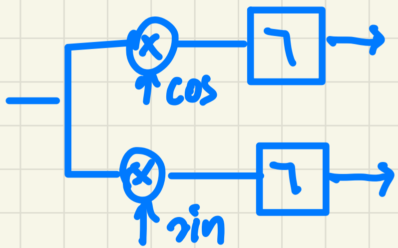
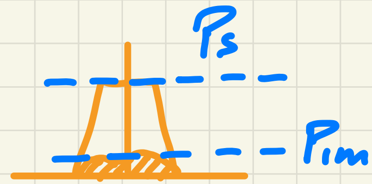
RF Circuit Design

L23

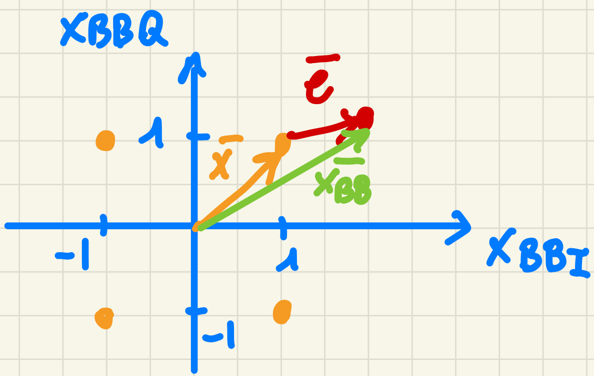
I/Q imbalances





$$IRR = \frac{P_s}{P_{im}}$$

$$\begin{cases} x_{BBI} = x_I \left(1+\frac{\varepsilon}{2}\right) \overbrace{\cos\frac{\theta}{2}}^{\simeq 1} - x_Q\left(1+\varepsilon/2\right) \underbrace{\sin \theta/2}_{\simeq \theta/2} \\ x_{BBQ} = x_Q\left(1-\varepsilon/2\right) \cos\theta/2 - x_I\left(1-\varepsilon/2\right) \sin\theta/2 \end{cases}$$



$$IRR = \frac{|\bar{x}|^2}{|\bar{e}|^2} = \frac{|\bar{x}|^2}{|\bar{x}_{BB} - \bar{x}|^2} = \frac{|x|^2}{(x_{BBI} - x_I)^2 + (x_{BBQ} - x_Q)^2}$$

$$SNR = \frac{2}{\left[\left(1+\frac{\varepsilon}{2}\right)\left(1-\frac{\theta}{2}\right)-1\right]^2 + \left[\left(1-\frac{\varepsilon}{2}\right)\left(1-\frac{\theta}{2}\right)-1\right]^2} =$$

$$\cong \frac{4}{\varepsilon^2 + \theta^2} = \frac{1}{\left(\frac{\varepsilon}{2}\right)^2 + \left(\frac{\theta}{2}\right)^2} = IRR$$

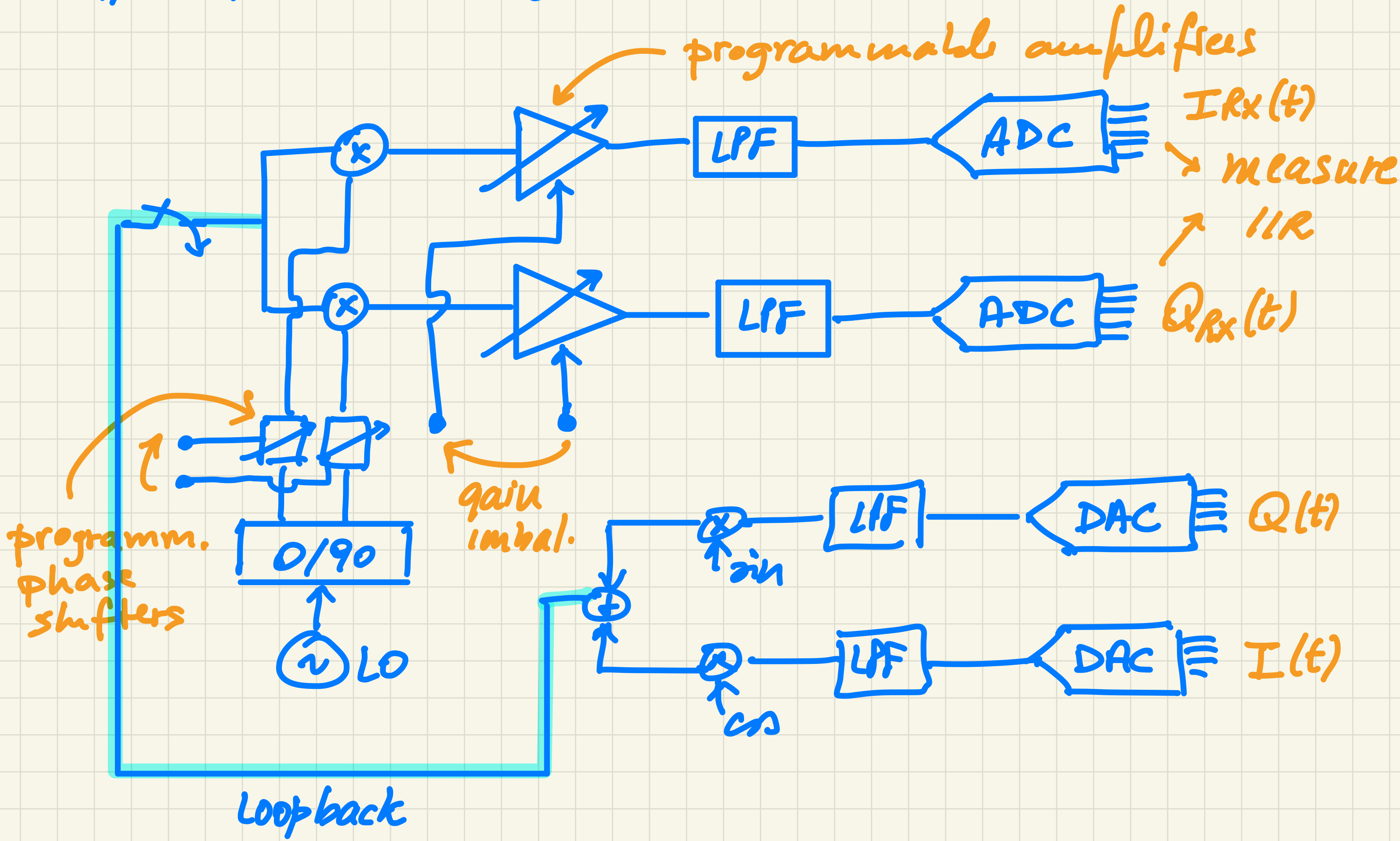
typically, an accurate design in GHz range leads to $IRR \simeq 30\,dB$

