EE194-EE290C

28 nm SoC for IoT

Ref: RF Microelectronics by Behzad Razavi. Second Edition
Terminology

In-Band Blocker Levels

Desired Channel

-70 dBm

-43 dBm

-30 dBm

-23 dBm

Out-of-Band Blocker Levels

Edge of Band

0 dBm
Filtering requirements impact the RF design of the transceiver.
RF Filtering

- Receive chain preceding channel-selection filtering must be sufficiently linear.
- Channel selection filtering is extremely difficult at the RF frequencies.

\[ Q_{BPF} \approx \frac{f_o}{BW} \]

\[ = \frac{2450\text{MHz}}{1\text{MHz}} = 2450 \]

In-Band interferers are typically removed near the end of the receive chain.
Rx Architecture

Heterodyne Receiver

RF Input

Mixer

IF Output

\[ f_{RF} \pm f_{LO} \]

\[ A_{RF} \cos(2\pi f_{RF} t + \phi_{RF}) \ast A_{LO} \cos(2\pi f_{LO} t + \phi_{LO}) \]

Desired Channel

\[ f_{IF=RF-LO} \quad f_{RF} \quad f_{RF+LO} \quad f \]
Image Problem

Heterodyne Receivers

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

\[ A_{IF} \cos(2\pi f_{IF}t) = A_{IF} \cos\left\{2\pi(f_{LO} - f_{RF})t\right\} \]
Image Rejection

Image Reject Filter

$f_{RF}$

$f_{image}$

$2f_{IF}$
Image Rejection

Image Reject Filter

Channel Select Filter

$f_{RF}$ $f_{image}$

$2f_{IF}$ $f_{IF}$ $f$
Image Rejection

Image Reject Filter

Channel Select Filter
Rx Architecture

Homodyne Receiver

BPF → LNA

\(\cos\omega_{LO}t\) → LPF → I

\(\sin\omega_{LO}t\) → LPF → Q
Symmetric vs. Asymmetric Spectra

\[ x_{BB}(t) \xrightarrow{VCO} f_{LO} \xrightarrow{f_{LO}} f \]
Symmetric vs. Asymmetric Spectra

Overlap of signal sidebands after down-conversion
Quadrature Downconversion

Two versions of the down converted signal that have a phase difference of 90°
Can reconstruct the original information.
Rx Architecture

Direct-conversion receiver (Homodyne)

- DC offset
- LO Leakage
- 1/f noise
LO Leakage

[Diagram showing LO leakage circuit with labels for Pad, LNA, Substrate, and LO.]
DC Offsets

\[ V_{RF} + kV_{LO} \]

\[ V_{IF} + V_{DC} \]

Baseband Signal

HPF
For 802.11b @ 20 Mb/s, f1 = 20 KHz

- Slow response to transient inputs.
  - LO frequency is switched to another channel, hence changing the LO leakage.
  - The gain of the LNA is switched, thus changing the reverse isolation of the LNA.
Rx Architecture

Low-IF Receiver

Less 1/f noise penalty
On-chip high-pass filtering becomes feasible.
Rx Architecture

Reject Image without filtering.
Quadrature down conversion as a 90° phase shifter.

\[ V_{RF} \]

\[ \cos \omega_{LO} t \rightarrow I \]

\[ \sin \omega_{LO} t \rightarrow Q \]
Hartley Architecture
Rx Architecture

\[ x(t) = A_{\text{sig}} \cos(\omega_{\text{sig}} t + \phi_{\text{sig}}) + A_{\text{image}} \cos(\omega_{\text{image}} t + \phi_{\text{image}}) \]

\[ x_1(t) = \frac{A_{\text{sig}}}{2} \cos\left((\omega_{\text{sig}} - \omega_{\text{LO}}) t + \phi_{\text{sig}}\right) + \frac{A_{\text{image}}}{2} \cos\left((\omega_{\text{image}} - \omega_{\text{LO}}) t + \phi_{\text{image}}\right) \]

\[ x_Q(t) = -\frac{A_{\text{sig}}}{2} \sin\left((\omega_{\text{sig}} - \omega_{\text{LO}}) t + \phi_{\text{sig}}\right) - \frac{A_{\text{image}}}{2} \sin\left((\omega_{\text{image}} - \omega_{\text{LO}}) t + \phi_{\text{image}}\right) \]

\[ x(t) = \frac{A_{\text{image}}}{2} \sin\left((\omega_{\text{LO}} - \omega_{\text{image}}) t - \phi_{\text{image}}\right) \]
Rx Architecture

\[ x(t) = -\frac{A_{\text{image}}}{2} \cos \left[ \left( \omega_{LO} - \omega_{\text{image}} \right) t - \phi_{\text{image}} \right] \]

\[ x_{90}(t) = -\frac{A_{\text{image}}}{2} \cos \left[ \left( \omega_{\text{image}} - \omega_{LO} \right) t + \phi_{\text{image}} \right] \]
Rx Architecture

\[ V_{RF} \xrightarrow{\cos \omega_{LO} t} I \xrightarrow{\text{LPF}} \xrightarrow{\text{ADC}} 90^\circ \xrightarrow{\text{IF}} \]

\[ V_{RF} \xrightarrow{\sin \omega_{LO} t} Q \xrightarrow{\text{LPF}} \xrightarrow{\text{ADC}} \]