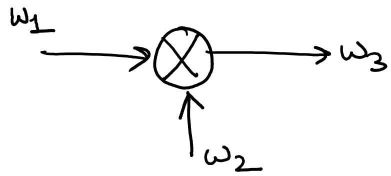
ECE 513 - Lecture 23

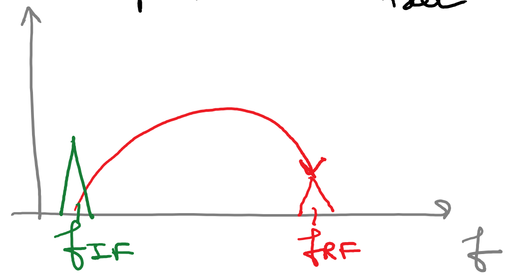
Tuesday, November 6, 2018 9:27 AM

Mixer :

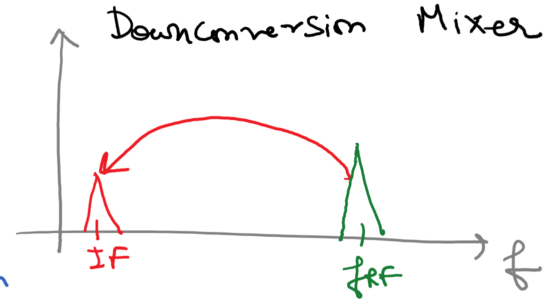
Look at the HW4 Solutions for Midterm Exam



Upconversion Mixer



Downconversion Mixer



* A mixer is 3-port circuit that employs nonlinear or time varying 'device' in order to perform frequency translation in RF systems.
  - ↳ if the time varying element is an R or G (switch)
    - ↳ resistive or passive
  - ↳ time varying transconductance (g_m) → Active Mixer
    - ↳ transistors

* Image reject mixers → require 90° phase shifters and in-phase power combiners or splitters.

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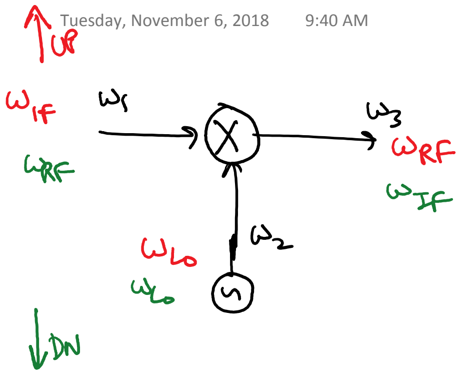

Ideal mixer behavior:

$$A\cos(\omega_1 t)\cdot B\cos(\omega_2 t) = \frac{AB}{2}\left[\cos((\omega_1-\omega_2)t) + \cos(\cancel{(\omega_1+\omega_2)}t)\right]$$

Filtered out

↳ only half of the output signal is retained, and the other half is filtered out.

↳ half of the output power is lost (3dB loss)

* In practice, the mixer (or multiplier) is implemented with a non linear element such as a diode or transistor or with switches.

↳ a large number of harmonics as well as undesired products of the input signals (intermodulation)

↳ To eliminate unwanted harmonics, filters are placed to select only the frequency of interest.

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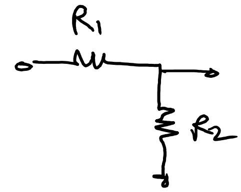
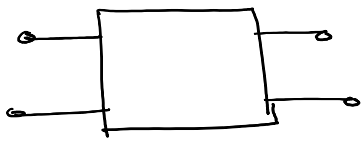
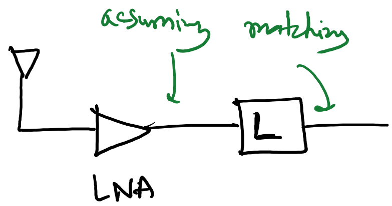
Aside. lossy component ⇒ loss L_{dB}





