18.09.25

UNIT – IV

Mixers and Detectors

Mixers:

→ Converting RF → Baseband / IF frequency. (RF Rx^{r})

→ Baseband + LO → RF (RF Tx^{r})

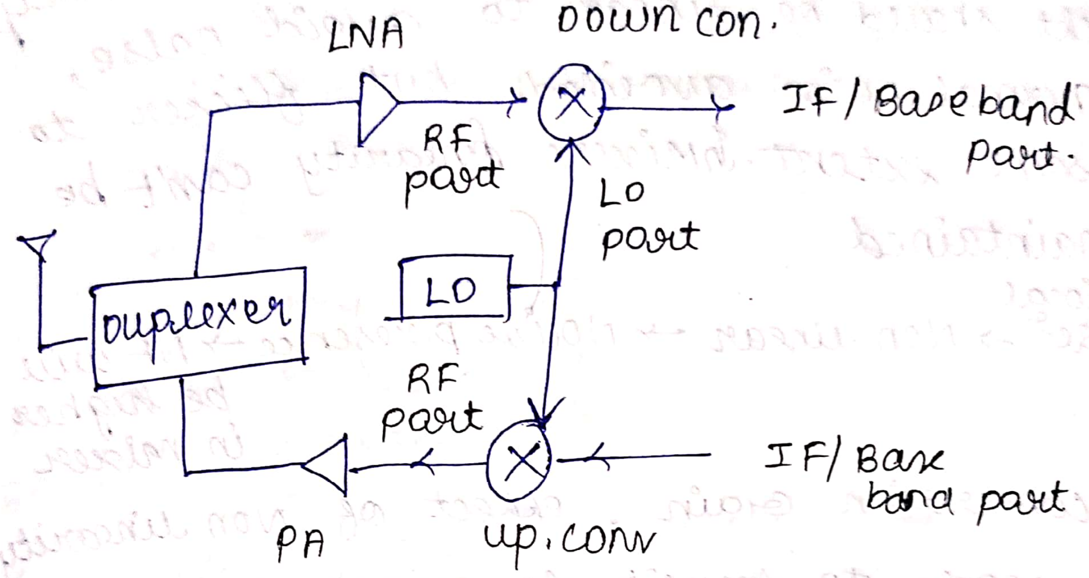
upconversion (Txr) — Down conversion (RXr)

up conversion:

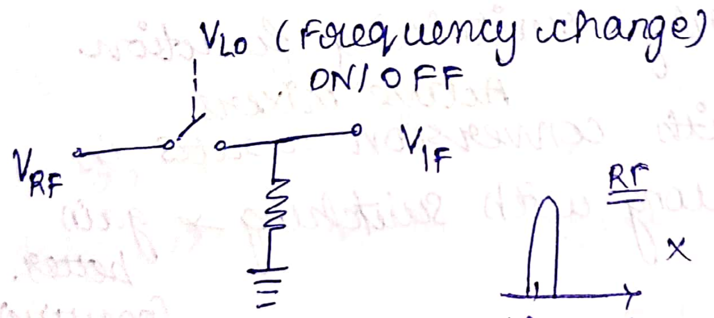
In Txr, mixer converts a low freq Baseband sig (audio (or) data) into high freq RF sig. mixing Baseband with LO signal to produce new signal at the sum of ori. freq (sometime diff)

Down conversion:
converts high freq RF back down to low frequency using IF or baseband by mixing RF with LO signal

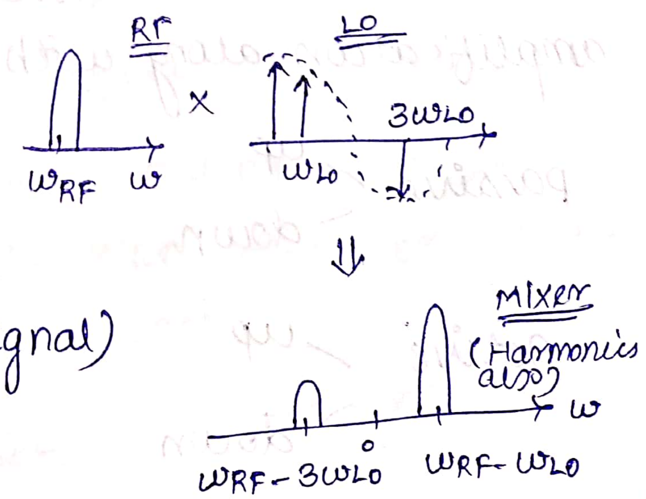
Generic Transceiver:



→ Abrupt change in LO frequency, decides frequency at end of mixers.
→ ckt mixes the RF i/p with all LO harmonics - mixing spurs.



