Direct-Conversion Radio Transceivers for Digital Communication

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Super-heterodyne Receiver

Advantages:

• Most popular radio architecture (98%)
• High Sensitivity
• High Selectivity
Super-heterodyne Receiver

Disadvantages:

• High parts count and complexity
• Needs Several Hi Q RF filters
• Difficult to integrate -filter elements
• Need to reject image with pre-selector filter

• Channel rejection in IF requires high dynamic range IF filter usually made with passive components
Image-Cancelling Down-conversion Mixer

Another way to achieve image cancellation without hi Q filters
Main Problems with Phasing Techniques

- Need close matching of phase and amplitude in each channel
- Active circuits need high dynamic range to prevent IM
Direct Conversion FSK Receiver (paging receiver)

Advantages:
- Fewer parts, filters
- Easier to integrate
- Image removed by IQ demodulation
- Critical filtering performed at base-band
  - Low power active filters
I-Q Demodulator

- Composite input signal (I-Q modulated carrier)
  - Power splitter
  - 90 deg. phase shift
  - Local oscillator (phase locked to the carrier frequency)

  - Polar coordinates
  - Rectangular coordinates

  - I baseband (In-phase component)
  - Q baseband (Quadrature component)
I-Q Mathematics

Baseband signal: \( x(t) = Ae^{j\theta} \)

Modulated signal: \( x(t) = Ae^{j\theta} \cdot e^{j\omega t} = Ae^{j(\omega t + \theta)} = A\cos(\theta)\cos(\omega t) - A\sin(\theta)\sin(\omega t) \)

\[ = x_I \cos(\omega t) - x_Q \sin(\omega t) \]

Demodulating the I Channel by multiplying by cosine of the local oscillator:

\[ = x_I \cos(\omega t) \cdot \cos(\omega t) - x_Q \sin(\omega t) \cdot \cos(\omega t) \]

\[ = x_I \cdot \frac{1}{2} [1 + \cos(2\omega t)] - x_Q \cdot \frac{\sin(2\omega)}{2} \rightarrow \text{Low Pass Filter} \rightarrow \frac{x_I}{2} \]

Demodulating the Q Channel by multiplying by sine of the local oscillator:

\[ = x_I \cos(\omega t) \cdot \sin(\omega t) - x_Q \sin(\omega t) \cdot \sin(\omega t) \]

\[ = x_I \cdot \frac{\sin(2\omega)}{2} - x_Q \cdot \frac{1}{2} [1 - \cos(2\omega t)] \rightarrow \text{Low Pass Filter} \rightarrow -\frac{x_Q}{2} \]
Direct –Up-Conversion Mixer for Transmitter (SSB)

Main disadvantage:
• Need good amplitude and phase matching
• E.g., 1% amplitude and 1% phase mismatch limits unwanted sideband rejection to 45db
• Mismatches can be trimmed
Digital Cell Phones (GSM)

- Direct Up-converter for Transmitter
- Super-heterodyne Receiver
Problems with Direct Conversion

- Spurious LO leakage
  - Interference to nearby receivers, need shielding
- Distortion with strong signals worse than with super-heterodyne technique
  - Need high linearity mixers
  - Interferers make way through mixers to BB filters
  - Second order distortion in single ended mixers
  - Need to use balanced circuits
- DC offset
Spurious Signals in Direct-Conversion Receiver from Mixer Nonlinearity

Not as much a problem in a Superheterodyne Receiver
Spurious signal falls outside IF passband
DC Offset Problem

• LO may re-enter mixer and be detected as DC (difference freq = 0)
• LO may radiate out antenna and be received
  • Varies with environment
• Strong nearby signal may leak to LO and mix with itself
• Small difference between carrier and LO
  • Need AFC on the LO
• All contributions worse with IQ channel mismatch
DC Error

• Eliminate with Capacitive Coupling
  – Signals with less DC component, e.g., wide band FSK
  – Wide band FSK has peak signal at +/- 4 kHz and much less at DC
  – E.g., Phillips single-chip paging receiver

• Digital Cell Phone uses different modulation scheme
  – Gaussian-Filtered Minimum-Shift Keying
  – Spectrum maximum at DC
  – Filtering DC reduces signal to noise severely
  – Can employ DSP techniques to monitor and remove DC
Impact of DC filter on SNR

100 kHz voice channel

Filters this narrow at low frequency are impractical
Quadrature Oscillators for DC Transceivers

• Need good phase noise similar to Super-heterodyne
• LO X n into Flip Flops
  – Need higher LO which may be difficult to construct
• Poly-phase filter following LO
  – Critical component matching and adjustment of filter elements

• Latest trend is baseband DSP
  Can detect gain and phase errors and compensate
Poly-phase Oscillator

- Less critical balancing of components
- No resonator - easier to integrate

Figure 7.22: Circuit of a five stage ring oscillator. It consists of five CMOS inverters with coupled in- and outputs.
DC Receiver Mixers

• Higher linearity than super-heterodyne receivers

• MOS FETs may out-perform BJT
  – Better switches
  – Cancellation of well defined quadratic non-linearity in a balanced configuration
Down-Conversion by Sub-Sampling RF

- Sampling 2X baseband to prevent aliasing
- Sampling clock at exact sub harmonic of carrier frequency = LO
- Harmonics of clock may leak out but are much lower than regular LO
- Alias noise and interferers into baseband
  - Need RF preselector filter (more filters!)
- Easier interface with subsequent DSP
Conclusions

• Direct conversion techniques lend towards integration
  – Fewer, less stringent filters

• Disadvantages over the super-heterodyne can be offset by more signal processing which is easier to integrate on chip