dB rejection of interfering signals for a carrier of –99dBm. The channel bandwidth is 200kHz. Determine the required phase noise of LO at these carrier frequency offset.



maximum allowable phase noise (*dBc/Hz*)

to achieve an adjacent channel rejection of *S*dB

= C(desired signal level, *dBm*)

-S(adjacent channel rejection, *dB*)

-I(undesired signal level, *dBm*)

-10logB

=-99*dBm*-9*dB*-I(*dBm*)-53*dB*

interfering signal level (dBm)	offset frequency (MHz)	maximum allowable phase noise (dBc/Hz)
-23	3.0	-138
-33	1.6	-128
-43	0.6	-118

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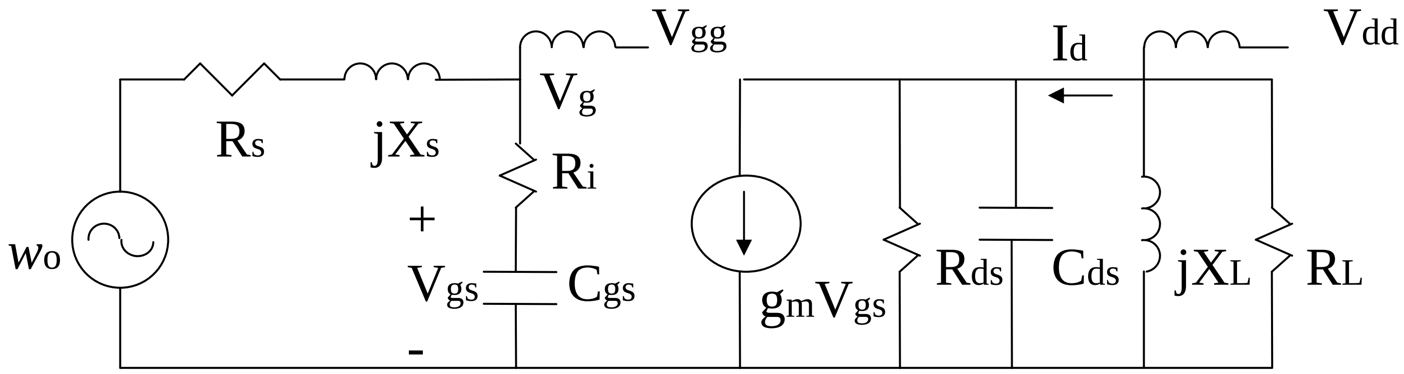
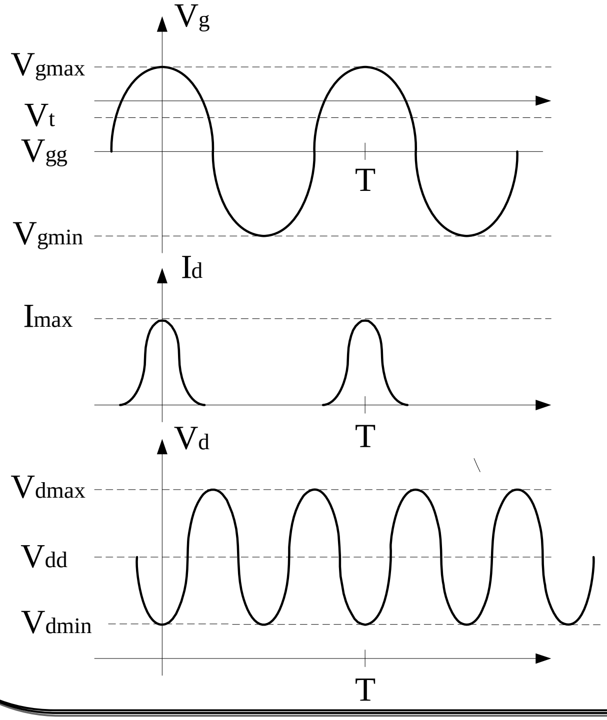
12.4 Frequency multipliers

Discussion

1. Reactive diode multiplier uses a varactor or a step-recovery diode to generate harmonics. The unwanted harmonics are usually terminated with short circuits. The desired harmonic is terminated with proper load. Theoretically it is then possible for 100% conversion efficiency.
2. Resistive diode multiplier uses a forward-biased Schottky-barrier detector diode to generate harmonics. Theoretically, the conversion efficiency then drops as the square of the multiplication factor.
3. Transistor multiplier uses the nonlinear characteristics of g_m, R_{ds}, C_{gs}, and C_{ds} with proper biases, input power and load to give proper current conduction duration and waveform to generate the desired harmonics.