Switching,
chopped signals
(Return to zero signal)



Performance parameters:

1. Noise & Linearity

2. Gain

3. port-to-port feed through.

* Thermal noise + Flicker Noise (due to non linearity)

ckt should be linear to avoid noise, Thermal noise avoided but flicker to some extent. In Mixers linearity can't be maintained

Local osc^r → Non linear → Noise presence → NF will be higher in mixer

* conversion Gain, effect of Non linearity leads to Amplitude suppression leads to -ve value hence conversion loss.

switching fun — passive mixer
— active mixer

passive mixer

Transistor only switching function

Active mixers

(CMOS) Transistor with conversion results in amplification along with switching → gain better. (positive)

passive — up
— down

Active — up
— down

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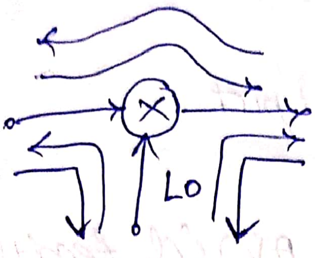
* 3-port N/W → Isolated each other
(like each port)
→ LO port
→ I/p port
→ o/p port

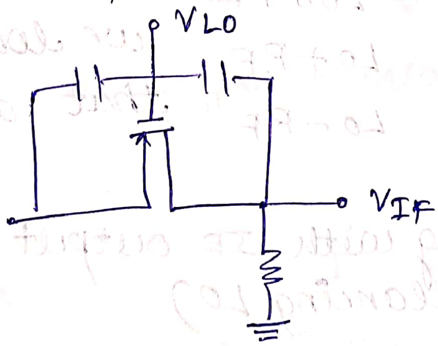
poor Isolation → RF and LO component leakages (Through ports)



Fd bck mechanisms

LO to RF Feed through
LO to IF Feed through
RF to IF Feed through

unbiased → parasitic capacitances → passes AC ripples → Back to RF.



LO to RF:
self mixing & DC offset.

In direct conv. Rxr → LO & RF close → Through feedthrough → LO re-enter mixer through RF & mix itself.
self mixing produces DC component (or) low frequency component.

DC offset can interfere with accurate detec^n of low fre or DC signals leading to signal distortion.

LO and IF:

Interference with Baseband signal.

RF and IF:

unwanted signal at IF output

Balanced mixers - sol^n → Avoid feedthrough
Nullify the effect in circuit level

LO - IF ⇒ output : $\boxed{LO, LO \pm RF}$ IF carries
feedthrough

If LO, $\overline{LO}$ (diff) ⇒ -LO-RF
-LO+RF
LO+RF
LO-RF

If any comp. we look take that alone.

↓

Avoids LO
achieved along with IF output
nullifies (Balancing LO)

Single Balanced   Double Balanced.

RF to IF ⇒ output RF and diff o/p

If $\underbrace{LO, \overline{LO}, RF, \overline{RF}}$
Balanced both LO and RF in output
(Double Balanced mixer)

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30.09.25

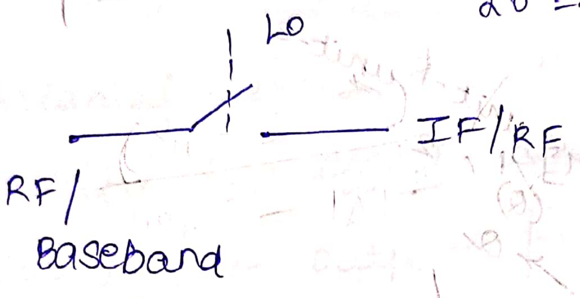
Mixers:

→ produces IF/Baseband sgl

on TX → upconversion mixer
[Baseband + LO ⇒ RF]

