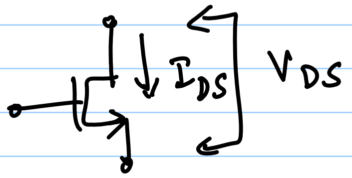
Note Title 9/22/2011

Lecture 24: Other mixers; Tx Architectures

Potentiometric mixers

Basic idea:

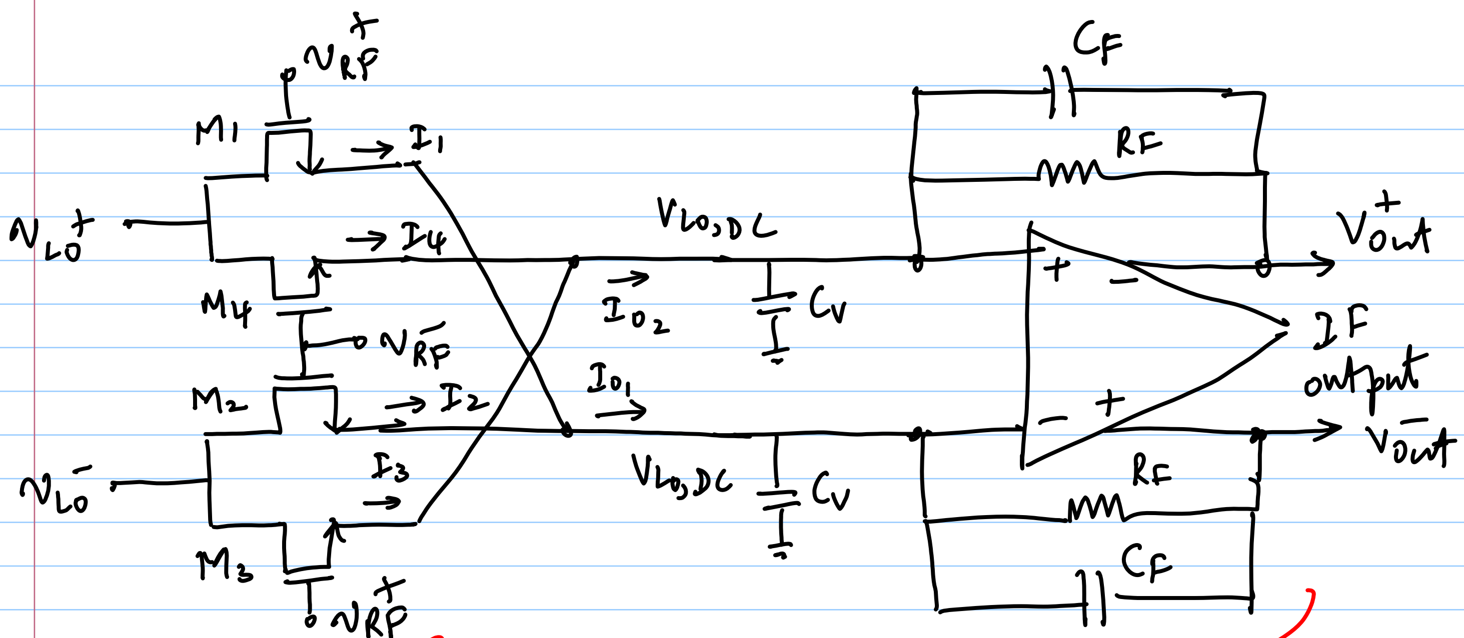


triode region MOSFET

set $R_{DS} \propto \dfrac{1}{v_{RF}}$

if V_{DS} = fixed, $I_{DS} = \dfrac{V_{DS}}{R_{DS}} \propto v_{RF}$

if $V_{DS} \propto v_{LO}$, $I_{DS} \propto v_{RF} \cdot v_{LO}$



mixing

filter out sum & higher freq. components

→ Double-balanced structure

* cancels CM DC

* cancels non-linear dependence on g_{ds}, V_{ds}

→ C_N & C_F – filter out high-freq. components

→ GHz input stage (MOSFETs)

→ Opamp operates @ low-freq. (IF, MHz)

* virtual gnd only @ IF

→ C_r ⇒ signal gnd @ high freq.