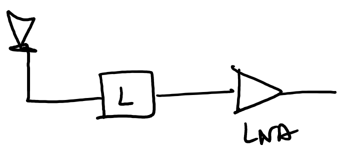
Razavi RF book

$$NF\big|_{dB} = L\big|_{dB}$$



linear quantity, not dB

$$F = F_{LNA} + \frac{(L-1)}{g_{LNA}}$$



$$F = L + \frac{F_{LNA} - 1}{1/L}$$

Downconversion Mixer

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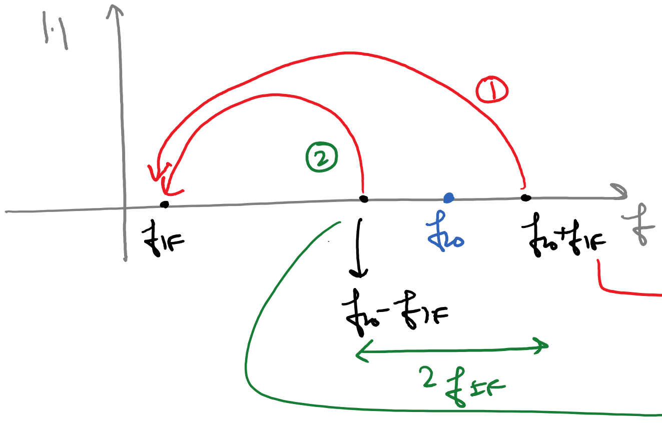


Both $\omega_{IF} = \omega_{RF} - \omega_{Lo}$ — ①
$\omega_{IF} = \omega_{Lo} - \omega_{RF}$ → ② are collected at the IF port

$f_{lo}+f_{IF}$ → Upper Side band (USB)

$f_{lo}-f_{IF}$ → lower Sideband (LSB)

* One of them is RF and other IM frequency.

↳ the choice of USB or LSB for RF frequency depends upon system design considerations

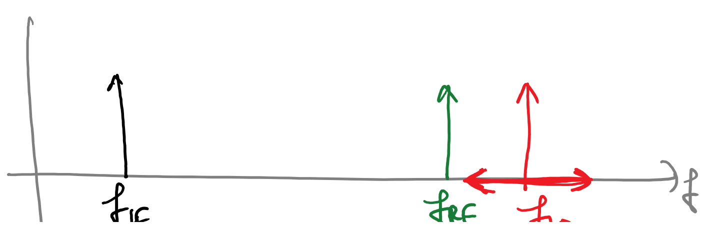
* Also, two Lo frequencies are possible for a given RF and IF frequency combination

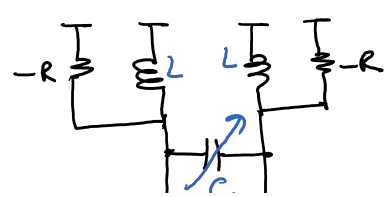
$$\omega_{IF} = \omega_{Lo} - \omega_{RF}$$

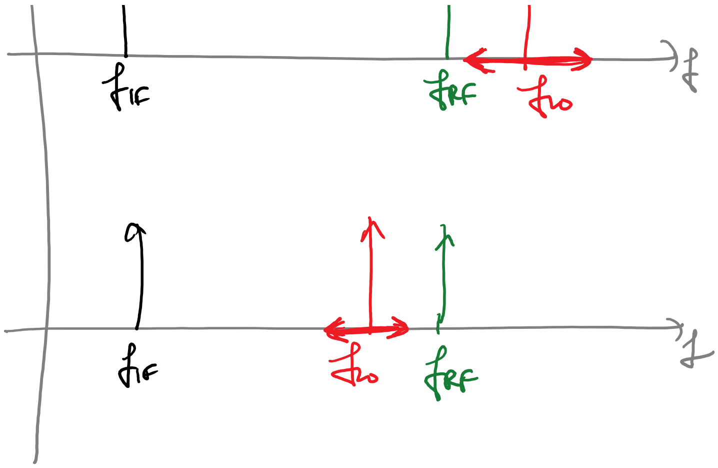
$$\text{or} \quad \omega_{IF} = \omega_{RF} - \omega_{Lo}$$