4. Operation principle of transistor multiplier

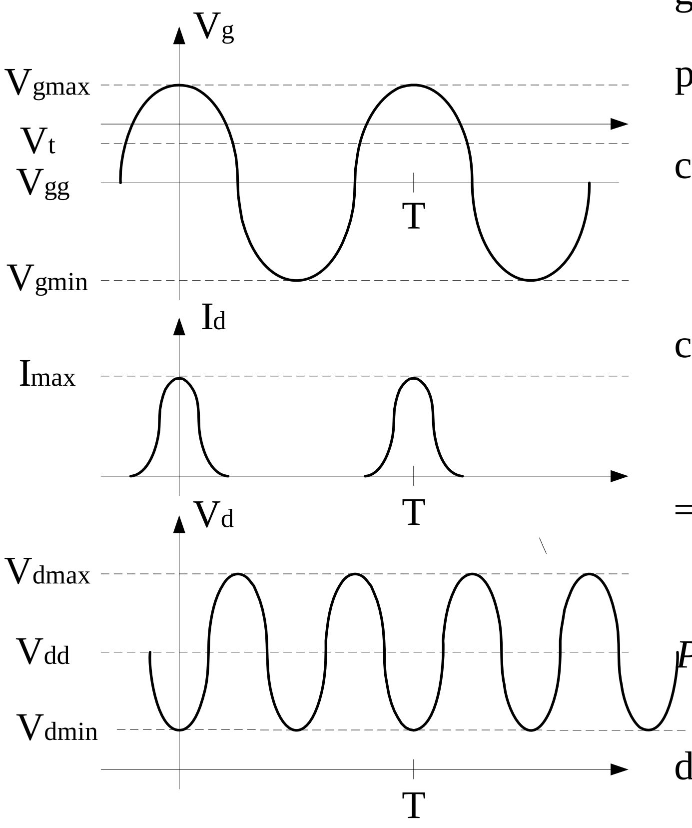




$$i_d(t) = \begin{cases} I_{\max} \cos \dfrac{\pi t}{\tau} \\ 0 \end{cases} = \sum_{n=0}^{\infty} I_n \cos \frac{2\pi n t}{T}$$

$$I_n = I_{\max} \frac{4\tau}{\pi T} \frac{\cos(n\pi\tau / T)}{1-(2n\tau / T)^2}$$

$$\text{optimal} \frac{\tau}{T} = \begin{cases} 0.35, n = 2 \\ 0.22, n = 3 \end{cases}$$



gate bias $V_{gg} = \dfrac{V_{g,\max} - V_{g,\min}}{2}$

peak value of gate voltage @ w_o $V_g = V_{g,\max} - V_{gg}$

conduction duration $\dfrac{1}{2}(V_{g,\max} - V_{g,\min})\cos\dfrac{\pi\tau}{T}$

$$= V_t - (V_{g,\max} - V_{gg})$$

$$\cos\frac{\pi\tau}{T} = \frac{V_t - (V_{g,\max} - V_{gg})}{\frac{1}{2}(V_{g,\max} - V_{g,\min})} = \frac{2[V_t - V_{g,\max} + (V_{g,\max} - V_{g,\min})/2]}{V_{g,\max} - V_{g,\min}}$$

$$= \frac{2[V_t - V_{g,\max}/2 - V_{g,\min}/2]}{V_{g,\max} - V_{g,\min}} = \frac{2V_t - V_{g,\max} - V_{g,\min}}{V_{g,\max} - V_{g,\min}}$$

$$P_{in} = \frac{1}{2}\left|I_g\right|^2 R_i = \frac{\left|V_g\right|^2 R_i}{2\left|R_i - j/w_o C_{gs}\right|^2}$$

drain voltage @ nw_o $V_L = (V_{d,\max} - V_{d,\min})/2 = I_n R_L$

$$P_n = \frac{1}{2}\left|I_n\right|^2 R_L$$

conversion gain $G_c = \dfrac{P_n}{P_{in}}$

5. Ex.12.6 a 12-24GHz FET doubler with parameters

$V_t = -2V, R_i = 10\Omega, C_{gs} = 0.2\,pF, C_{ds} = 0.15\,pF, R_{ds} = 40\Omega$

and operating parameters $V_{g,\max} = 0.2V, V_{g,\min} = -6V, V_{d,\max} = 5V$

$V_{d,\min} = 1V, I_{\max} = 80mA$ find the conversion gain

gate bias $V_{gg} = \dfrac{V_{g,\max} - V_{g,\min}}{2} = -2.9V$, ac gate voltage @ w_o $V_g = V_{g,\max} - V_{gg} = 3.1V$

conduction duration $\cos\dfrac{\pi\tau}{T} = \dfrac{2V_t - V_{g,\max} - V_{g,\min}}{V_{g,\max} - V_{g,\min}} = 0.29 \rightarrow \dfrac{\tau}{T} = 0.406$

$$P_{in} = \frac{1}{2}\left|I_g\right|^2 R_i = \frac{\left|V_g\right|^2 R_i}{2\left|R_i - j/w_o C_{gs}\right|^2} = 10.7mW$$

drain current @ $2w_o$ $I_2 = I_{\max}\dfrac{4\tau}{\pi T}\dfrac{\cos(2\pi\tau/T)}{1-(4\tau/T)^2} = 21mA$

$$I_2 R_L = \frac{V_{d,\max} - V_{d,\min}}{2} \rightarrow R_L = 95.2\Omega,\ X_L = 2w_o L = \frac{1}{2w_o C_{ds}} \rightarrow L = 0.293nH$$

$P_2 = \dfrac{1}{2}\left|I_2\right|^2 R_L = 21mW$, conversion gain $G_c = \dfrac{P_2}{P_{in}} = 2.9dB$

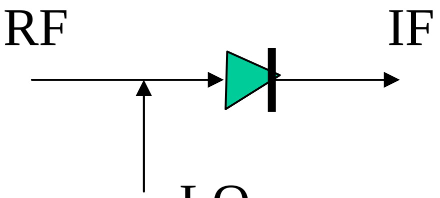
12.5 Overview of microwave sources

Discussion

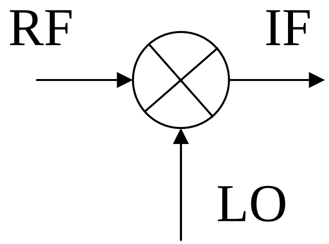
1. Solid-state sources operate at lower power and lower frequency, while microwave tubes operate at higher power and higher frequency (p.609, Fig.12.24).
2. Solid-state sources use diode circuitss (Gunn diode, IMPATT diode) or transistor circuits (GaAs MESFET, DRO, YIG oscillator) with power combining circuits for higher output power (p.610, Figs.12.25, 12.27).
3. Microwave tubes
   power-frequency for oscillator tubes (p.614, Fig. 12.28)
   power-frequency for amplifier tubes (p.615, Fig. 12.29)