$M_1 - M_4$ in linear region

$$I_1 = \beta_1 \left[V_{RF}^{+} - V_{LO,DC} - V_{T_1} - \left(\frac{V_{LO}^{+} - V_{LO,DC}}{2} \right) \right] \left(V_{LO}^{+} - V_{LO,DC} \right)$$

$$I_2 = \beta_2 \left[V_{RF}^{-} - V_{LO,DC} - V_{T_2} - \frac{\left(V_{LO}^{-} - V_{LO,DC} \right)}{2} \right] \left(V_{LO}^{-} - V_{LO,DC} \right)$$

$$I_3 = \beta_3 \left[V_{RF}^{+} - V_{LO,DC} - V_{T_3} - \frac{\left(V_{LO}^{-} - V_{LO,DC} \right)}{2} \right] \left(V_{LO}^{-} - V_{LO,DC} \right)$$

$$I_4 = \beta_4 \left[V_{RF}^{-} - V_{LO,DC} - V_{T_4} - \frac{\left(V_{LO}^{+} - V_{LO,DC} \right)}{2} \right] \left(V_{LO}^{+} - V_{LO,DC} \right)$$

$$I_{O_1} = I_1 + I_2$$

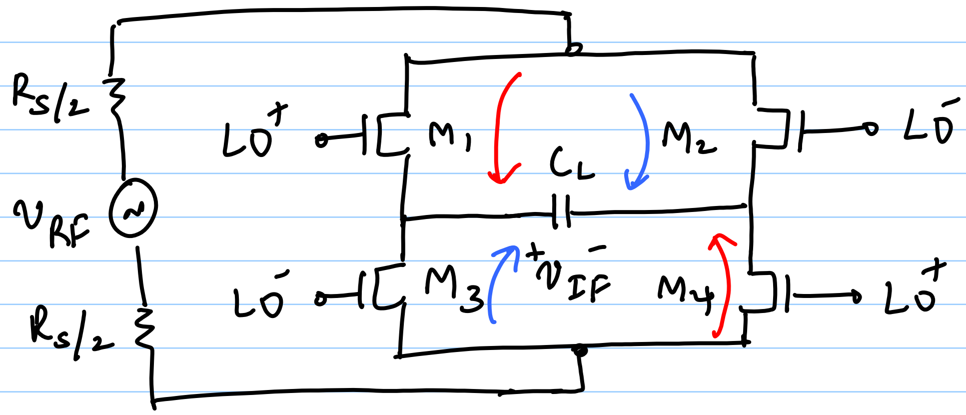
$$I_{O_2} = I_3 + I_4$$

$$V_{out}^{+} - V_{out}^{-} = R_F \left(I_{O_2} - I_{O_1} \right) = \beta R_F \left(V_{RF}^{+} - V_{RF}^{-} \right) \left(V_{LO}^{+} - V_{LO}^{-} \right)$$

* can offer very good linearity e.g. $IIP_3 \approx 40\,dBm$
* very high NF (e.g. 30dB)
  → resistive noise of M_{1-4}
  → overall DR around the same as Gilbert mixer

Passive Mixer

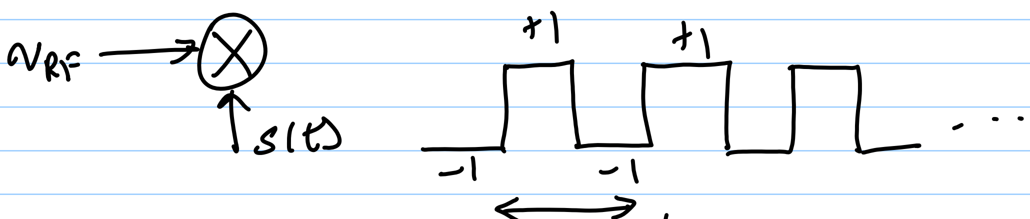
* extremely low-power operation
* use MOS as switches
* avoids $V \rightarrow I$ conversion



Double-balanced passive Mixer

+ve phase → $M_1 - M_4$ conducting $\Rightarrow v_{IF} = v_{RF}$

-ve phase → $M_2 - M_3$ conducting $\Rightarrow v_{IF} = -v_{RF}$



$T_{LO} = \frac{1}{f_{LO}}$

we know $s(t) = \frac{2}{\pi}\left[\sin(\omega_{LO}t) + \frac{1}{3}\sin(3\omega_{LO}t) + \cdots\right]$

$\Rightarrow$ output has $\omega_{LO} \pm \omega_{RF}$, $3\omega_{LO} \pm \omega_{RF}$ etc.

