Chapter 5.
Transceiver Architecture

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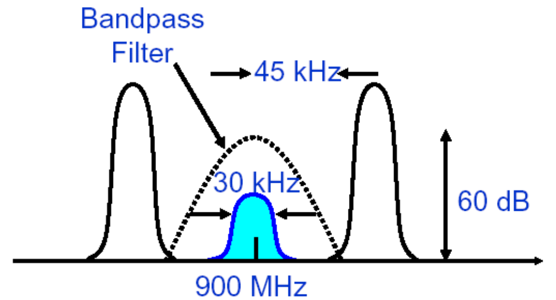
Contents

General Considerations

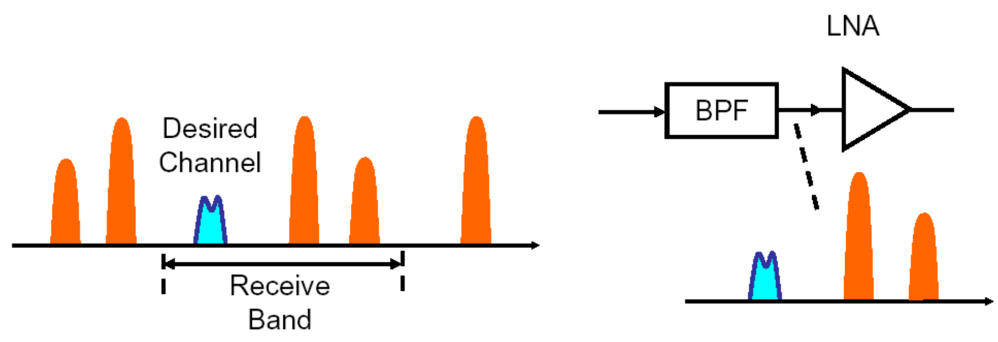
- **Constraints**
  - Limited spectrum allocated
    - 30kHz in IS-54, 200kHz in GSM
    - Limited rate of information : require appropriate coding, compression, bandwidth efficient modulation

- **Role of transmitters (Tx) and receivers (Rx)**
  - Tx
    - narrow-band modulation, amplification, filtering to avoid leakage to adjacent channels
  - Rx
    - Antenna matching
    - Desired channel selection
    - Undesired signal rejection
    - Amplification
    - Demodulation
    - Error detection and/or correction
    - Information conditioning and output

General Considerations – Cont.

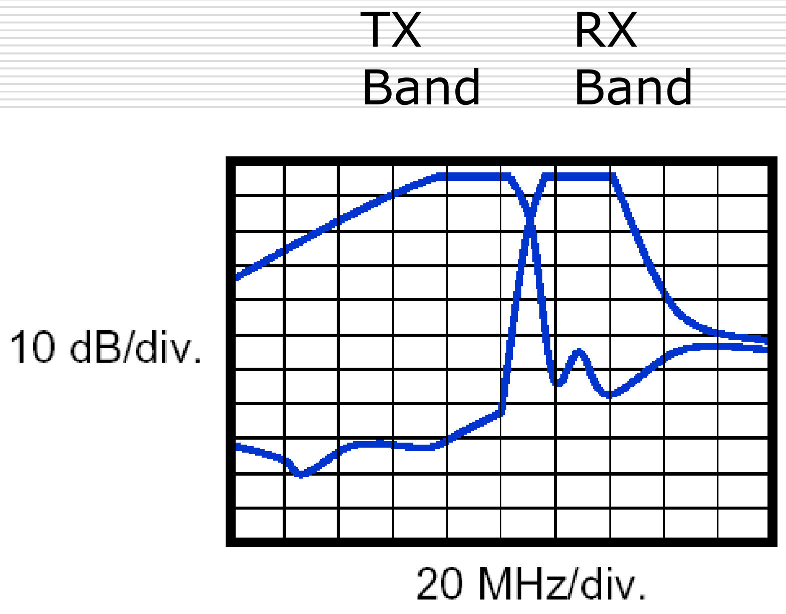


- **Difficulty of interference rejection**
  - Example: 900 MHz, 30 kHz BW channel rejection at 60 kHz
  - Require extremely high-Q Filter
  - Typically high Q filter has high insertion loss
- **Band and channel**
  - Band: entire spectrum of a standard (25 MHz in GSM)
  - Channel: signal BW of only one user (200 kHz in GSM)
  - Band selection