e.g. $\varepsilon = 0.1$ (10% matching)

$\theta = 1^\circ = \frac{1^\circ}{180^\circ} \cdot \pi = 0.0174\ rad$ (1 degree phase matching)

$\Rightarrow IRR = 10 \log \frac{1}{0.00257} = \sim 26\ dB$

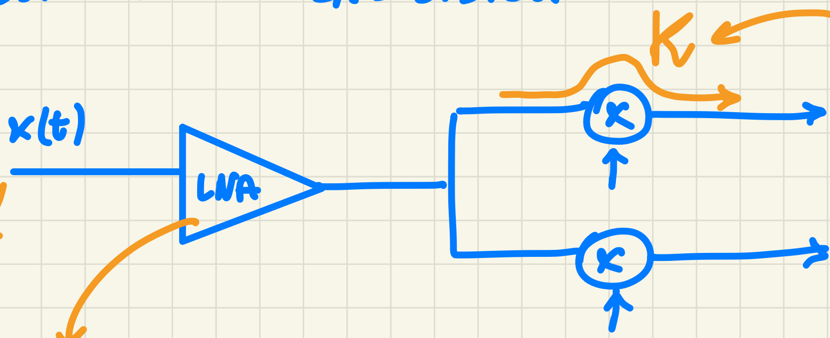
I/Q mismatch calibration

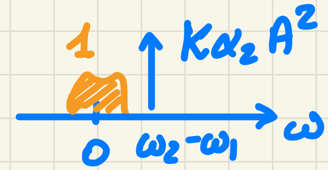


- Even-order distortion

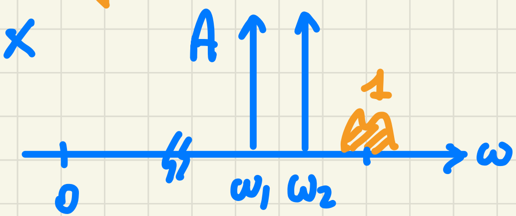
sol. use differential circuits

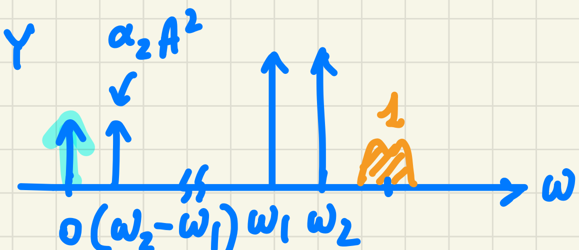
mixer RF-to-IF feedthrough

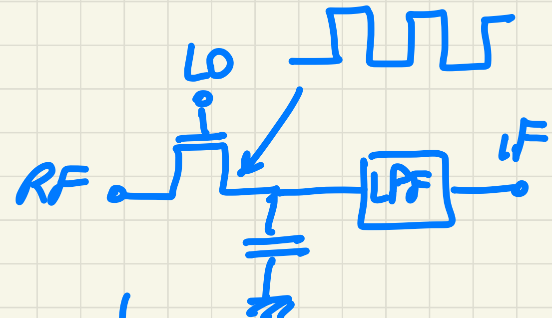




$$y(t) \simeq \alpha_1 x(t) + \alpha_2 x^2(t)$$







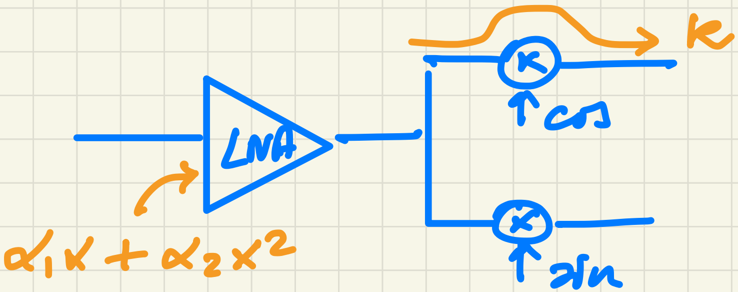
in single balanced mixer

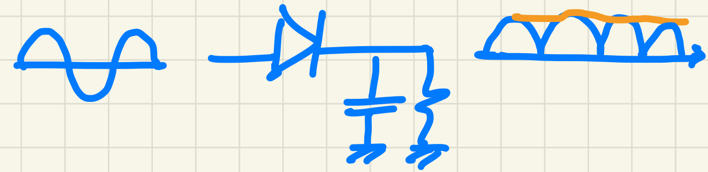
$K \simeq -30$ dB

$$V_{IF} = \frac{1}{2} V_{RF} + \text{o.t.} \Rightarrow K = \frac{1/2}{1/\pi} = \frac{\pi}{2}$$

