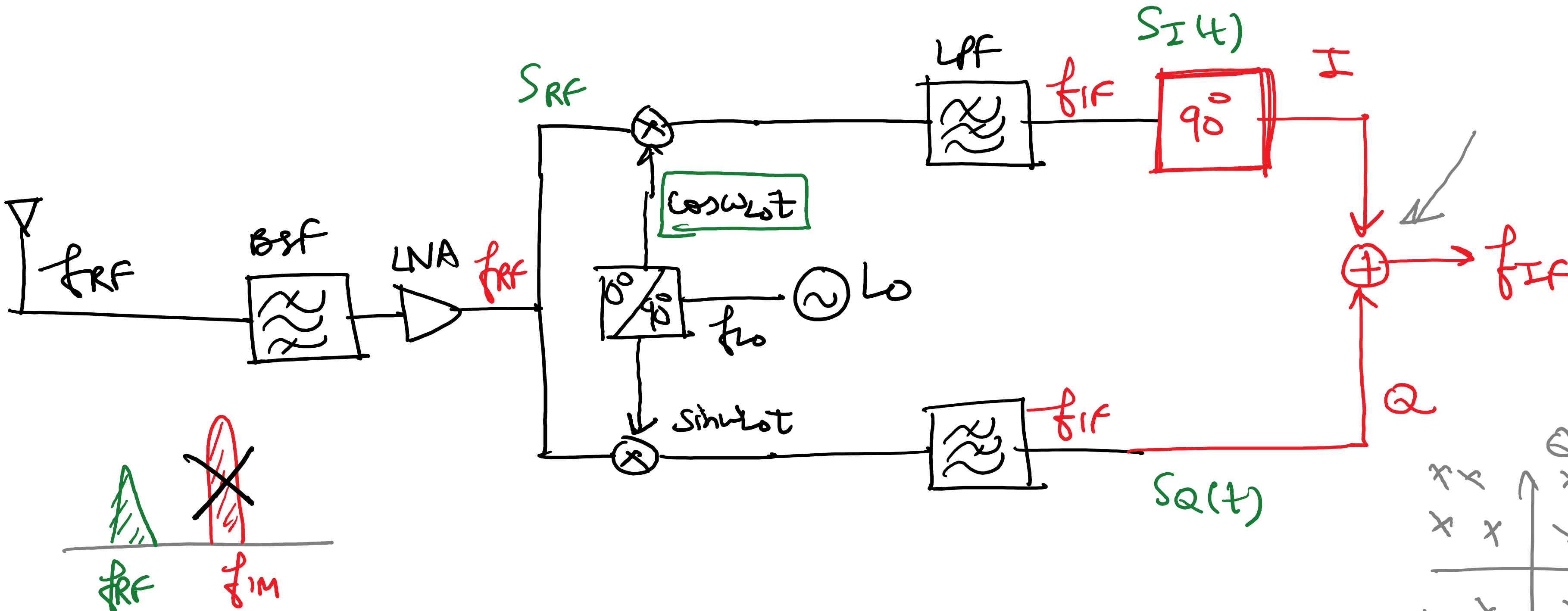
# ECE 513- Lecture 5

Tuesday, September 4, 2018 9:20 AM

## Hartley Image Reject Receivers





$$S_{RF} = A_{RF}\cos(\omega_{RF}t + \alpha_{RF})$$

$$S_{IM} = A_{IM}\cos(\omega_{IM}t + \alpha_{IM})$$

$$f_{RF} = f_{LO} - f_{IF} \quad \& \quad f_{IM} = f_{LO} + f_{IF}$$

$$\Rightarrow \omega_{RF} = \omega_{LO} - \omega_{IF} \quad \& \quad \omega_{IM} = \omega_{LO} + \omega_{IF}$$

$$S_I(t) = A_{RF}\cos(\omega_{RF}t + \alpha_{RF}) \cdot \cos(\omega_{LO}t) + A_{IM}\cos(\omega_{IM}t + \alpha_{IM}) \cdot \cos(\omega_{LO}t)$$

$\downarrow$ multiply $\cos A \cos B$, LPF and arrange the terms

$$S_I(t) = \frac{A_{RF}}{2}\cos(\omega_{IF}t - \alpha_{RF}) + \frac{A_{IM}}{2}\cos(\omega_{IF}t + \alpha_{IM}) \longrightarrow (1)$$