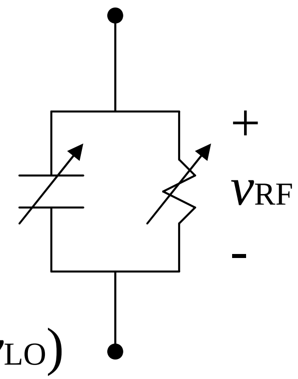
12.6 Mixers

- single-ended mixer



down converter





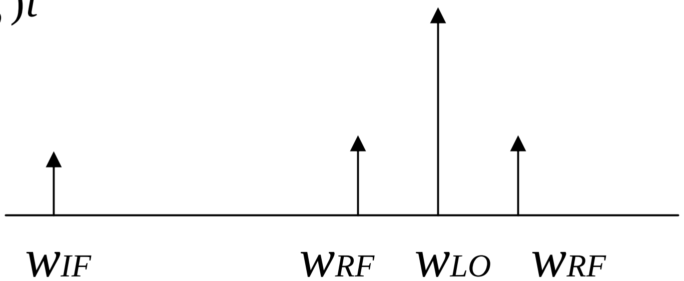
C(v_{LO})

R(v_{LO})

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

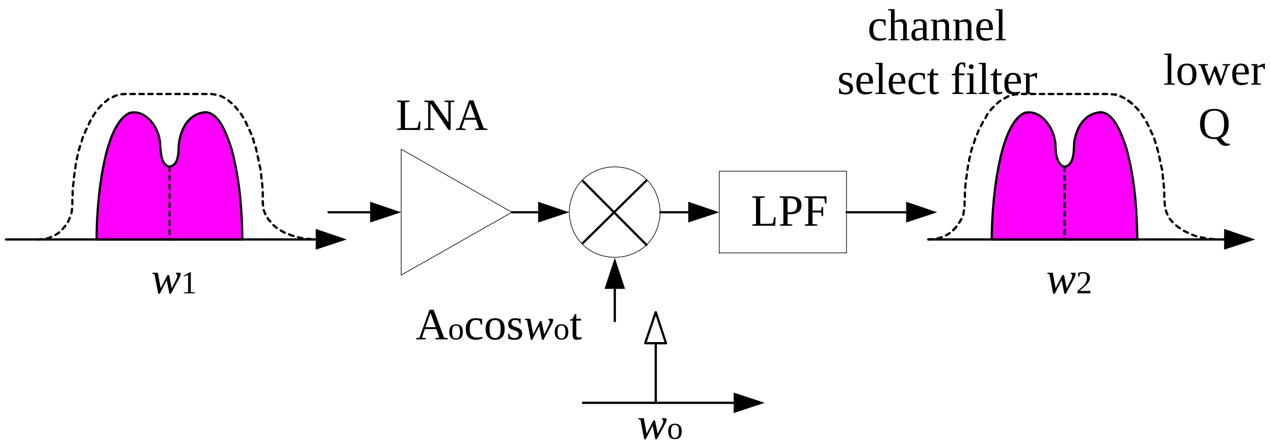
$$v_{IF}(t) \propto \cos(w_{rf} - w_{LO})t$$

linear time-varying components



Discussion

1. heterodyne receiver

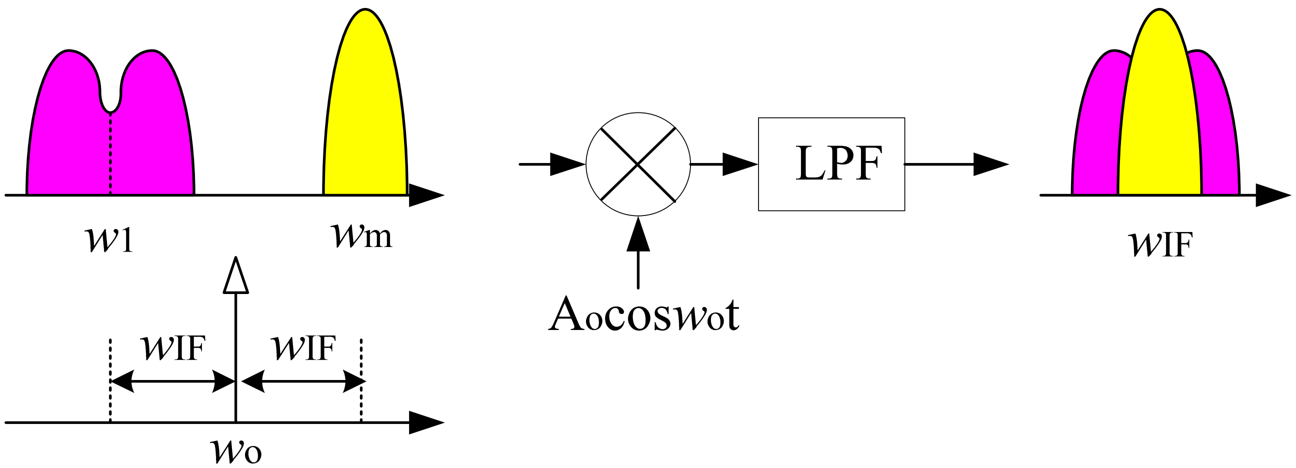


Relax the Q required of the channel-select filter.