$$G_c = \frac{2}{\pi} \quad (= -3.92\,dB)$$

practical implementations: $G_c \sim -6$ dB

* Sinusoidal LO can give larger gain

$$G_{c,sin} = \frac{\pi}{4} \quad (= -2.1\,dB)$$ ← Ref. Thomas Lee 2nd edition, page 430

* Load filtering T.F.

$$H(s) = \frac{1}{\frac{sC_L}{g_{o,av}} + 1}$$

{$g_{o,av}$ = average value of output conductance}

* Can we L-match to boost input voltage (offset conversion loss)
* NF, IIP_3 — strong functions of LO drive
  e.g. NF ~ 10 dB (SSB); IIP_3 ~ 10 dBm
* no DC current $\Rightarrow$ can still have $1/f$ noise
  → P_{mixer} < 1 mW is common
  → power consumption only in LO buffers

Tx Architectures

Reminder: Bandpass signal $x(t)$ can be written as:

Polar: $x(t) = a(t)\cos(\omega_{LO}t + \varphi(t))$

AM ($a(t)$), PM ($\varphi(t)$)

Cartesian: $x(t) = x_I(t)\cos\omega_{LO}t - x_Q(t)\sin\omega_{LO}t$

$x_I(t) = a(t)\cos\varphi(t)$ (in-phase)

$x_Q(t) = a(t)\sin\varphi(t)$ (quadrature)

complex envelope:

$$x(t) = \mathrm{Re}\left[\tilde{x}(t)\, e^{j\omega_{LO}t}\right]$$

$$\tilde{x}(t) = x_I(t) + j\,x_Q(t) = a(t)\, e^{j\varphi(t)}$$

$x_I(t)$ & $x_Q(t)$ are real signals

$\Rightarrow \quad x_I(t) \rightarrow X_I(f) \; ; \quad X_I(f) = X_I^*(-f)$ etc.

* pairs of signals can be considered "complex" if they satisfy:

$$c = a + jb \quad \& \quad z = x + jy$$

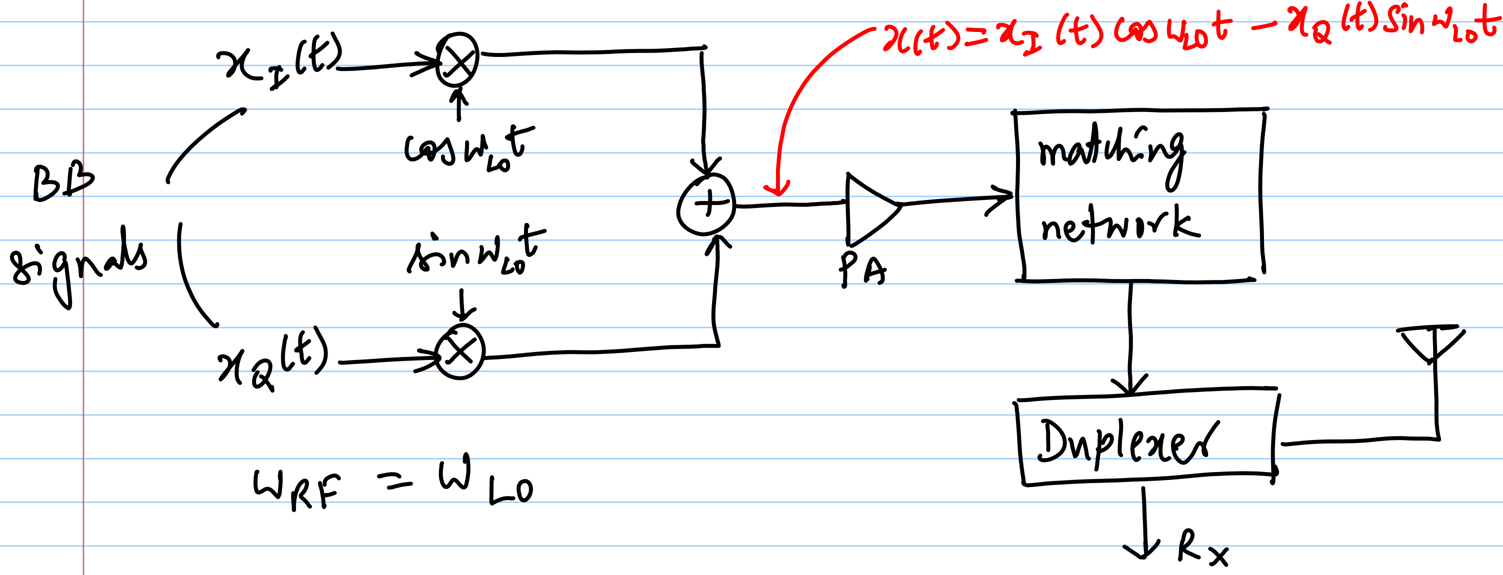
$$\Rightarrow \quad c + z = (a+x) + j(b+y)$$