$\downarrow$ $90°$ phase shift

$$S_{I_{90°}}(t) = \underbrace{\frac{A_{RF}}{2}\sin(\omega_{IF}t - \alpha_{RF})}_{} + \frac{A_{IM}}{2}\sin(\omega_{IF}t + \alpha_{IM}) \longrightarrow (2)$$

Similarly for the Q-path

$$S_Q(t) = A_{RF} \cdot \cos(\omega_{RF}t + \alpha_{RF}) \cdot \sin(\omega_{LO}t) + A_{IM}\cos(\omega_{IM}t + \alpha_{IM}) \cdot \sin(\omega_{LO}t)$$

$\downarrow$ LPF and rearrange terms

$$S_Q(t) = \underbrace{\frac{A_{RF}}{2}\sin(\omega_{IF}t - \alpha_{RF})}_{} - \frac{A_{IM}}{2}\sin(\omega_{IF}t + \alpha_{IM}) \longrightarrow (3)$$

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Add Eq ② & ③

$$S_{IF}(t) = \underbrace{A_{RF}} \cdot \sin(\omega_{IF} t - \underbrace{\phi_{RF}})$$

↳ recover original modulating bits

* Image Reject RX are sensitive to

① Amplitude mismatch and phase error between the I & Q paths

↳ monolithic integration

② If the LO phases ($\cos \omega_{LO} t$ & $\sin \omega_{LO} t$) are not in exact quadrature ⇒ I & Q terms are not identical

↳ fraction of image remains at $f_{IF}$.

# Image Reject Ratio (IRR) :

Razavi 2nd ed. Chap-4

If the LO waveforms are

$$\underbrace{(1+\varepsilon)}_{\text{Amplitude mismatch}} \cos(\omega_{LO} t + \underbrace{\Delta\theta}_{\text{phase error}}) \quad \& \quad \sin(\omega_{LO} t)$$

Received & Image input signal

$$\Rightarrow A_{RF} \cos(\omega_{RF} t + \alpha_{RF}) + A_{IM} \cos(\omega_{IM} t + \alpha_{IM})$$

$$\left.\frac{P_{IM}}{P_{RF}}\right|_{out} = \frac{A_{IM}^2}{A_{RF}^2} \cdot \underbrace{\left( \frac{(1+\varepsilon)^2 - 2(1+\varepsilon)\cos\Delta\theta + 1}{(1+\varepsilon)^2 + 2(1+\varepsilon)\cos\Delta\theta + 1} \right)}_{IRR} \simeq \frac{4}{\varepsilon^2 + \Delta\theta^2}$$