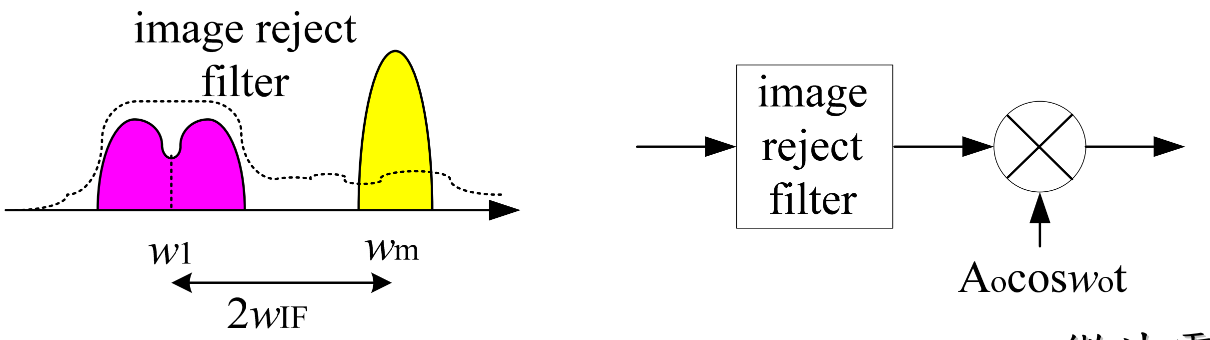
Down-conversion mixer typically has high noise, it's then preceded by a LNA.

2. problem of heterodyne receiver

Image degrades the receiver sensitivity.



Use image-reject filter, but it introduces losses.