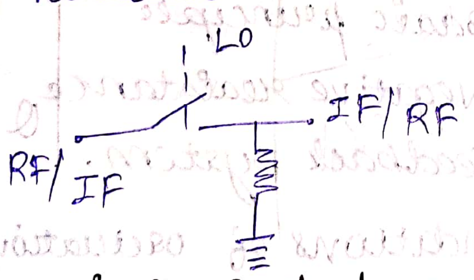
on RX → Down conversion mixer
[RF + LO ⇒ IF/Baseband]

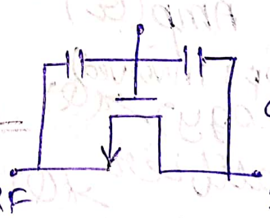
LO ⇒ switching
Based on ON/OFF



* TD as switch on FD, leads to frequency shifts.

* LO is preferably sinusoidal signal, switching occurs, chopped sgl as input leads to frequency variations at output.





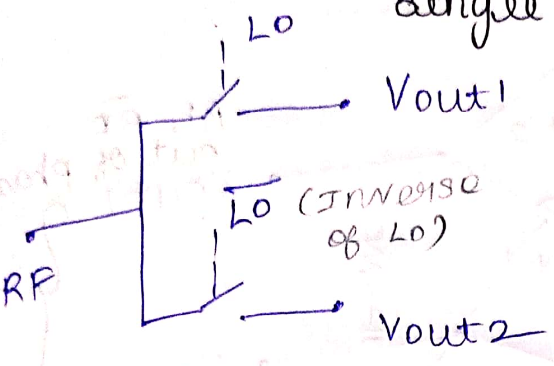
(Due to Biasing Parasitic cap. occurs)

single Ended mixer → Drawback Feedthrough

LO to RF feedthrough occurs because of parasitic capacitances along with IF, RF and LO occurs.

* To suppress this Balanced mixers are used (Differential results)

single Balanced



Differential output:

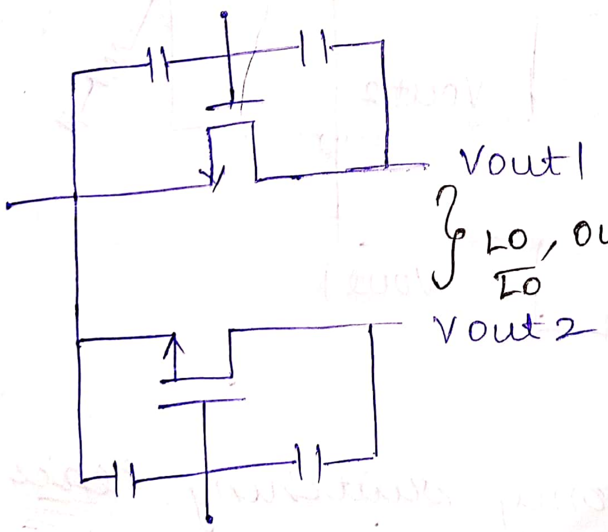
$V_{RF}^{+} - V_{RF}^{-}$ /

$V_{RF}^{-} - V_{RF}^{+}$

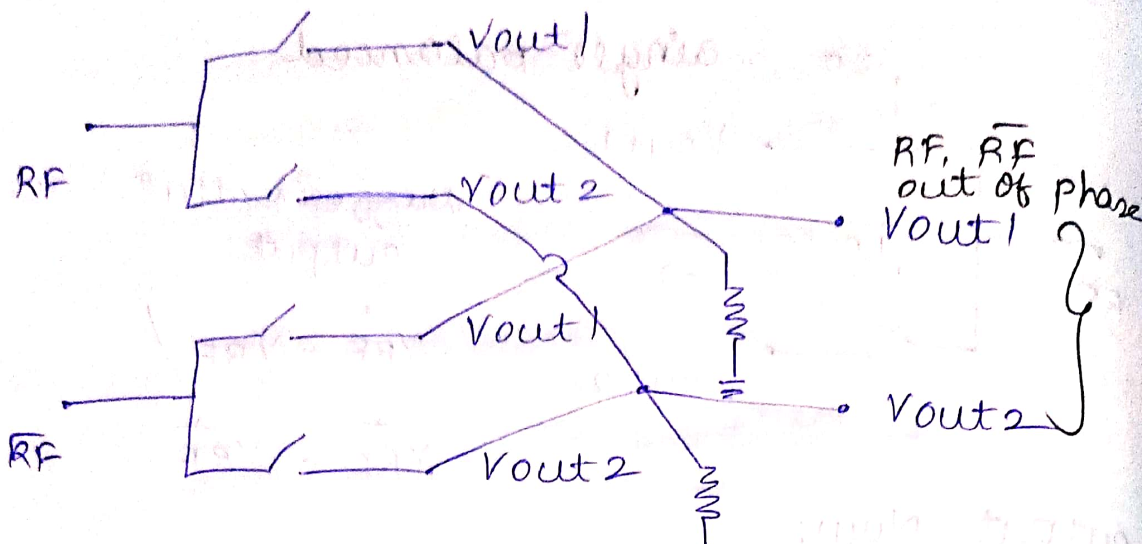
output Now:

IF, ~~LO~~, ~~$\overline{LO}$~~, RF ; Hence LO gets cancelled

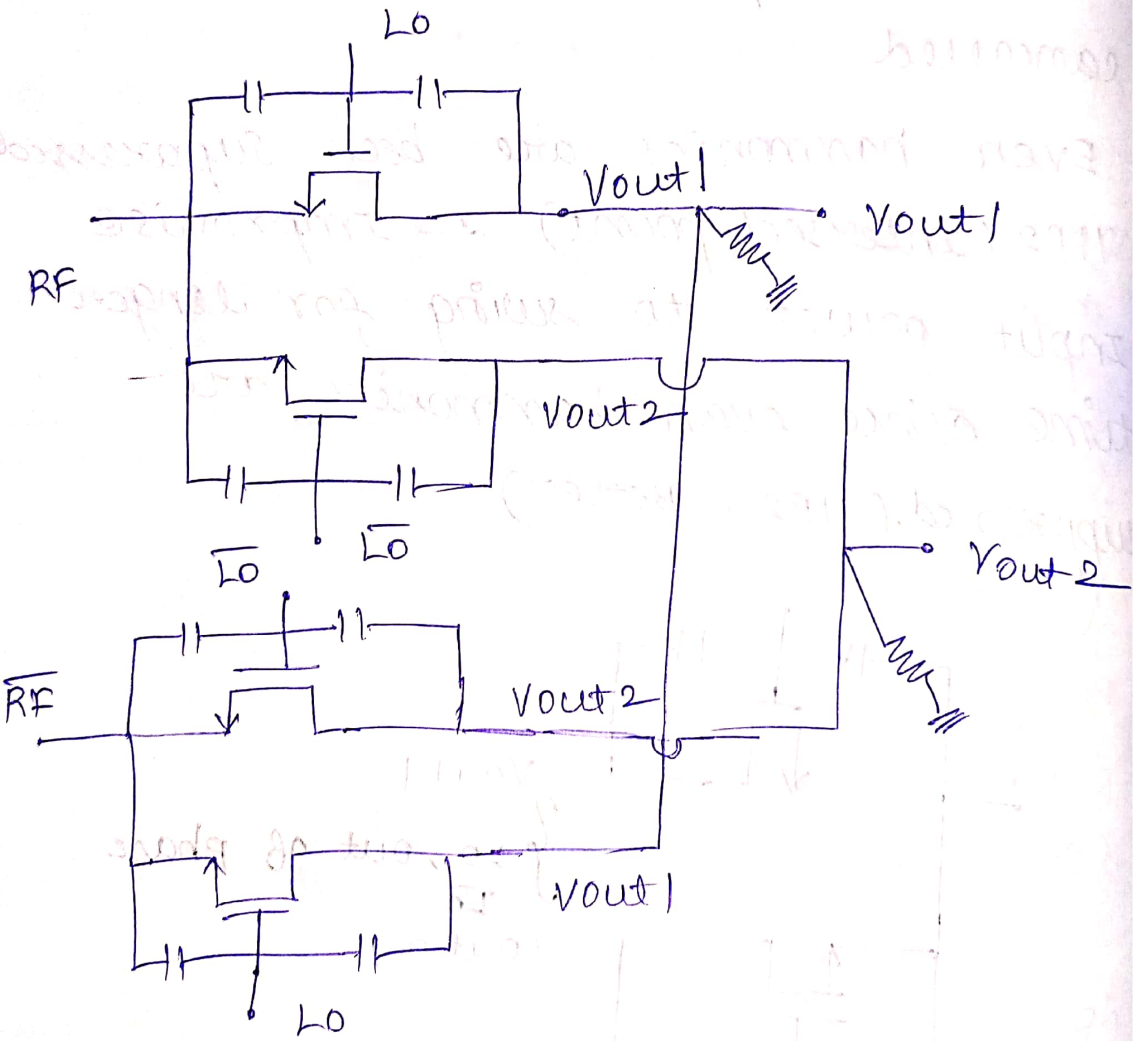
* Even harmonics are been suppressed
IIP2 (Intersect point) ← Improvise
Input power to swing for longer time since even harmonics are suppressed. (IIP2 - Better)