$$A_V = \frac{V_{IF}(\omega_{IF})}{V_{RF}(\omega_{RF})} = \frac{1}{\pi}$$

Unwanted demodulation of AM interferers



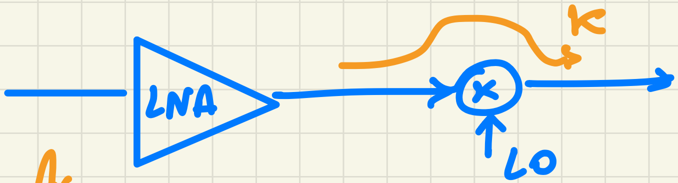


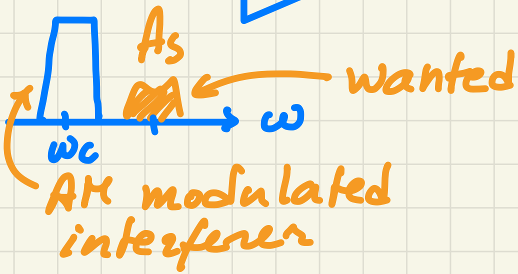
$$x(t) = \underbrace{\left[A_{int} + a(t) \right]}_{\text{AM modulation of an interferer}} \cdot \cos \omega_c t$$

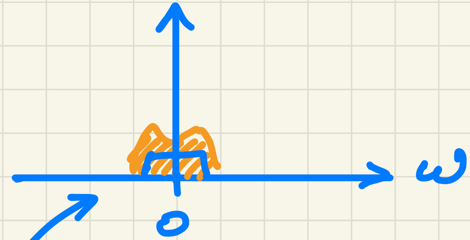
$\dfrac{1+\cos 2\omega_c t}{2}$

$$\alpha_2 x^2(t) = \alpha_2 \cdot 2 \cdot A_{int} \cdot a(t) \cdot \cos^2 \omega_c t + o.t. =$$

$$= \underbrace{\alpha_2 \cdot \cancel{2}\, A_{int} \cdot a(t) \cdot \frac{1}{\cancel{2}}}_{\text{Low-pass unwanted component}} + o.t. \rightarrow \underbrace{\alpha_2 A_{int}^2}_{\text{DC offset}} \cdot \frac{1}{2}$$

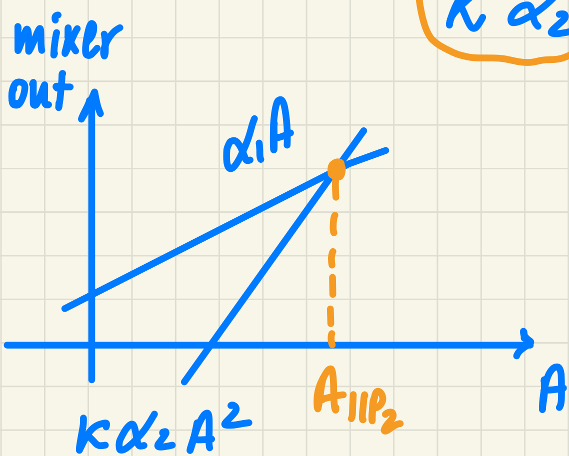






$K \cdot \alpha_2 \cdot A_{int} \cdot \underbrace{a(t)}$

$$\sqrt{SNR} = \frac{\alpha_1 \cdot A_{s,rms}}{K\alpha_2 \cdot A_{int} \cdot a_{rms}} = \frac{A_{IIP_2} \cdot A_{s,rms}}{A_{int} \cdot a_{rms}}$$



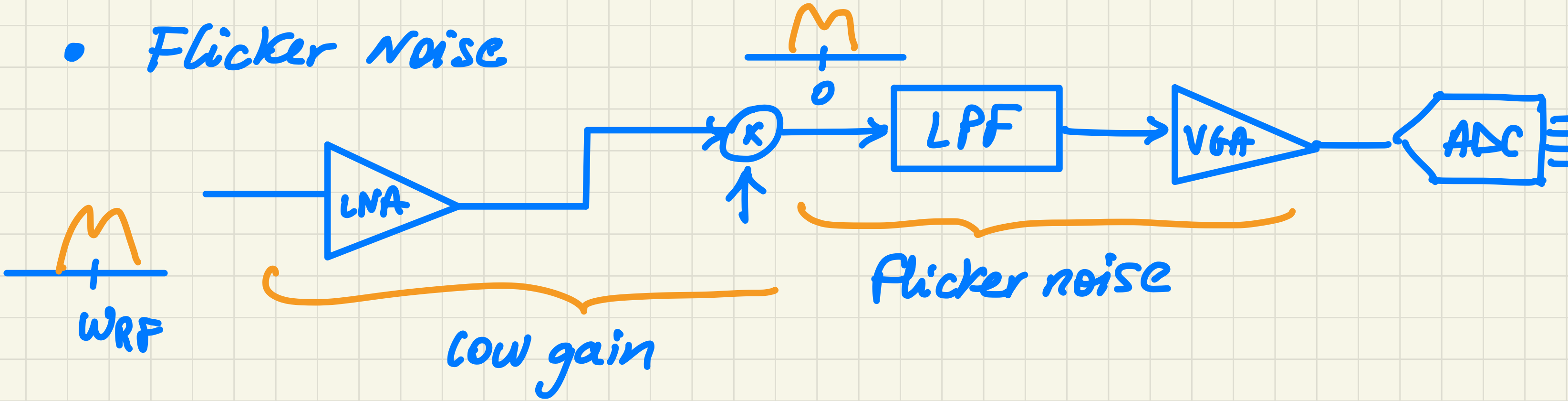
$$\alpha_1 A_{IIP_2} = K\alpha_2 A_{IIP_2}^2$$