$$\& \quad cz = (ab - xy) + j(bx - ay)$$

Tx Architectures

* Noise, interference rejection, band selectivity are more relaxed (compared to Rx)
* Obviously, Linearity & power efficiency are concerns

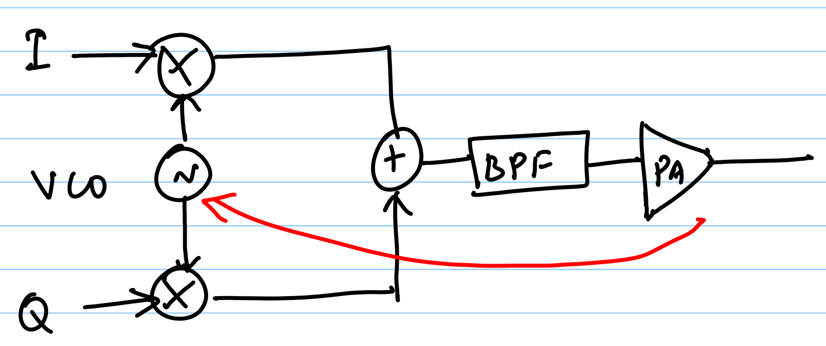
1) Direct-conversion Tx: (Homodyne)

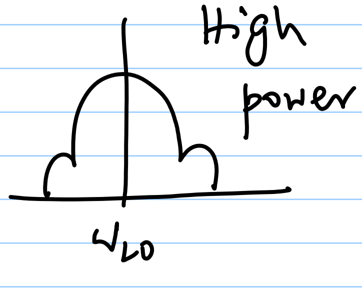


$\omega_{RF} = \omega_{LO}$

* BB signal is produced in the Tx (i.e. it is strong) $\Rightarrow$ noise of mixers is not critical

PA pulling:





* "Injection Locking": PA corrupts VCO spectrum

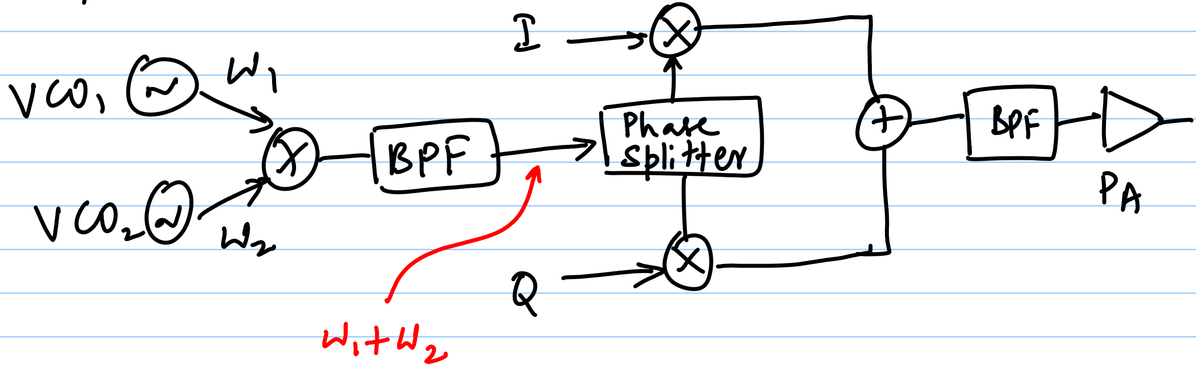
→ EM coupling

→ supply coupling

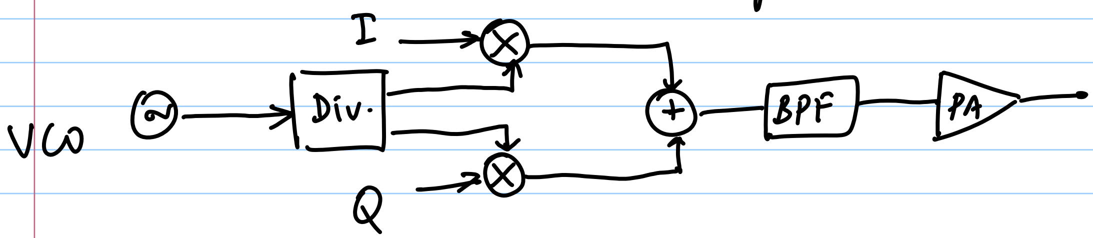
* Pulling gets worse if PA is turned ON & OFF periodically (e.g. GSM)