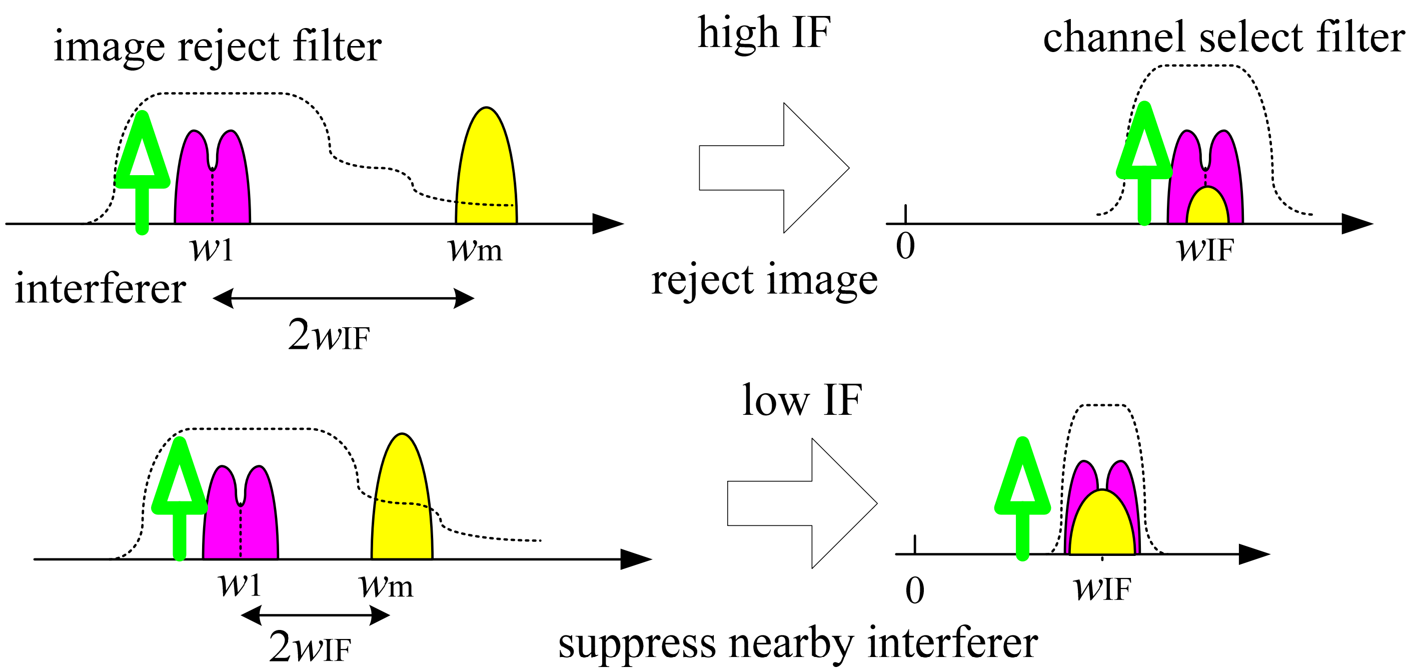
3. choice of IF depends on

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

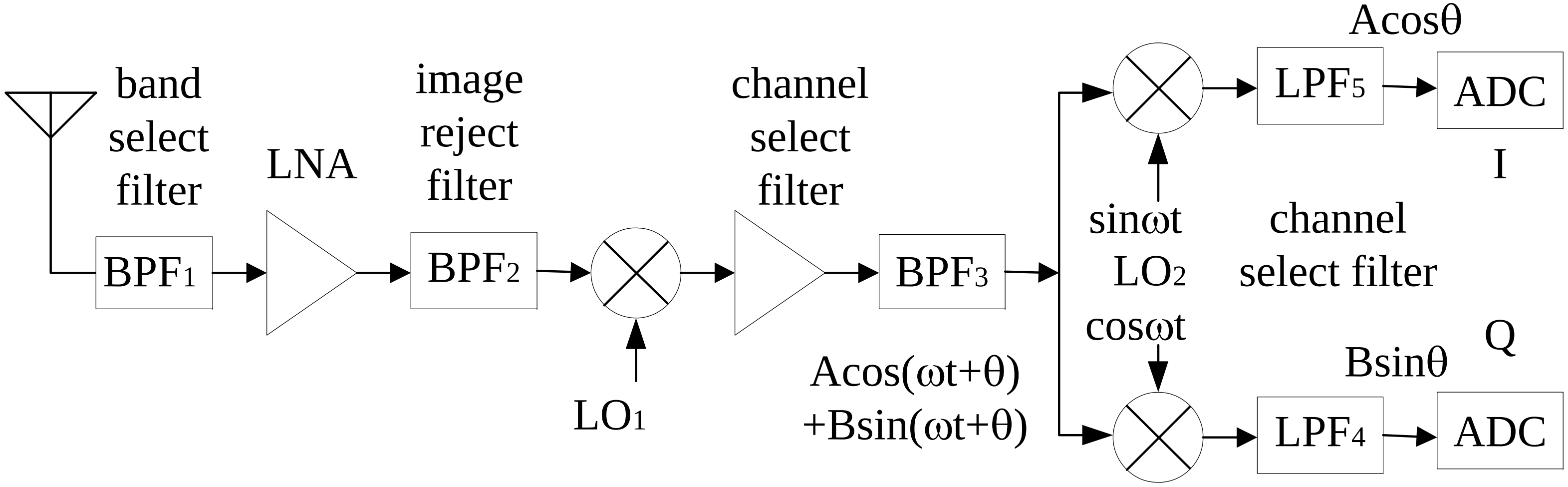


4. dual-IF hetrodyne receiver

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

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

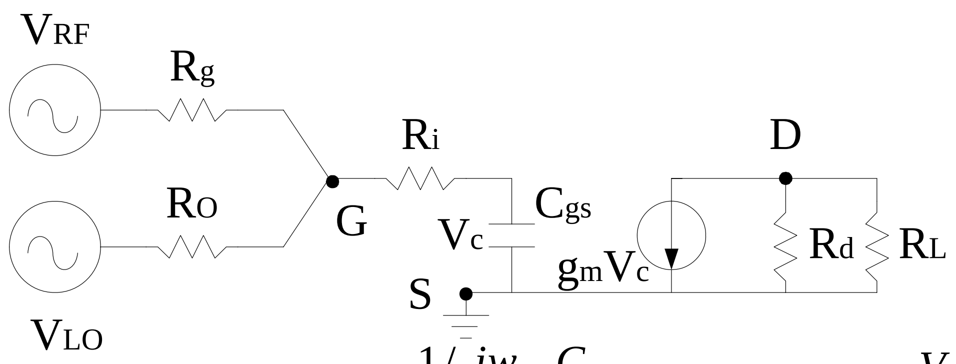
LO/RF isolation

6. 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

7. 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.



$$v_c^{RF} = V_c^{RF} \cos w_{RF} t, V_c^{RF} = V_{RF} \frac{1/jw_{RF}C_{gs}}{Z_g + R_i + 1/jw_{RF}C_{gs}} = \frac{V_{RF}}{1 + jw_{RF}C_{gs}(R_i + Z_g)}$$

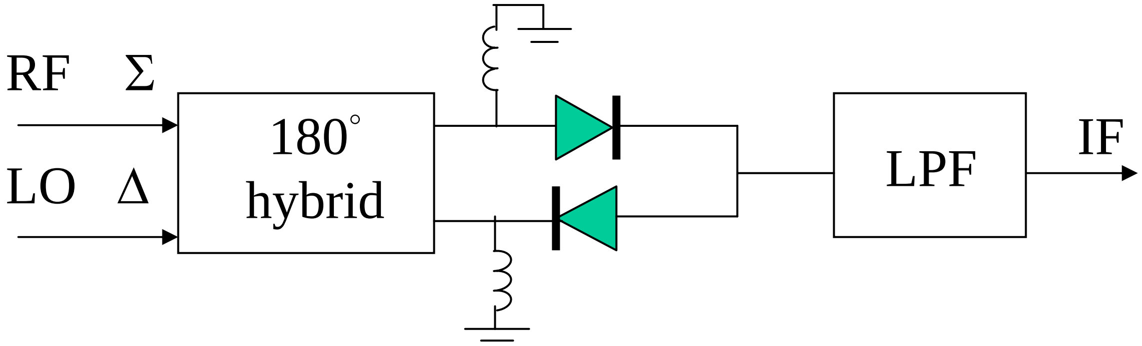
$$g_m(t)v_c^{RF}, g_m(t) = g_o + 2\sum_{n=0}^{\infty} g_n \cos nw_o t \rightarrow g_1 V_c^{RF} \cos w_{IF} t$$