$$\Downarrow$$

$$A_{IIP_2} = \frac{\alpha_1}{K\alpha_2}$$

2nd nonlin. demodulates amplitude modulations

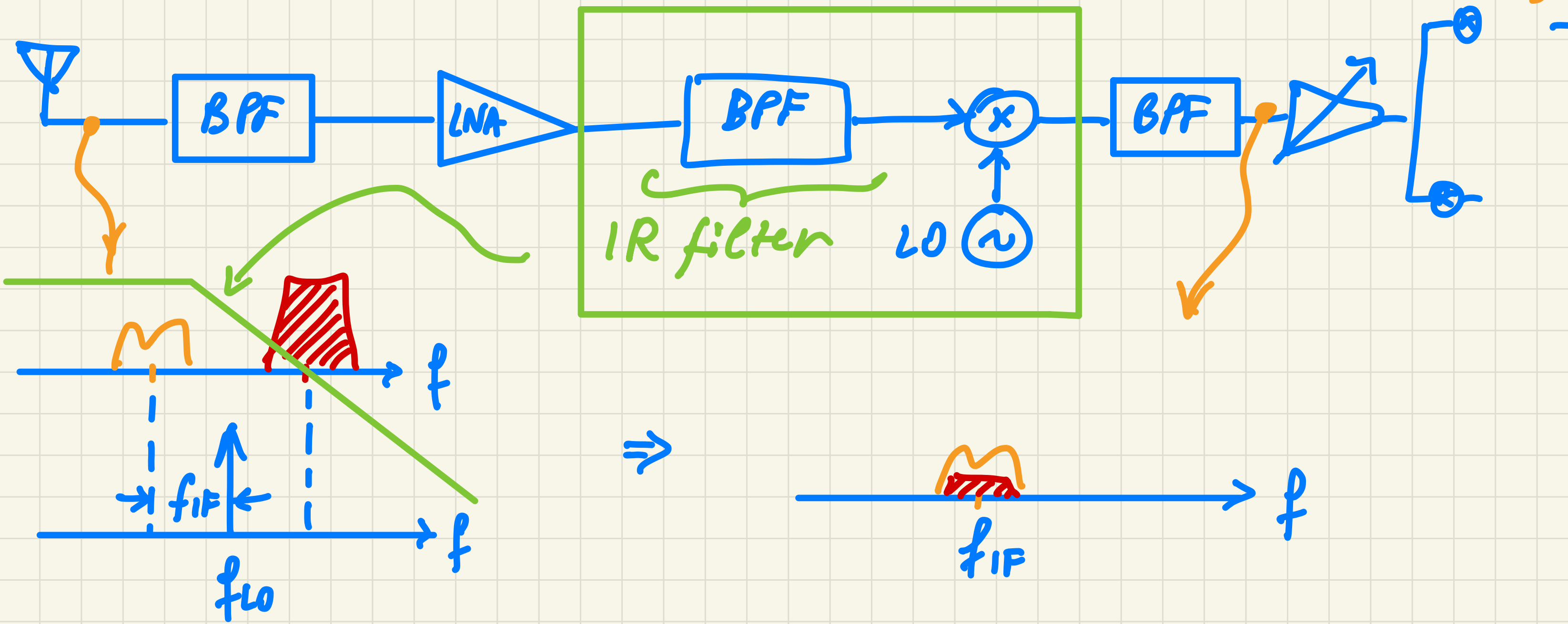
- Flicker Noise



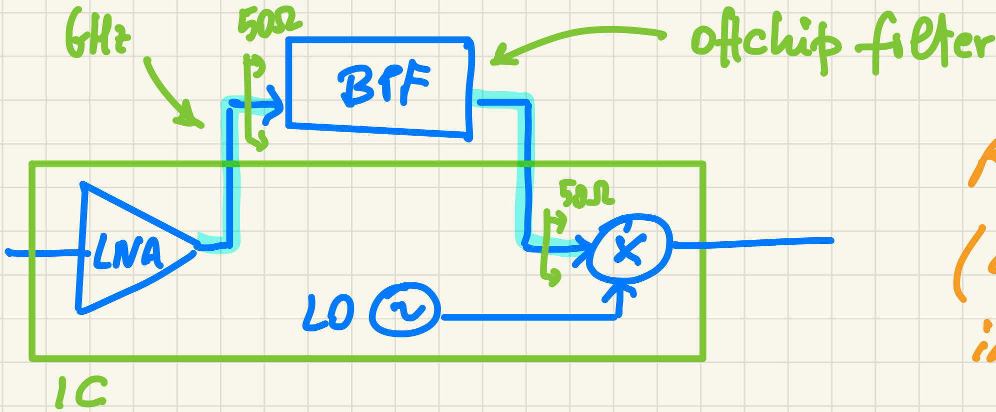
Solutions:
- large devices in mixers and VGA/LPF
- Offset cancellation techniques

Image-Reject Receivers

image rejection based on filtering



Variant : dual-IF architecture (to relax image problem)