for $\varepsilon \ll 1$, $\Delta\theta \ll 1$ rad

ratio of powers output

at the output

Weaver Architecture ← similar to Hartley Receiver

↑ Read from the Textbook

# Direct Conversion (Zero-IF) Receiver

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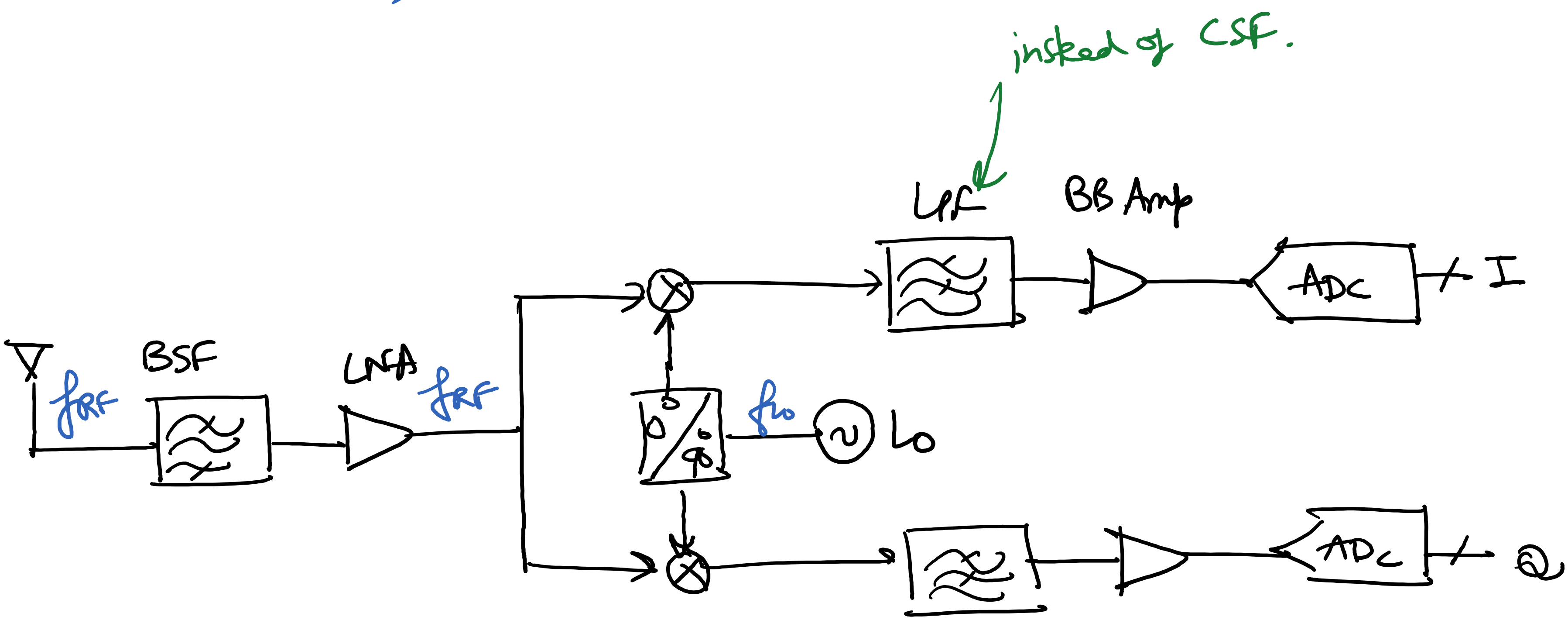
↳ Colebrooke, 1924




$$f_{RF} = f_{LO} \Rightarrow f_{IF} = 0$$

↳ the modulated carrier is downconverted to baseband

↳ special case of heterodyne RX

(f) Image problem dissappears $\Rightarrow$ signal is its own image

↳ IRF is no longer needed

↳ CSF is replaced by a LPF

# Issues with Zero-IF Rxs

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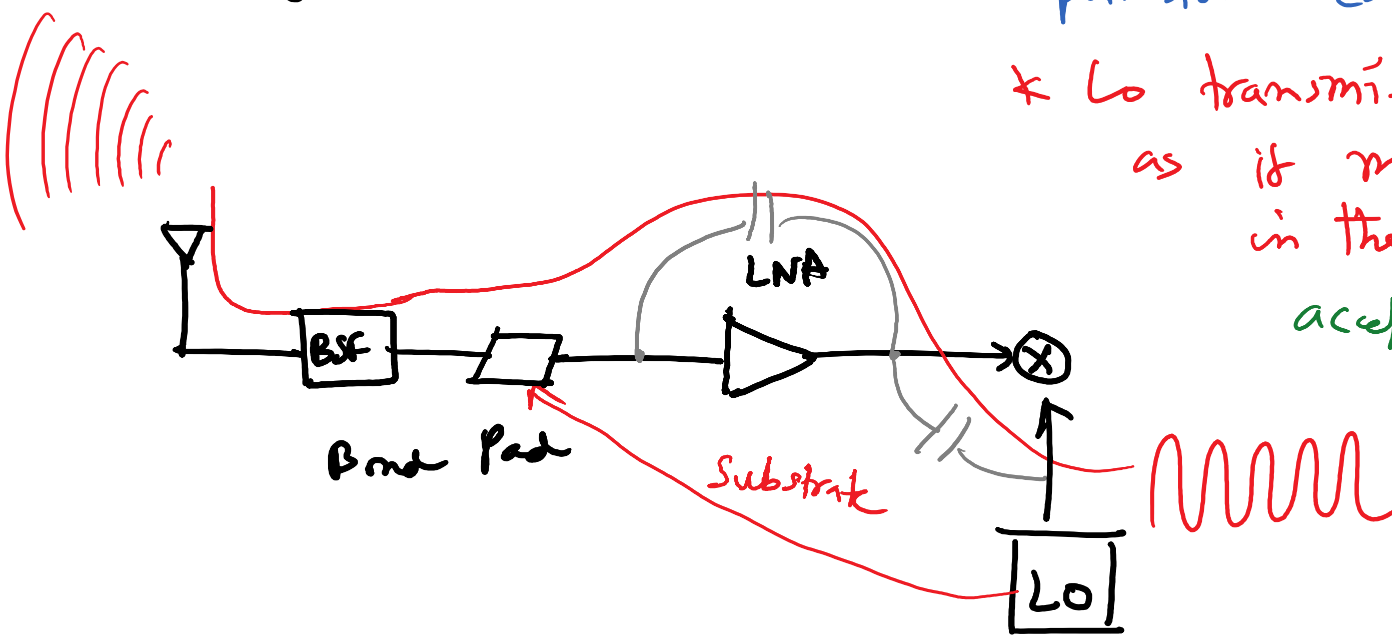
## LO leakage:

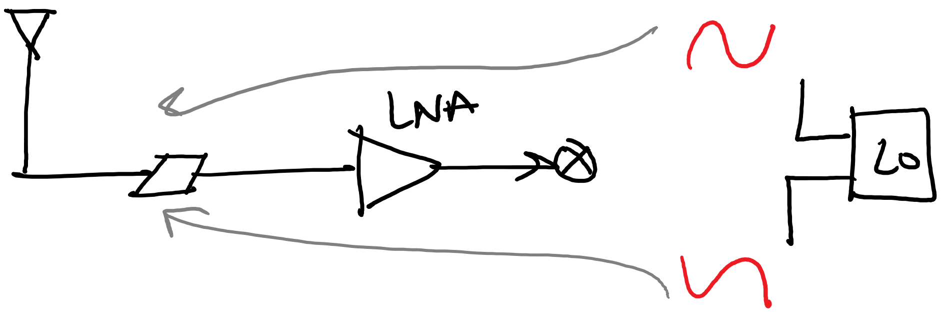
* LO couples to the antenna thru parasitic capacitance & substrate
* LO transmission is undesirable as it may affect other Rx in the band

acceptable value is −50 to −70 dBm measured at the antenna

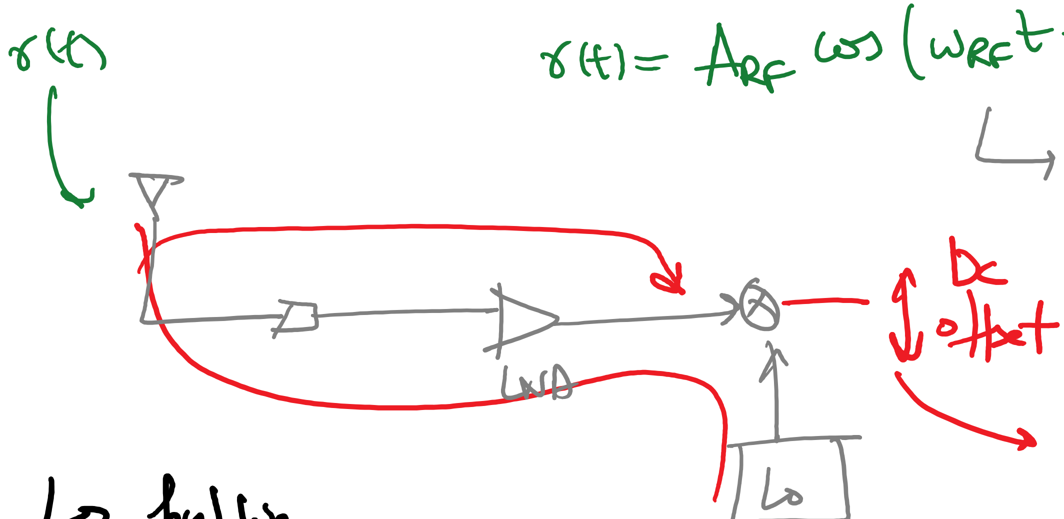



* LO leakage is suppressed by the BSF in heterodyne architecture ( $f_{RF} = f_{LO} - f_{IF}$ )

* Lo leakage is avoided by symmetric layout



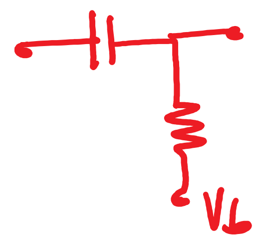

* DC offset due to Lo self-mixing




$$r(t) = A_{RF} \cos(\omega_{RF} t + \alpha_{RF}) \cdot \cos(\omega_{Lo} t)$$

↳ DC terms

$$\cos^2\theta = \frac{1 + \cos 2\theta}{2}$$




* Lo pulling

* Even-order nonlinearities.