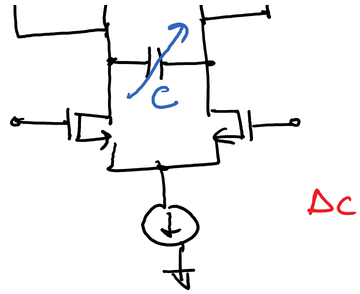
↳ The best choice for Lo frequency is determined by practical design constraints

↳ Eg. USB Lo $(\omega_{Lo} > \omega_{RF})$ is often preferred because it requires a VCO with a smaller tuning ratio for a given range of RF frequencies.









$$\omega_{LO} = \frac{1}{\sqrt{LC}}$$

* In mmWave RX, higher LO (frequency divider) are difficult to implement

↳ LSB LO.

Ex 9.1 :

5.2 GHz WLAN

$f_{RF} = 5.2\ \text{GHz}$ and $f_{IF} = 1\ \text{GHz}$.

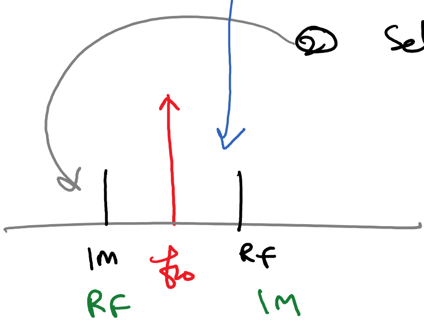
① Select $f_{LO} = f_{RF} - f_{IF} = 4.2\ \text{GHz}$

↳ $f_{IM} = f_{LO} - f_{IF} = 3.2\ \text{GHz}$

② Select $f_{LO} = f_{RF} + f_{IF} = 6.2\ \text{GHz}$

↳ $f_{IM} = f_{LO} + f_{IF} = 7.2\ \text{GHz}$

↳ Think !



$$f_{LO} = \frac{f_{RF} + f_{IM}}{2}$$

Switch based Commutating Mixer

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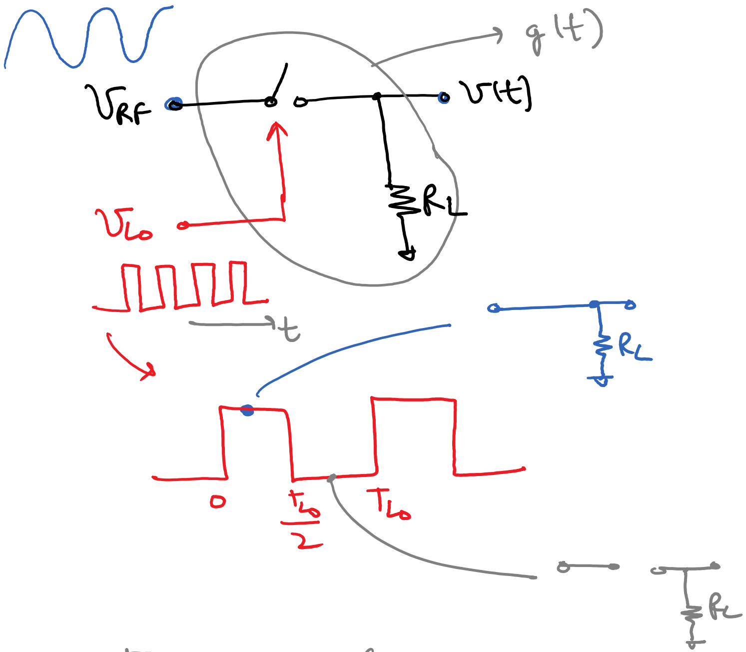
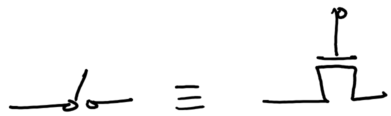
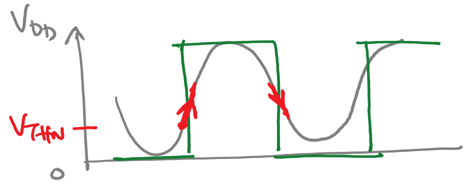
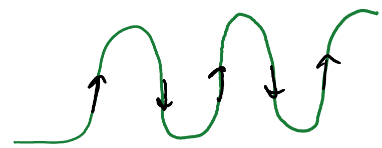


Time varying Circuit



* Why use square waves for V_{LO}?