Double Balanced :



Both LO & RF suppressed

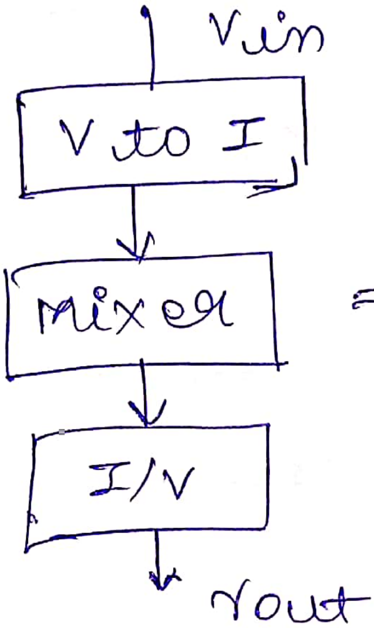


FET does only switching hence passive mixers.

Mixers → conversion loss.

passive mixers → Negative gain.

In Active mixers, negative mixers removed by using V to I conversion Block and vice versa



⇒ Mixing is terms of current hence avoid voltage drops, which occurs in passive mixers can be avoided in active mixers

* Active mixers at TX end

$\underbrace{\text{Mixter} \rightarrow \text{power Amp}}_{\text{TX.}}$

→ Drop of mixer can be addressed.

RX → passive mixers

02.10.25 Mixers

passive - Voltage switch

Active mixers:

characteristics:

Noise Figure

Conversion Gain

Image Frequency

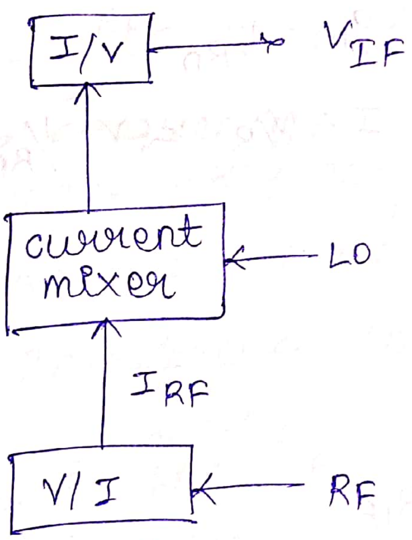
IMD - Inter Mediate Distortion (Non-linearity)

V-I converter

I - mixer

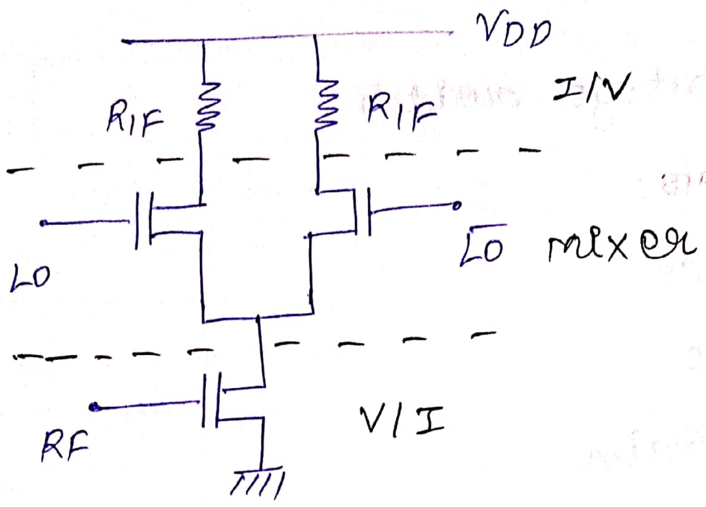
I-V converter

Block Diagram:



1. conversion Gain

* circuit diagram using single Balanced



Mixers → DC source and Freq. mixing

Accounting gm V to I → LO → mixing

LO & $\overline{LO}$ as switch passes across the resistors we yield voltage

$$\text{conversion gain} = \frac{V_{IF}}{V_{RF}}$$

$I_{RF} = V_{RF}\, g_m$

$g_m = 1/R_D$

$I = V/R = V \cdot 1/R_D$

$I_{IF} = I_{RF}\, LO$

$I_{IF} = I_{RF} \cos \omega_{LO} t$

$V_{IF} = I_{IF} \times R_{IF}$

$= I_{RF} \cos \omega_{LO} t \times R_{IF}$

$= V_{RF}\, g_m \cos(\omega_{LO}\, t) \times R_{IF}$

$$\boxed{CG = \frac{V_{IF}}{V_{RF}} = g_m \cos(\omega_{LO} t) R_{IF}}$$

$g_m R_{IF}$ = Quantified amount

Not a conversion loss

2. Noise Figure

$$NF = \frac{SNR_{o/p}}{SNR_{I/p}}$$

$NF \simeq$ conversion Gain

mixer:

$$V_{IF} = V_{LO} \times V_{RF}$$

$$V_{LO} = A_{LO} \cos(\omega_{LO} t)$$

$$V_{LO} = A_{LO} \cos(2\pi f_{LO} t)$$

$$V_{RF} = A_{RF} \cos(2\pi f_{RF} t)$$

$$V_{IF} = A_{LO} A_{RF} \cos(2\pi f_{LO} t) \cos(2\pi f_{RF} t)$$

$$V_{IF} = \frac{A_{LO} A_{RF}}{2} \left[\cos 2\pi [(f_{LO} + f_{RF})] t + \cos 2\pi [(f_{LO} - f_{RF})] t\right]$$

$$V_{IF} = \frac{A_{LO} A_{RF}}{2} \cos 2\pi (f_{LO} - f_{RF}) t$$

Image Frequency:

An Image Frequency is a frequency that produces some IF frequency which causes interference to Intendant frequency.

$f_{Img} = f_{LO} - f_{IF}$

$= f_{LO} + f_{IF}$

Eg: $f_{LO} = 110 MHZ$

(contains Info) $f_{RF} = 100 MHZ$

$f_{IF} = f_{LO} - f_{RF}$

$f_{IF} = 10 MHZ$

$(f_{RF} - f_{IF})$

$f_{IMG} = 100 - 10 = 90 MHZ$

$= 100 + 10 = 120 - 10 = 110 MHZ$

$(f_{RF} + f_{IF})$

Now f_{IMG} as input (no Info)

$f_{IMG} - f_{LO} = 10 MHZ$ (same)

same frequency but if Amplitude differs easy to reject Image freq component.

* Image Rejection filter to avoid, Tune it.

80 - 120 MHZ → LNA → Image Rej Filter → Mixer
(Band filter)

Non-linearity Effects. $V = V_{in} + V_{in}^2 + V_{in}^3 + \dots$

$V_{in} = A \cos \omega t$

Image modulation distortion (IMD)

squaring

$V_{in}^2 = A^2 \cos^2 \omega t$

$= \frac{A^2}{2}(1 + \cos 2\omega t)$

$= \underbrace{\frac{A^2}{2}}_{\text{DC component}} + \frac{A^2}{2} \cos \underline{2\omega t}$ → second harmonics

$V_{in}^3 = (A\cos \omega t)^3 = A^3 \cos^3 \omega t$

$= A^3 \cdot \left[\frac{3}{4} \underbrace{\cos \omega t}_{\text{Fundamental}} + \frac{1}{4} \underbrace{\cos 3\omega t}_{\text{Third Harmonics}} \right]$

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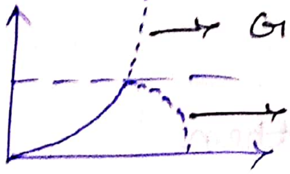
Fundamental freq → Gain Expansion/
(Amplitude) Gain compression