Solution: $\omega_{VCO} \neq \omega_{LO}$

a) Offset LO freq.



b) LO frequency dividers (very common in modern systems)

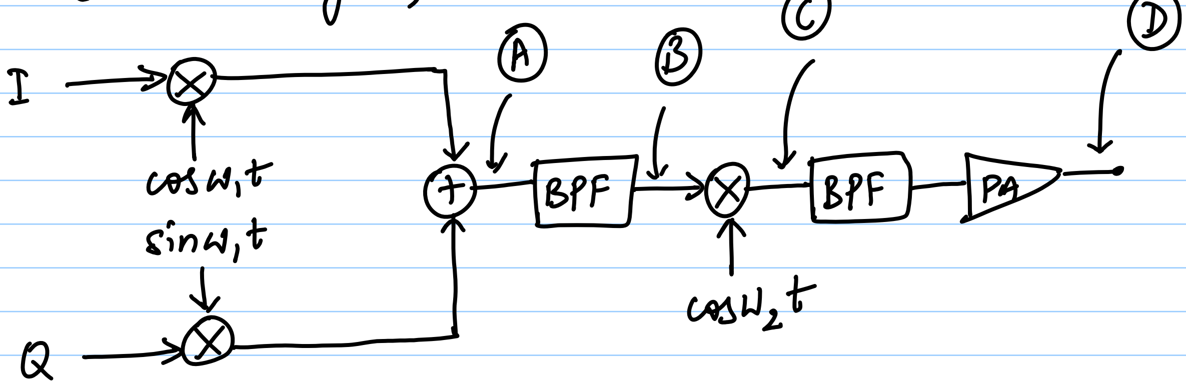


e.g. $\div 2$ or $\div 4$

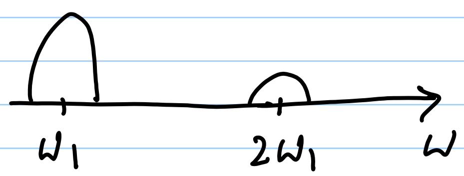
* $\div 2$ circuit can be easily designed to produce $0°, 90°$ signals

* Can still have pulling from harmonics of PA output (e.g. 2nd or 4th harmonic)

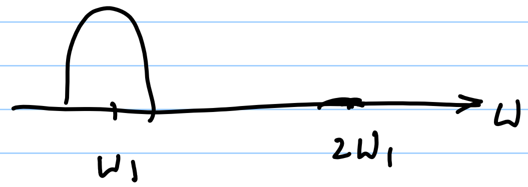
2) Two-step Tx : another solution to pulling
(Heterodyne)



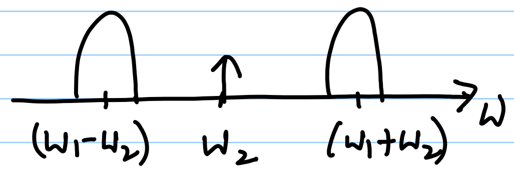
A



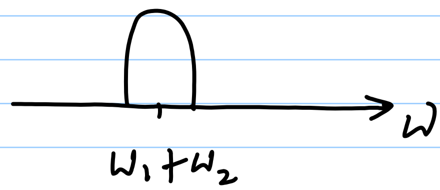
B



C



D



* $\omega_{PA} = \omega_1 + \omega_2 \gg \omega_1, \omega_2$
* $\omega_1 = \omega_{IF}$ (intermediate freq.)
* $BPF_1 \rightarrow$ removes ω_1 harmonics

  $BPF_2 \rightarrow$ removes $(\omega_1-\omega_2)$ sideband

remember : $(\omega_1+\omega_2)$ & $(\omega_1-\omega_2)$ – equal amplitudes

BPF_2 – difficult to realise, off-chip passive device (expensive)