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

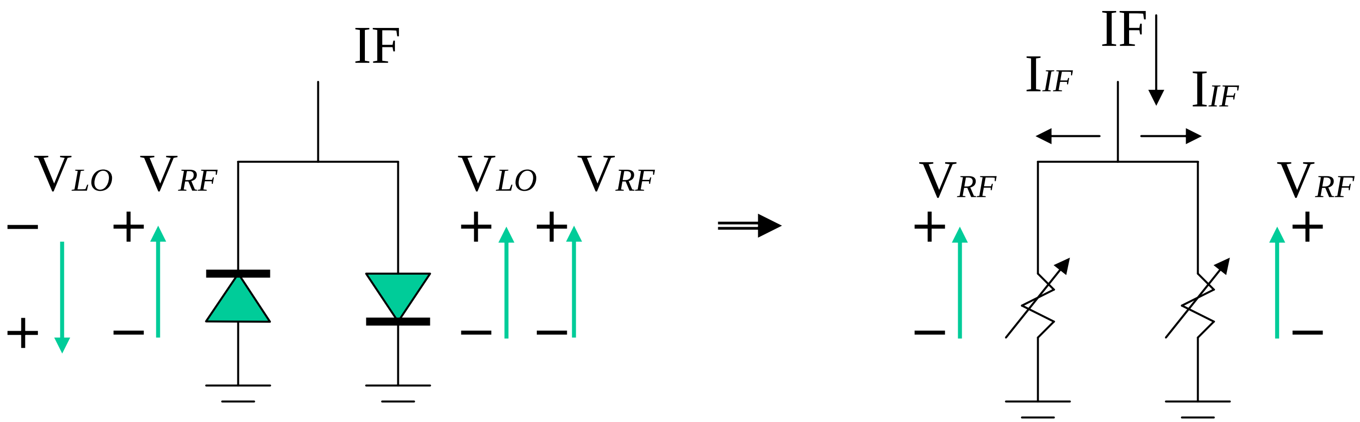
$$G_c = \frac{P_{IF,ava}}{P_{RF,ava}} = \frac{\left|V_D^{IF}\right|^2 R_L / \left|Z_L\right|^2}{\left|V_{RF}\right|^2 / 4R_g} = \frac{4R_g R_L}{\left|Z_L\right|^2} \left|\frac{V_D^{IF}}{V_{RF}}\right|^2 \underset{R_L = R_d}{\overset{R_g = R_i}{\Longrightarrow}} G_c = \frac{g_1^2 R_d}{4w_{RF}^2 C_{gs}^2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

8. single-balanced mixer

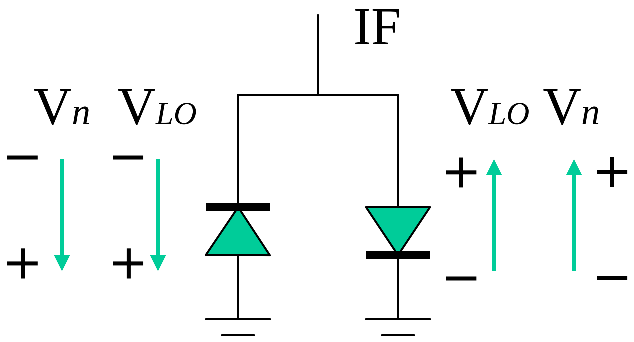
good
RF/LO
isolation

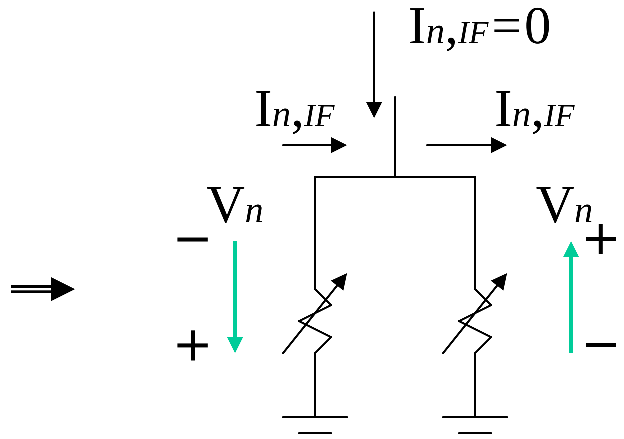


phasor representation

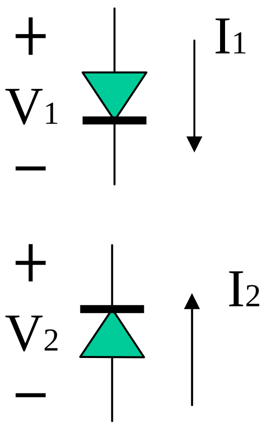


LO AM noise suppression





LO even-harmonic suppression

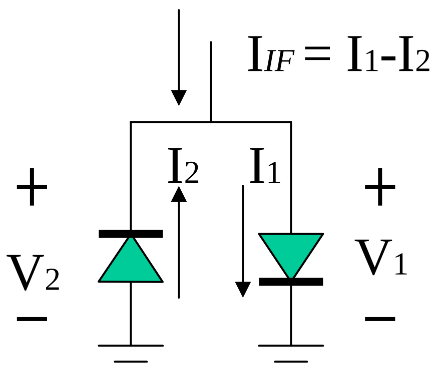


$$I_1 = aV_1 + bV_1^2 + cV_1^3 + dV_1^4$$

$$I_2 = -aV_1 + bV_2^2 - cV_2^3 + dV_2^4$$

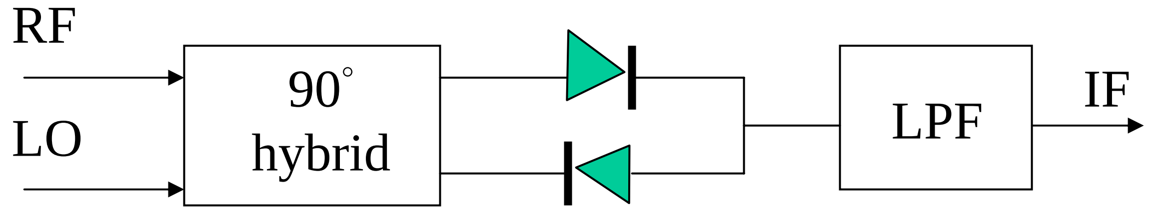
$$v_1 = -v_{LO} \cos w_{LO} t + v_{RF} \cos w_{RF} t$$