Eg: In CC t^r



IIP 2 - second harmonics is 1dB (amp) down the fundamental freq
↓
(Intercept point)

$$V_{IF} = V_{LO} \times V_{RF}$$
$$= A_1 A_2 [\cos \omega_1 t \times \cos \omega_2 t]$$

$$(V_{IF})^2 = A_1^2 A_2^2 (\cos(\omega_1+\omega_2)^2 t + \cos(\omega_1-\omega_2)^2 t)$$
$$= A_1^2 A_2^2 (\cos \omega_1^2 t + \cos \omega_2^2 t + 2\cos \omega_1 \omega_2 t$$
$$+ \cos \omega_1^2 t + \cos \omega_2^2 t - 2\cos \omega_1 \omega_2 t)$$

Fund freq + Non linearity → Additional fre close to Fundamental (IMD)
Distortion ←

To overcome ⇒ sharp filtering effects
choice of LO.

Non linear - Image Frequency.

06.10.25

Image Rejection mixer:

f_{RF}, f_{LO}, f_{IF}

$$f_{IF} = |f_{RF} - f_{LO}|$$

f_{image} ⇒ if $f_{LO} > f_{RF}$ then

(To be removed)

$$f_{img} = f_{LO} + f_{IF}$$

if $f_{LO} < f_{RF}$ then

$$f_{LO} - f_{IF}$$

Filter suppresses original info hence phase shift in LO

* split RF
* split LO (90° shift on one path) and another original
* combine.

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

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

Let:

$$V_{LO,I} = V_{LO} \cos(\omega_{LO} t)$$

$$V_{LO,Q} = V_{LO} \sin(\omega_{LO} t) \text{ Quadrature}$$

$$V_{IF,I} = V_{RF} \times V_{LO,I}$$

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

$$V_{IF,I} = \frac{V_{RF}V_{LO}}{2}\left[\cos(\omega_{RF}-\omega_{LO})t + \cos(\omega_{RF}+\omega_{LO})t\right] \quad \text{— (1)}$$

$$V_{IF,Q} = V_{RF}\cos(\omega_{RF}t) \times V_{LO}\sin(\omega_{LO}t)$$

$$= \frac{V_{RF}V_{LO}}{2}\left[\sin(\omega_{RF}-\omega_{LO})t + \sin(\omega_{RF}+\omega_{LO})t\right]$$

$$V_{IF} = e^{j(\omega_{RF}-\omega_{LO})t} + e^{j(\omega_{RF}+\omega_{LO})t}$$

After LPF

$$V_{IF} = e^{j(\omega_{RF}-\omega_{LO})t}$$

$$= \cos(\omega_{RF}-\omega_{LO})t + j\sin(\omega_{RF}+\omega_{LO})t$$

when phase shift $\sin \rightarrow \cos \Rightarrow$ same phase (Inphase retains)

$f_{image} = f_{IF} + f_{LO}, \; f_{LO} - f_{IF}$

Down conversion part working

$f_{image} = f_{LO} - f_{IF}$

Instead of RF, Image freq.

In (1)

$$V_{IF,I} = \frac{V_{image}V_{LO}}{2}\left[\cos(\omega_{LO}-\omega_{IF}-\omega_{LO})t + \cos(\omega_{LO}-\omega_{IF}+\omega_{LO})t\right]$$

on LPF

$$= \frac{V_{img}V_{LO}}{2}\left[\underline{\cos(-\omega_{IF})t} + \cos(2\omega_{LO}-\omega_{IF})t\right]$$

$$V_{image,Q} = \frac{V_{image} V_{LO}}{2} [\sin(\omega_{LO} - \omega_{IF} - \omega_{LO})t + j\sin(\omega_{LO} - \omega_{IF} + \omega_{LO})t]$$

$$V_{image,Q} = \frac{V_{image}, V_{LO}}{2} [\sin(-\omega_{IF}) + j\sin(2\omega_{LO} - \omega_{IF})$$