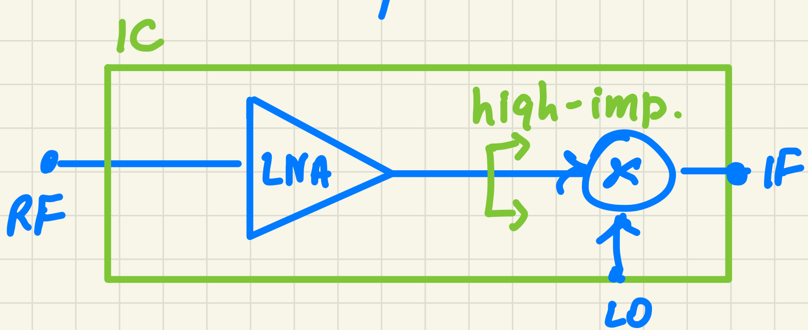


RF off-chip blocks (as filters) require impedance matching

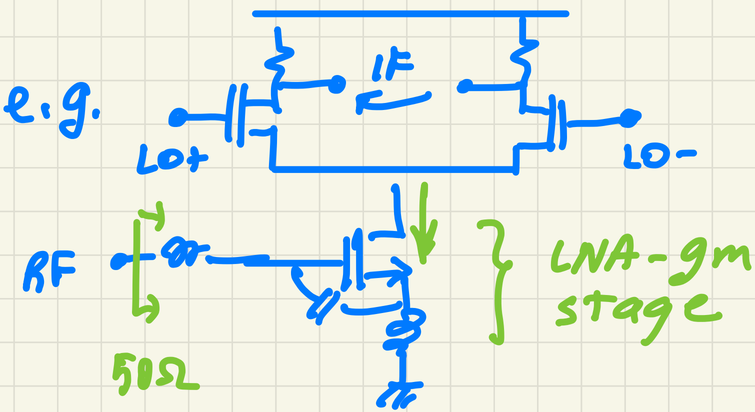
⇓

large power consumption

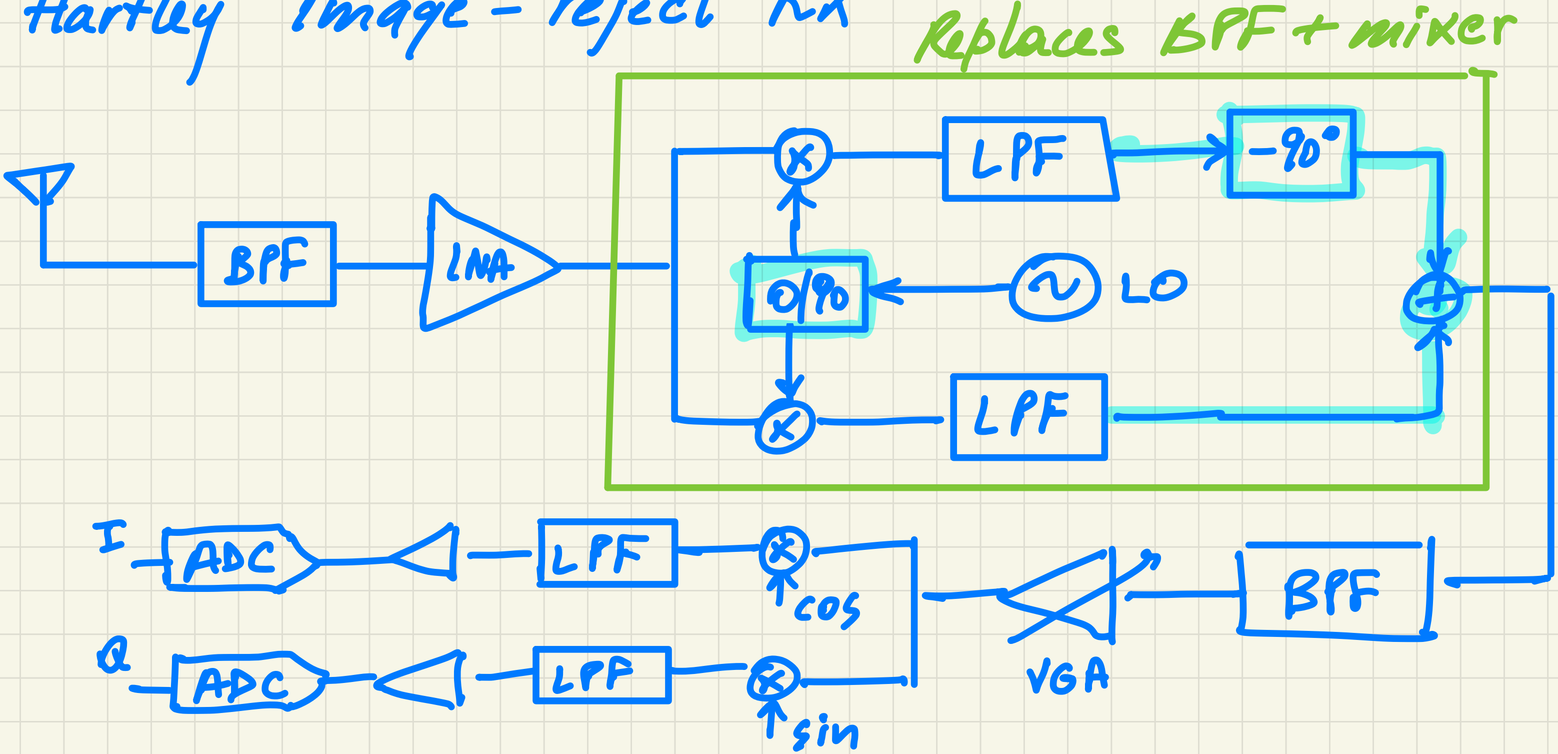
LNA : requires an output stage to drive 50 Ω impedance



e.g.

