Chapter VI
A Detailed Look at Wireless Signal Chain Architectures
Receiver Architectures

- Receivers are designed to detect and demodulate the desired signal and remove unwanted blockers.
- Receiver must also get rid of unwanted signals that it generates (e.g. mixer spurs).
- Receiver uses variable gain and power detection.
- Most Receivers will have some form of Automatic Gain Control.
- Diversity: Some Receiver Systems have two separate Receive Paths (Antennas separated by a quarter wavelength).
- A Diversity Receiver will either pick the strongest signal or “intelligently” combine both signals to increase signal power.
Blockers – a closer look

- Blockers can be orders of magnitude larger than the desired signal
- Large Blockers can jam a receiver
- Blockers can inter-modulate with each other and produce IMD products right at the frequency of the desired signal
- Some Blockers can be filtered (e.g. out-of-band) but others must be tolerated.
A Superheterodyne (Single Conversion) IF Sampling Receiver

- Mixes the received signal from RF down to a single IF
- Uses SAW filters to remove blockers and unwanted mixing components
- Detects signal power and implements AGC at the IF
- Reduces number of down-conversions by sampling the spectrum at an Intermediate Frequency but requires a high performance ADC
- Is the most popular architecture in non-cellular applications
IF Sampling Signal Flow

A

B

C/D

E

F

H

I

LO Leakage

LO Leakage
How IF sampling works

- The receiver uses RF and IF filters to eliminate the transmit signal and blockers so that only the desired signal is sampled.
- The ADC must sample at twice the signal bandwidth to meet Nyquist criteria.
- Oversampling can be used to improve the signal to noise ratio by 3 dB for each doubling of the sample frequency.
- Harmonics of ADC driver amp that are not filtered will degrade performance.
- There is usually a clock recovery loop in an FPGA or DSP or both that locks the sampling rate to a multiple of the symbol rate.
Direct Conversion Receiver

- Saves money by mixing RF spectrum to baseband in a single step
- Reduces component count and eliminates IF SAW filters
- There is a reason why RF engineers have not tried this sooner – removing DC offsets at baseband
Direct Conversion Receiver

- **Rx Band**
  - DC
  - Freq
  - Power (dBm)

- **Tx Band**
  - Power (dBm)
  - Transmit Signal
  - Desired Signal
  - In-Band Blockers

- **In-Band Blockers**
  - Blocker IMD Product
  - DC Offset from LO Self Mixing & IP2 Intermodulation
  - BB Amp Distortion
  - Nyquist Filter

- **Desired Carrier**
  - DC
  - Fs/2
  - Fs
Direct Conversion Receiver

- In-Band Blockers can only be eliminated at the end of the signal chain or in the digital domain.
- In-Band Blockers can mix in the Front End (before mixer) to produce an unwanted product at baseband.
- LO leakage to the RF input causes self-mixing and produces an unwanted dc offset at dc (right in the middle of the desired signal).
- Non-Ideal 90 degree balance in the Demodulator produces unwanted images of blockers which can be close to the carrier.
- Direct Conversion Receivers are cheaper and smaller (no IF SAW filters, cheaper ADCs, only one mixer).
Transmitter Architectures

- Super Heterodyne with IQ Modulator
- Super Heterodyne with Real IF DAC Synthesis
- Direct Conversion
- Low IF to RF Conversion
Superheterodyne Transmitter using IQ Modulator

- Superheterodyne Transmitter uses one or more Intermediate Frequencies.
- DAC constructs the baseband signal, centered either at dc or at a low Intermediate Frequency (IF)
- Gain control and filtering may be implemented at RF, IF, and baseband.
- Lots of power back-off to avoid distortion in non-constant envelope systems
Superheterodyne Transmitter using IQ Modulator
Superheterodyne Transmitter using IQ Modulator

- Noise and Spurs generated in the IF stage can be filtered
- After mix to RF, band filtering removes out of band noise along with the image
- In-Band noise generated in mix to RF cannot be removed
Example: Superhet with IF Synthesis of signal in IQ format

Driving IQ mod with a low IF creates a single-sideband-like spectrum at the modulator output.

Once IF has been filtered (removing unwanted sideband and LO), modulation quality (EVM) is excellent.
Example: Superheterodyne Receiver with IF Synthesis of signal in IQ format

Unwanted LO leakage and Upper Sideband are filtered at IF, resulting in excellent EVM

If low IF is high enough, do a single up-conversion to RF
Direct Conversion Zero IF Architecture

- Direct Conversion mixes a base-band signal from a dual DAC up to the transmission frequency in a single step.
- With no IF, gain control, filtering, and equalization must be performed either in the digital backend, at the reconstructed analog base-band output or at RF.
- Effects of LO leakage and Upper Sideband Leakage occur in-band potentially interfering with the signal's EVM.
- Dual channels are required to generate the complex signal, any channel mismatch causes in-band distortion which cannot be filtered.
- High quality components are required to generate an accurate signal
- In-Band Modulator Noise cannot be filtered
- Calibration of LO leakage and Quadrature balance is generally necessary
- PA to LO leakage can modulate or “pull” the PLL
Example: Direct Conversion Transmitter

-15 dBm

BAND FILTER

-18 dBm

-3 dB

-18 dBm

-3 dBm

+45 dBm

AD9767 TxDAC

+45 dBm

AD8349

PA

48 dB

RMS Detector

AD8362

AD8362

60 dB RMS Detector

1760 +/-30 MHz

1580 +/-30 MHz

1462.5 +/-37.5 MHz

DAC

DAC

AD9767 TxDAC

0 to -20 dB

-5 dBm

IQ Mod

0 90

0

A

B

C

D

E

Freq

DC

Tx Band

Freq

DC

Tx Band

Freq

DC

Tx Band

Freq

ANALOG DEVICES
Poor OIP3 causes Adjacent Channel Leakage

Think of a broadband spectrum multiple tones inter-modulating with each other

- IM3 products produce Adjacent Channel Power/Leakage/Distortion
- Use 3-to-1 decay of IMD products to reduce dBc IMD but this degrades SNR
ACP and Noise vs. Output Power

- ACP degrades with increased output power due to IMD
- Noise is independent of input and output power
- At low power levels ACP degrades because of falling SNR
Example: Low IF to RF Transmitter using IF Synthesizing DAC and Passive Mixer

- Baseband DAC, IQ Modulator and PLL are replaced by an IF Synthesizing DAC or DDS modulator
- Trade Off: High Performance DDS/DAC + SAW + Mixer + PLL vs. IQ DAC + Modulator + PLL
- None of the problems typically associated with Direct Conversion
- Probably more expensive than Direct Conversion
Low IF to RF Architecture

- High Performance DAC generates “real” IF at a low IF (100-200 MHz)
- Mixer performs Double Sideband Modulation
- Advantage: Unwanted LO and Sideband are removed -> excellent EVM
- Challenge: To move unwanted LO and upper sideband out of band means that the IF must be quite high