on using combiner

$\cos(-\theta) = \cos\theta$

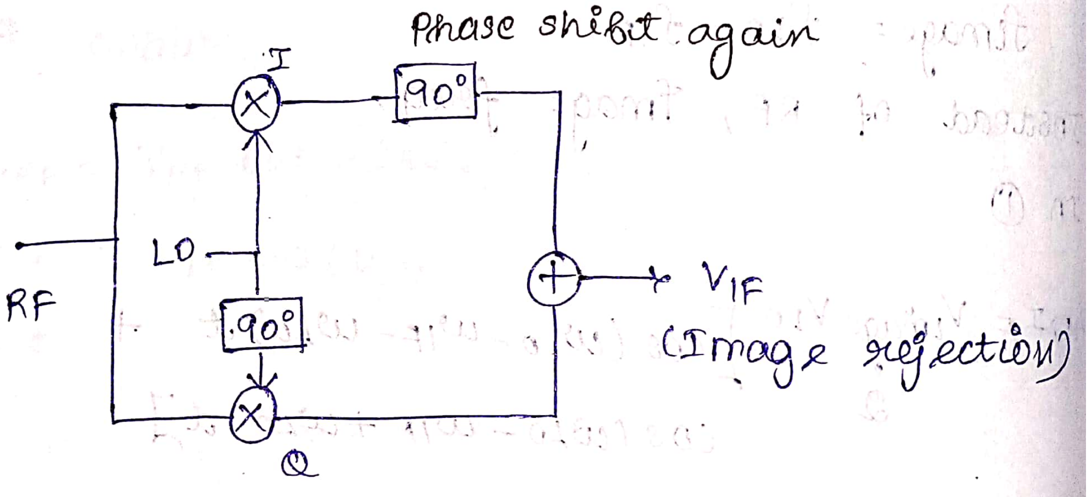
$\sin(-\theta) = -\sin\theta$

V_{IF} image $= \cos(\omega_{IF}) - j\sin(\omega_{IF})$

Again doing phase shift

$\boxed{V_{IF,\ image} = 0}$ $[\cos(\omega_{IF}) - \cos(\omega_{IF}) = 0]$

Block diagram:



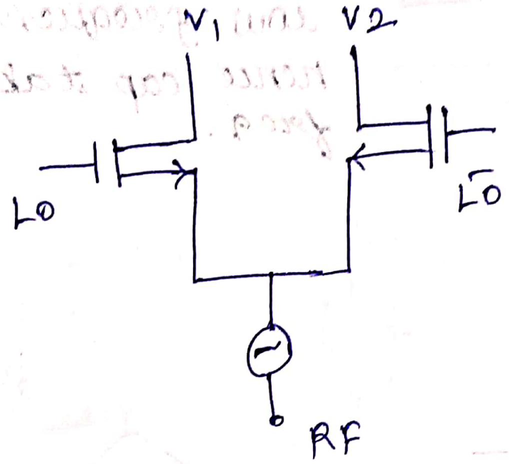
Types:

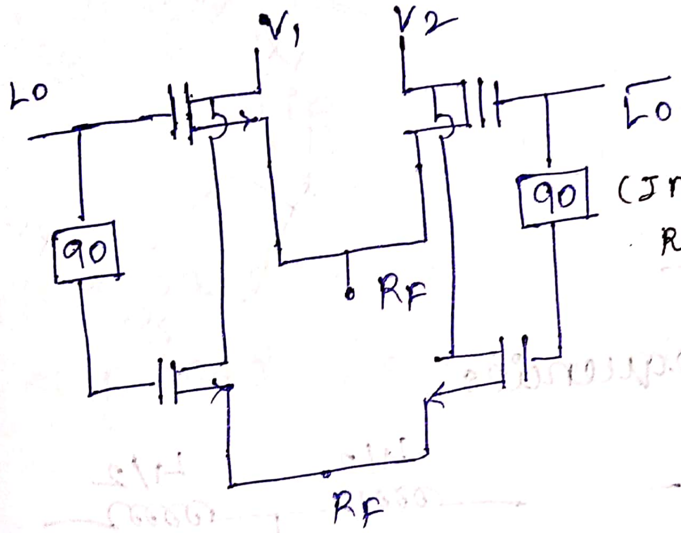
1. Quadrature Image Rejection
2. Single Balanced Image Rejection
3. Double Balanced Image Rejection

→ Feedthrough presents in Quadrature IRM

→ single & double balanced overcomes feedthrough too.

single Balanced Image Rejection mixer:





(Image rejection & LO suppression).