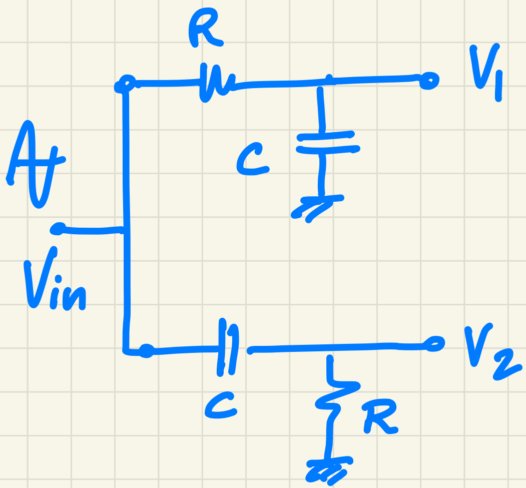


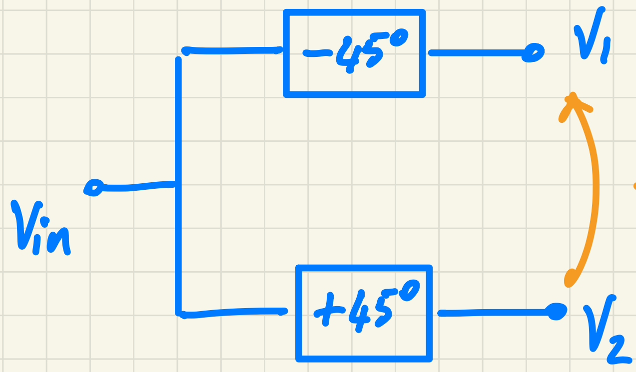
Hartley Image-reject RX



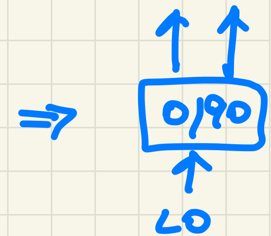
Avoids ext. BPF filter for image rejection