# RF Transmitter Architectures

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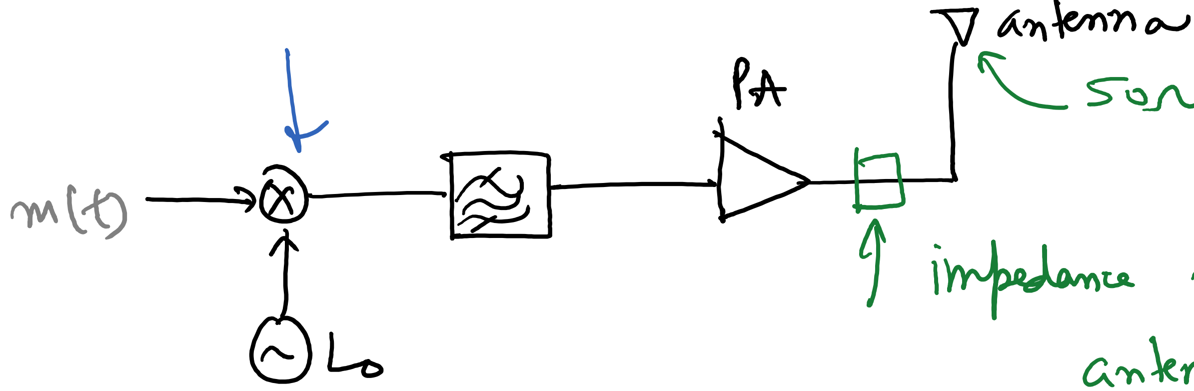



← 50Ω load

↑ impedance match between PA and antenna

* PA is a key component in the transmitter

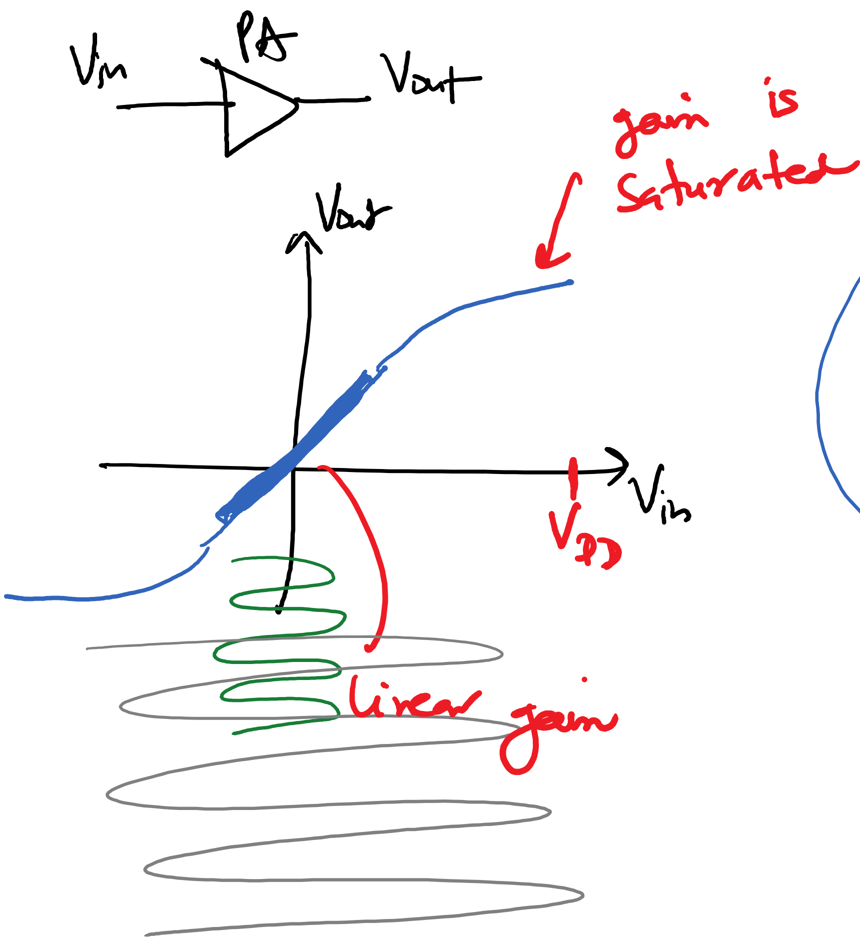
The modulation of the carrier is performed:

① Linearly by frequency translation using a mixer

② By directly modulating the carrier amplitude, frequency, phase or pulse width

↳ Direct modulation is implemented either in linear or non-linear fashion.