<u>Unwanted Emissions</u>

1) <u>Emission Mask</u>

India : TRAI
US : FCC

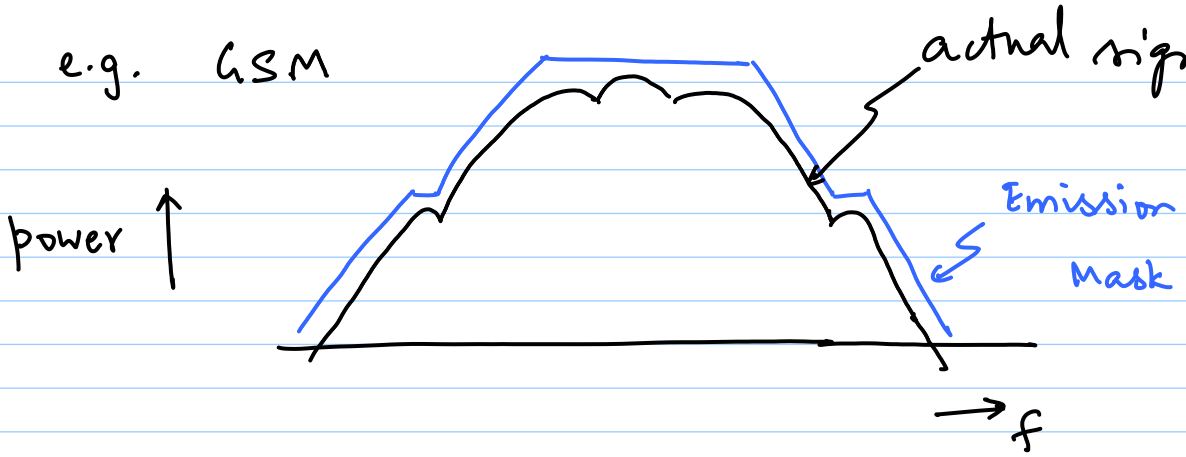
* Very strict regulations on radiated Tx signal (from wireless standard & regulating authority)

→ negligible radiation in adjacent channels

$\Rightarrow$ "Emission mask"

→ Tx output spectrum must lie below the mask.

e.g. GSM



2) Adjacent Channel Power (ACP)

ACP = relative adjacent channel power for modulated signal (dBc)

→ ratio of powers integrated over a certain BW

→ usually limited by Tx linearity performance (low freq. offsets)

CDMA – ACPR (ACP ratio)

WCDMA – ACLR (AC Leakage Power Ratio)

GSM → ORFS (output radio freq. spectrum)

3) Spurs: unwanted freq. components, harmonics

* mixers, VCO/PLL, PA non-linearities etc.
* FDD: spurs in Rx band are very troublesome
* can act as interferers for other users

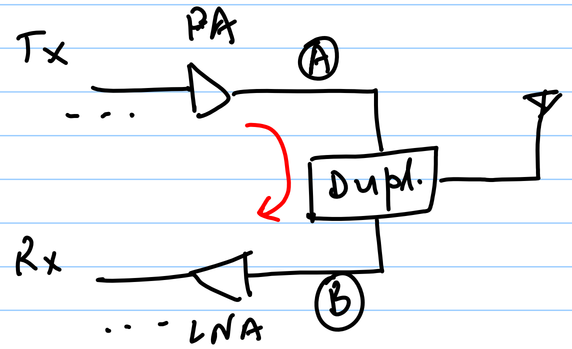
4) Noise :

* Output thermal noise is critical
  → raises Rx band noise floor in FDD-based systems (Tx & Rx ON simultaneously)

* $P_{MDS} = -174\,dBm + 10\log B + NF + SNR$ ← is affected

* (Noise @ Rx input) = (Rx-band noise @ Tx output) $-$ $\underbrace{\text{(Duplexer Rejection)}}$

From A to B @ Rx-freq. offset from Tx



e.g. Duplexer rejection = 50 dB; $f_{Tx} = 824$ MHz ; $f_{Rx} = 869$ MHz

Tx noise @ 45 MHz offset = $-160\,dBc/Hz$; $P_{Tx} = +27\,dBm$

$B = 3.84$ MHz

$$\rightarrow N_{Tx} @ B = -160\,dBc/Hz + 27\,dBm - 50\,dB$$

$$= -183\,dBm/Hz$$

We want $N_{Tx} << -174\,dBm/Hz$ so that noise floor is not raised

$10\log kT$

Note: Rx → in-band noise matters most

Tx → in-band noise matters less

→ Rx-band noise matters most