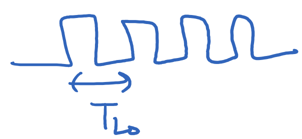
* rather have sharp edges at the transitions

* Assume ideal switch ($R_{on} = 0$ & $R_{off} = \infty$)

* The normalized time-varying conductance of the switch in series with R_L can be given by

$$g(t) = \begin{cases} 0 & \text{when Switch is open} \\ 1/R_L & \text{when Switch is closed} \end{cases}$$

$$= \frac{1}{R_L} \cdot \text{rect}\left(\frac{t}{T_{LO}}\right)$$

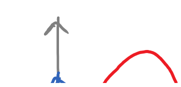


Expand as Fourier Series

harmonic term

$$\Rightarrow \quad g(t) = \underbrace{\frac{1}{2R_L}}_{a_0} + \sum_{n=1}^{\infty} \underbrace{\frac{2}{n\pi R_L} \sin\left(\frac{n\pi}{2}\right)}_{a_n} \cos(n\omega_{LO} t)$$

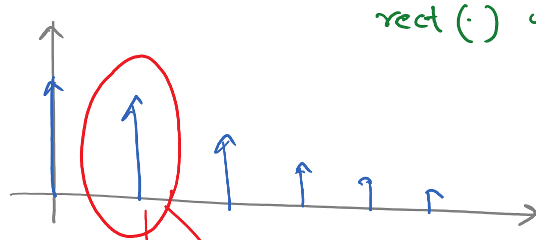
Fourier series of rect(·) wave terms



↓

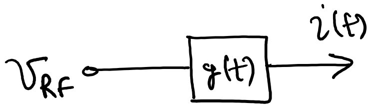
Average is due to on/off switch with 50% duty cycle

rect(·) wave terms



ω_{LO}

filtered out using a BPF.



$$v_{RF}(t) = V_{RF}\cos(\omega_{RF} t)$$

$$i(t) = g(t)\cdot v_{RF}(t) = \frac{V_{RF}}{2R_L}\cos(\omega_{RF}t) + \frac{V_{RF}}{R_L}\sum_{n=1}^{\infty}\frac{2}{n\pi}\sin\left(\frac{n\pi}{2}\right)\cos(n\omega_{LO}t)\cos(\omega_{RF}t)$$

$$= \frac{V_{RF}}{2R_L}\cos(\omega_{RF}t) + \frac{V_{RF}}{R_L}\sum_{n=1}^{\infty}\frac{1}{n\pi}\sin\left(\frac{n\pi}{2}\right)\Big[\cos((n\omega_{LO}+\omega_{RF})t) + \cos((n\omega_{LO}-\omega_{RF})t)\Big]$$

* After Bandpass filtering, the IF component corresponding to $n=1$ ($\omega_{IF} = \omega_{LO} - \omega_{RF}$), we obtain

$$i_{IF}(t) = \underbrace{\frac{V_{RF}}{\pi R_L}}_{I_{IF}}\cos(\omega_{IF} t)$$

* Voltage Conversion gain

$$A_v = \frac{V_{IF}}{V_{RF}} = \frac{I_{IF}\cdot R_L}{V_{RF}} = \frac{\frac{V_{RF}}{\pi}\cdot\frac{R_L}{R_L}}{V_{RF}} = \boxed{\frac{1}{\pi}}$$