* Depending upon the type of modulation
  ↳ PA operates in linear or saturated regime




$P_T \Rightarrow \frac{V_{sig}^2}{Z_0}$

has ramifications for the efficiency and power consumption of the entire TX.

# Direct Conversion Transmitter

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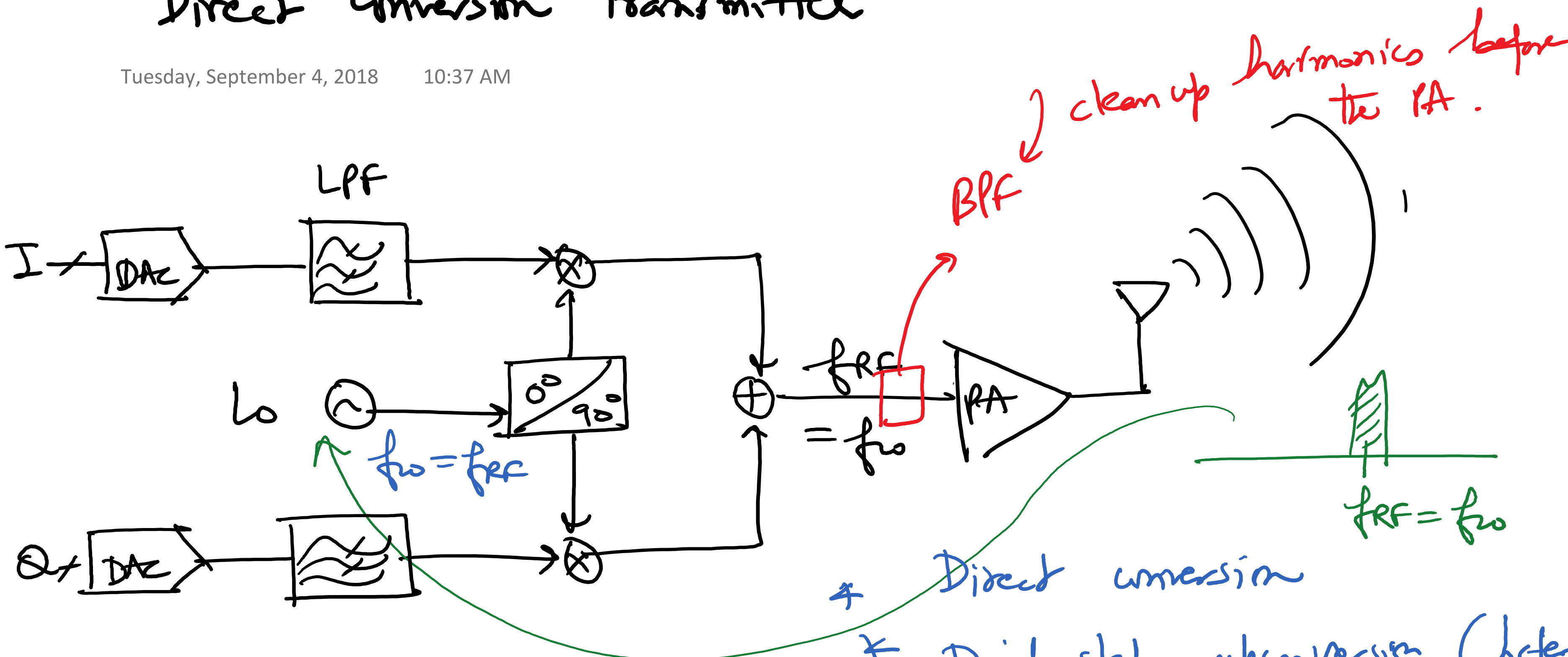


* Direct conversion
* Dual-step upconversion (heterodyne)
* Direct Modulation Transmitters.

(−) Stringent matching between I & Q paths

(−) PA signal "pulls" the oscillator and changes its frequency ⇒ Need good LO isolation/buffering

[READ from the Book]