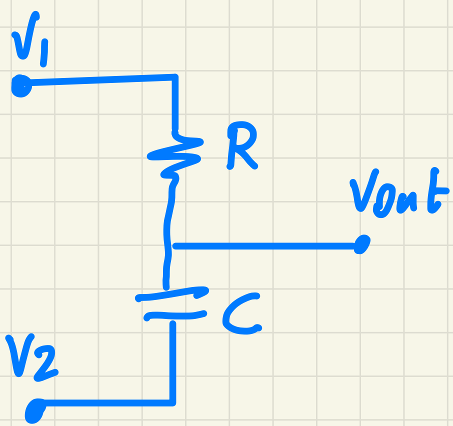
Requires two mixers, quadrature LO

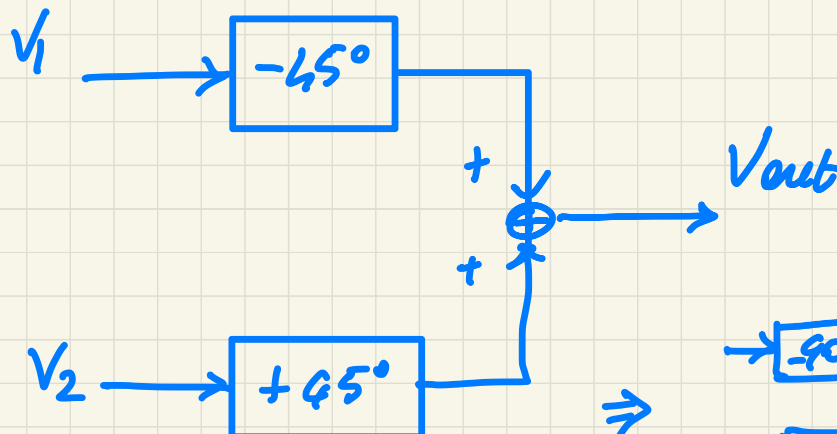


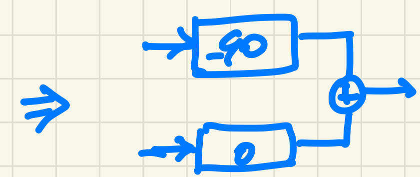


$$f_{in} = \frac{1}{2\pi RC}$$

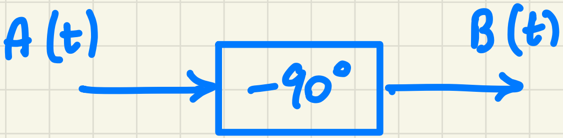


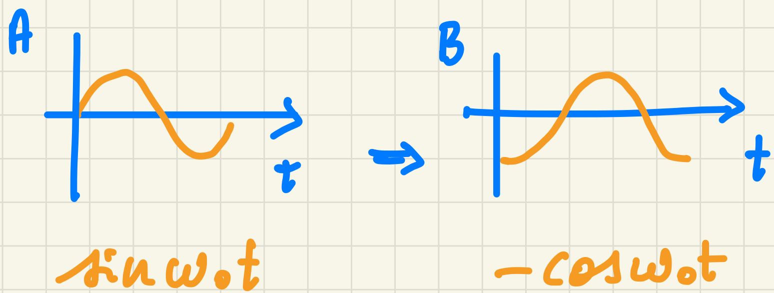




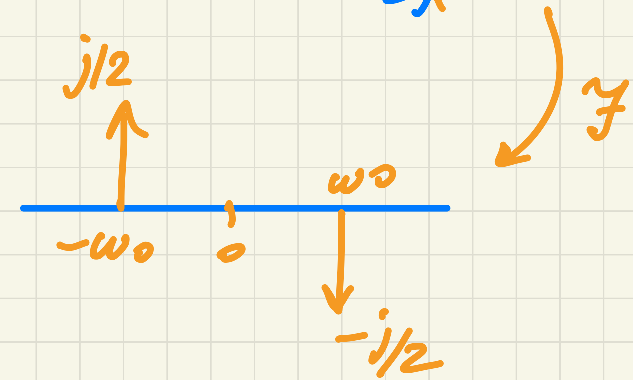


Transfer function of phase shifter

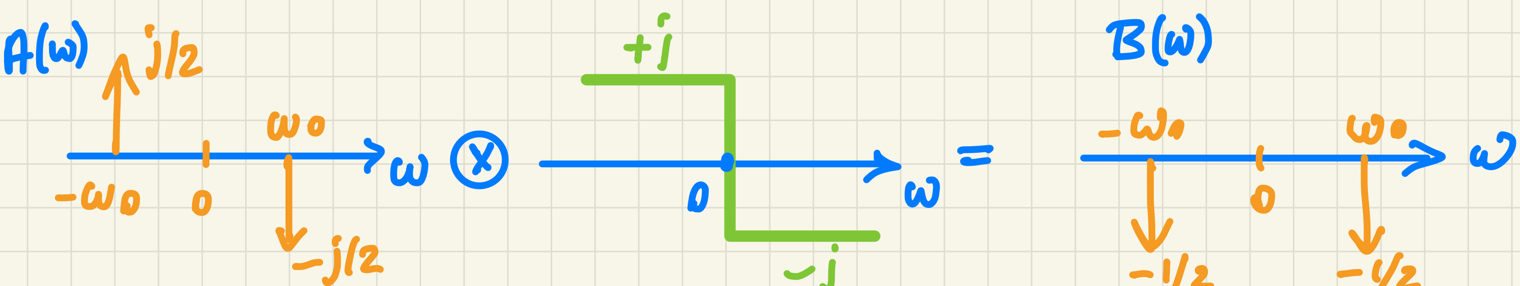




$$\sin \omega_0 t = j\,\frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{-2\cancel{j}}$$



In Fourier domain :