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

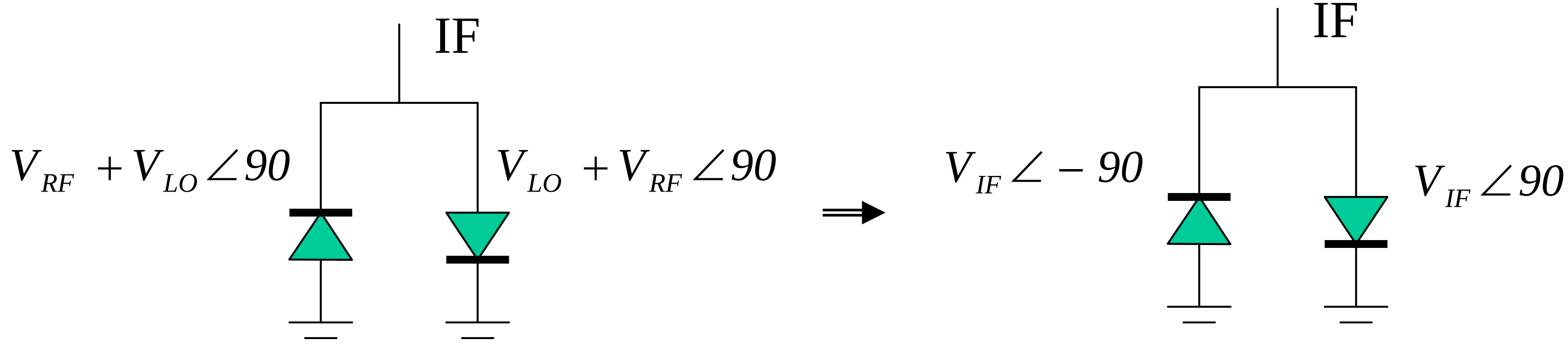


good
RF VSWR

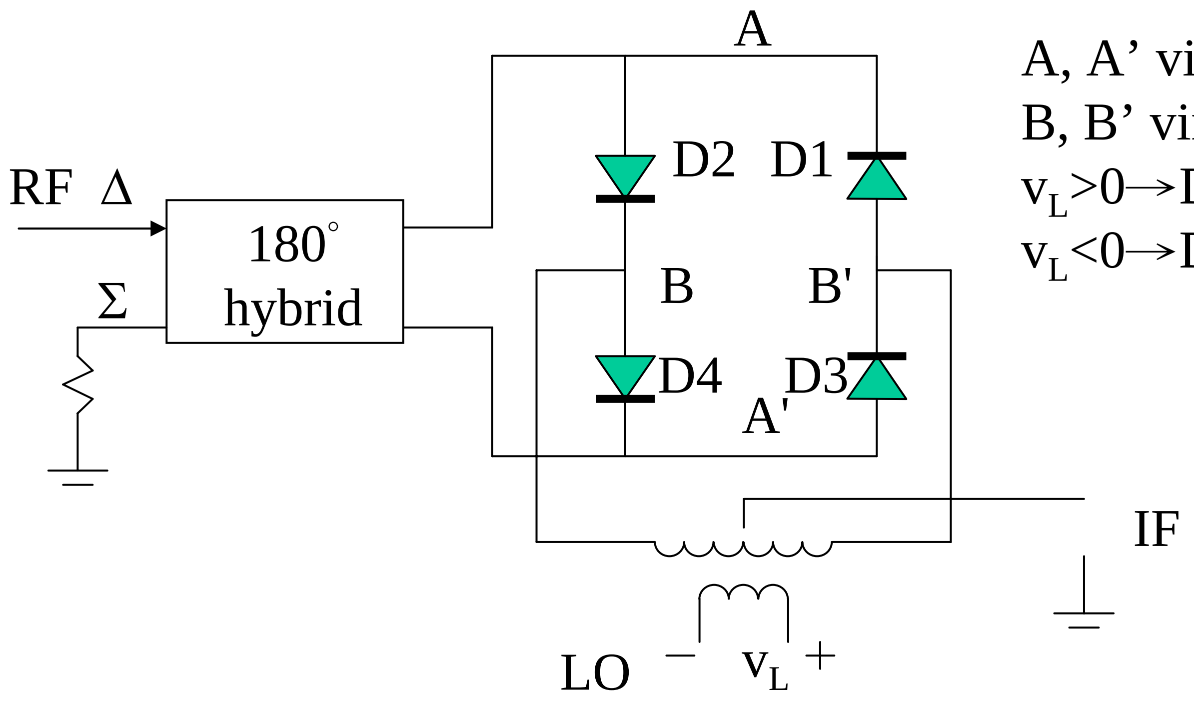
poor RF/LO
isolation



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



9. double-balanced mixer



A, A' virtual ground for LO

B, B' virtual ground for RF

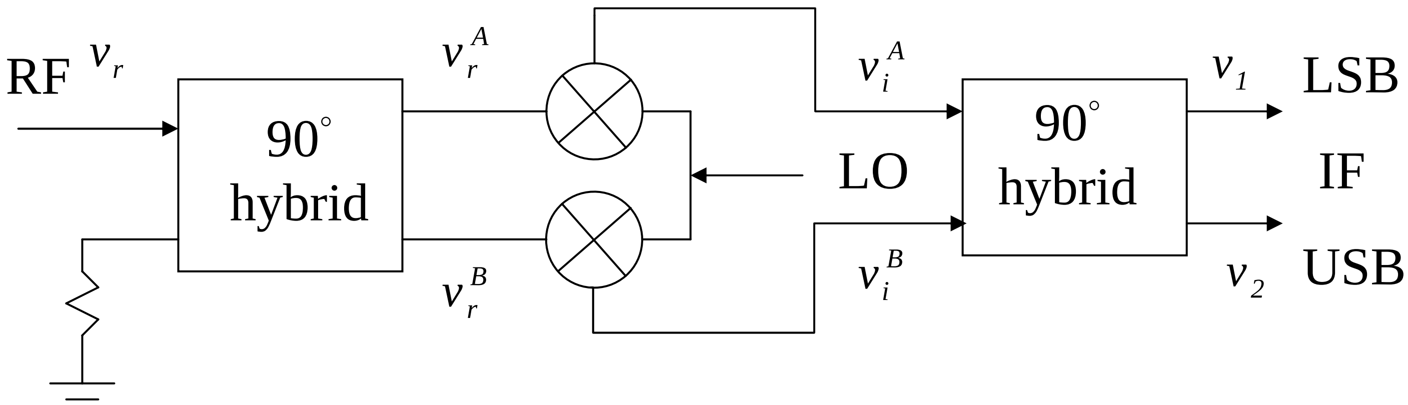
$v_L>0 \rightarrow$ D1, D2 on

$v_L<0 \rightarrow$ D3, D4 on

good RF/LO isolation

LO and RF even-harmonics suppressed

10. image-rejection mixer



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