* maximum possible conversion gain of a single-sided switch mixer $= 1/\pi$

* In reality the non-zero switch resistance needs to be accounted for

$$\boxed{A_v = \frac{1}{\pi}\cdot\frac{R_L}{R_L + r_{sw}}}$$

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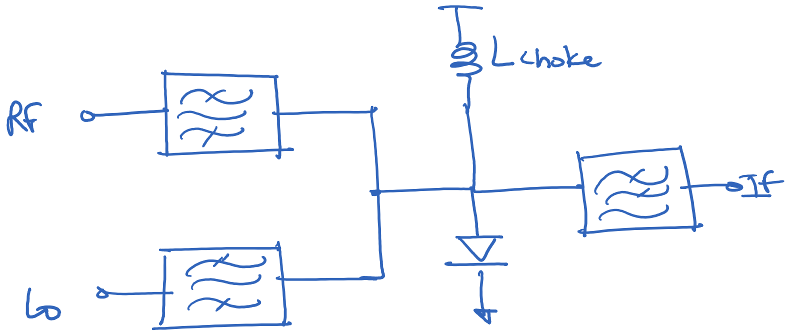
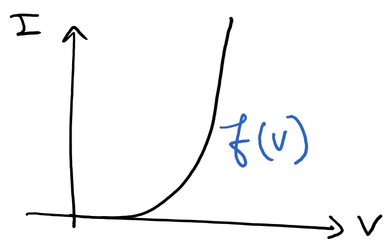
Mixer

Time varying device

Non-Linear Device
- diodes
- BJTs, HBTs
- MOSFETs in their square law region



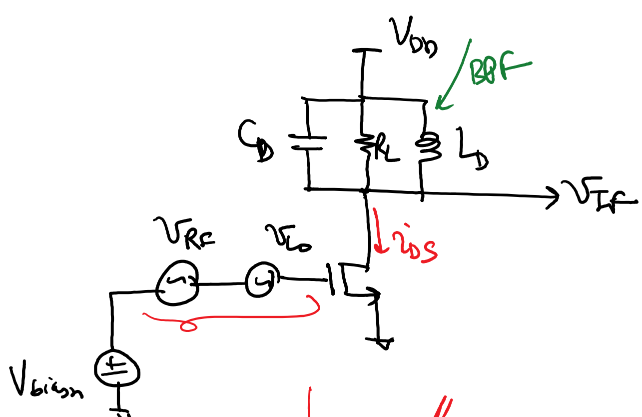


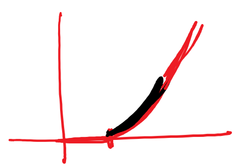
$f(V_{RF} + V_{LO})$

$f(x) \simeq f(x_0) + f'(x_0)(x-x_0) + \underbrace{f''(x_0)(x-x_0)^2}+ \ldots$

$(V_{RF} + V_{LO})^2 = V_{RF}^2 + V_{LO}^2 + 2 V_{RF} V_{LO}$

FET multiplier





$K' n C_{ox} \frac{W}{L}$

$i_{DS}(t) = \frac{\beta}{2}\left[V_{LO}\cos(\omega_{LO} t) + V_{RF}\cos(\omega_{RF} t) - V_{THN}\right]^2$

$= \beta V_{LO} V_{RF} \cos(\omega_{LO} t)\cos(\omega_{RF} t)$ → $\omega_{LO} - \omega_{RF}$ ✓, → $\omega_{LO} + \cancel{\omega_{RF}}$

$+ \frac{\beta}{2} V_{LO}^2 \cos^2(\cancel{\omega_{LO}} t) + \frac{\beta}{2} V_{RF}^2 \cos^2(\cancel{\omega_{RF}} t) + \frac{\beta}{2} V_{THN}^2$

$- \beta V_{THN} V_{LO} \cos(\cancel{\omega_{LO}} t) - \beta V_{THN} V_{RF} \cos(\cancel{\omega_{RF}} t)$

filter should allow $\omega_{LO} - \omega_{RF}$

and reject $\omega_{LO} + \omega_{RF}$

ω_{LO}

ω_{RF}

$v_{IF} = \frac{\beta}{2} V_{LO} \cdot V_{RF}$

$v_{IF} = \frac{\beta}{2} v_{LO} v_{RF}$ ω_{RF}

$\Rightarrow$ Voltage conversion gain $A_c = \frac{V_{IF}}{V_{RF}} = \frac{\beta}{2} R_L V_{LO}$ ← depends upon V_{LO} (amplitude of the LO signal)

& second derivative of MOSFET I-V characteristics.