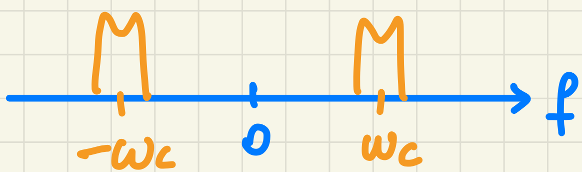


$G(\omega) = -j \cdot \text{sign}(\omega)$ transfer function

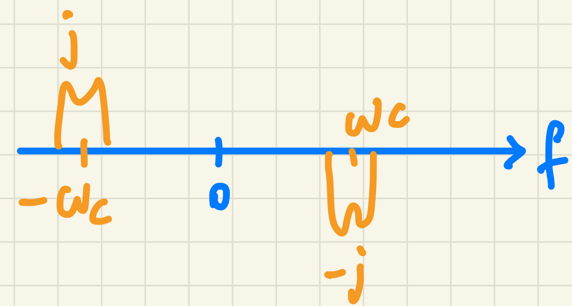
$A(\omega)$

$B(\omega) = G(\omega) \cdot A(\omega)$

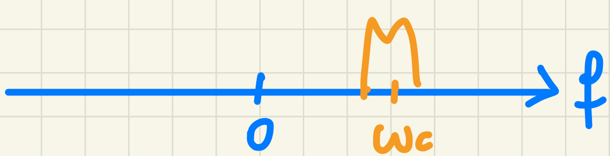
Hilbert transform



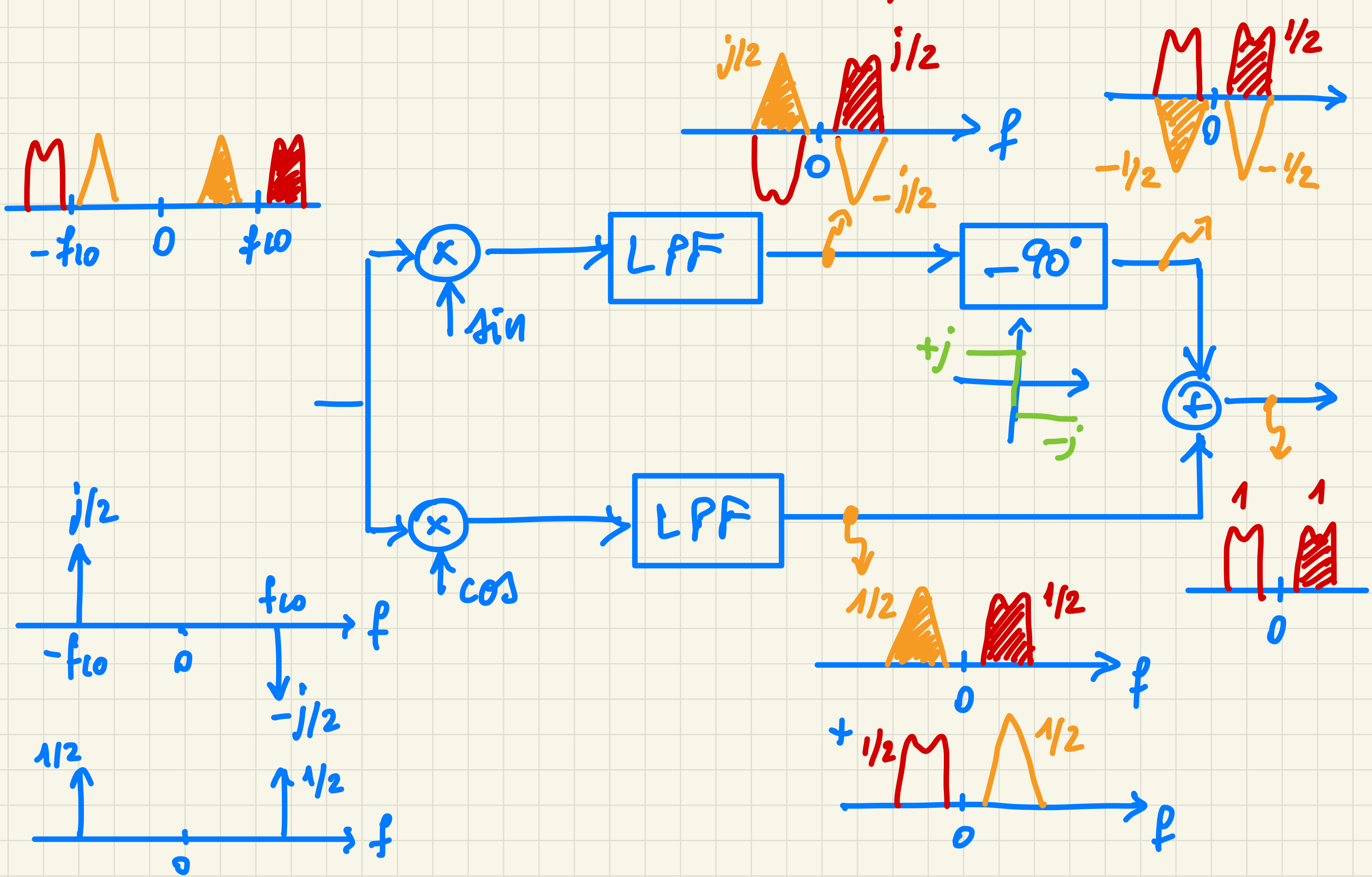
$\Rightarrow$



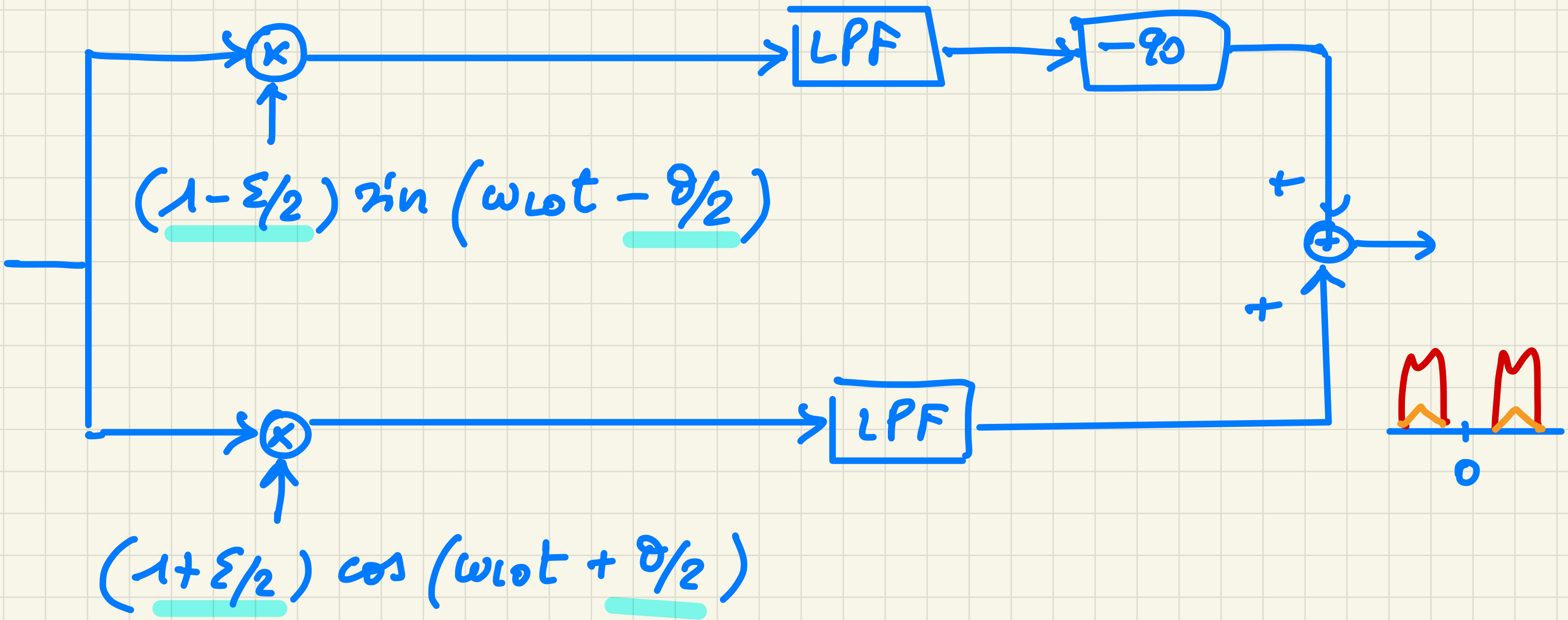
$S(\omega) = \underbrace{A(\omega)} + j \cdot B(\omega)$ Analytical signal



$A(t) = \text{Re}\{S(t)\}$



$-f_{LO}$
0
f_{LO}
sin
cos
LPF
LPF
$-90°$
$+j$
$-j$
$j/2$
$-j/2$
$1/2$
$-1/2$
+
f
1
1
0



$$IRR = \frac{P_s}{P_{im}} = \dots = \frac{4}{\varepsilon^2+\theta^2}$$