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

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

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

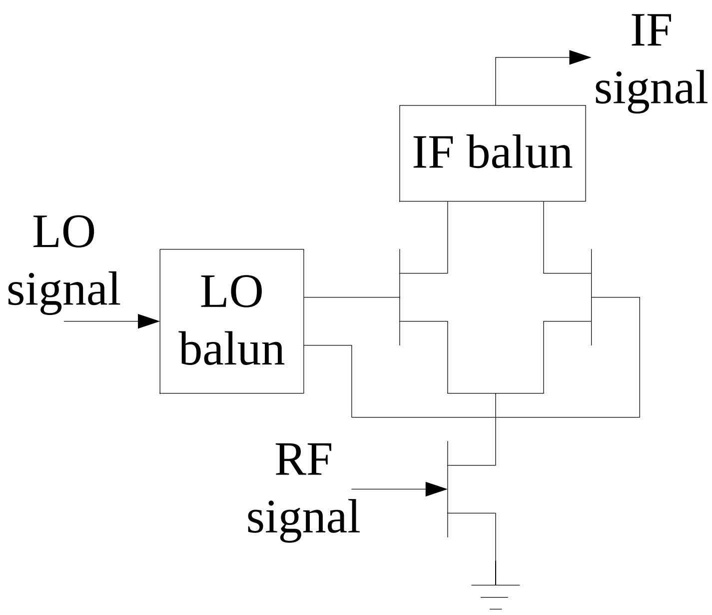
$$v_i^B = USB \angle w_i t + LSB \angle - w_i t = USB \angle w_i t + LSB \angle w_i t$$

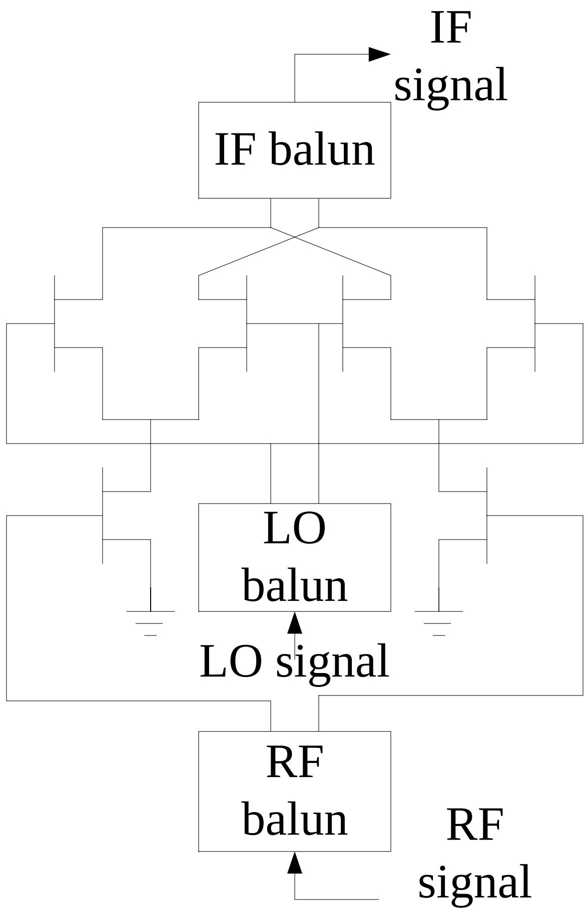
$$v_1 = v_i^A \angle - 90 + v_i^B = 2LSB \angle w_i t$$

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

11. differential mixer

Gilbert cell mixer





ADS examples: Ch12_prj