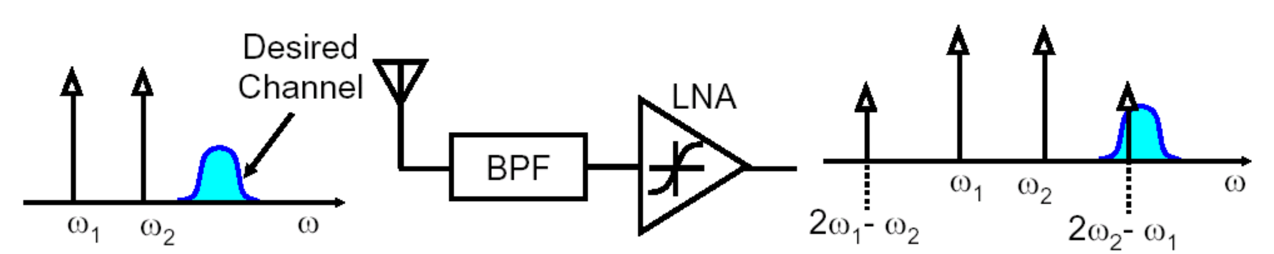
Front-End Band Pass Filter (BPF)

- **Front-end BPF**
  - Finite transition bandwidth
  - out-of-band rejection is critical (~ 30 dB)
  - Higher out-of-band rejection
    - Means higher in-band loss
    - Higher power amp power loss
  - Loss in BPF
    - 2 dB of 1 W is 370 mW
- **Choice of BPF filter**
  - Trade-off between out-of–band rejection and in-band loss
  - In-band loss being the more critical parameter
  - Practical front-end BPF can only select band



Linearity

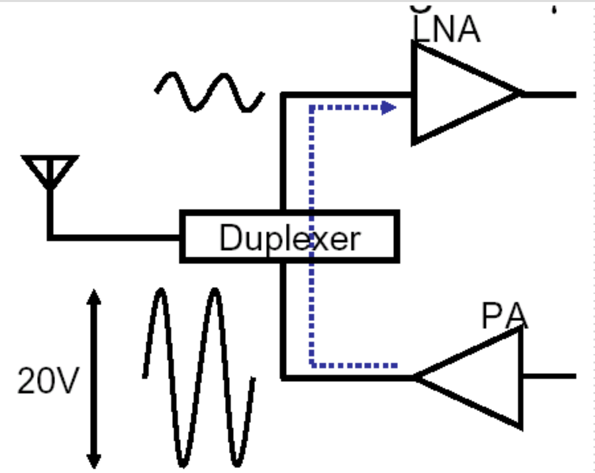
- **Linearity**
  - IM3 product of in-band interferers may fall in the desired channel
    - IIP3 of each stage must be sufficiently high
  - Nonlinearity is important even if the signal carries information only in phase or frequency
    - Zero-crossing is corrupted by IM product



- **Supply voltage rejection**
  - PA periodically turns on and off to save power
  - Large current drawn by PA and finite output impedance of battery -> V_{cc} fluctuation and noise
  - Require noise immunity and supply rejection of the building blocks

Dynamic Range

- **Required DR for the received signal is typically greater than 100dB**
  - Input range minimum ~ μV → Low noise, low cross talk required
- **1W PA and 30dB out-of-band attenuation duplexer**
  - 1 W PA → 20 V peak to peak
  - Leakage to Rx path ~-26dBm(=30mVpp) at the LNA input
  - Desensitization of LNA (P_{1dB}~-25dBm) and mixer
  - TDD(NADC & GSM) avoids this by offsetting transmit and receive time slots

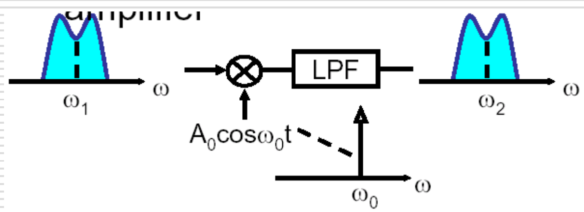


  - With a large dynamic range
    - Automatic Gain Control (AGC)

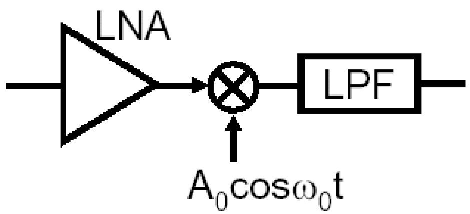
Contents

Heterodyne Receivers

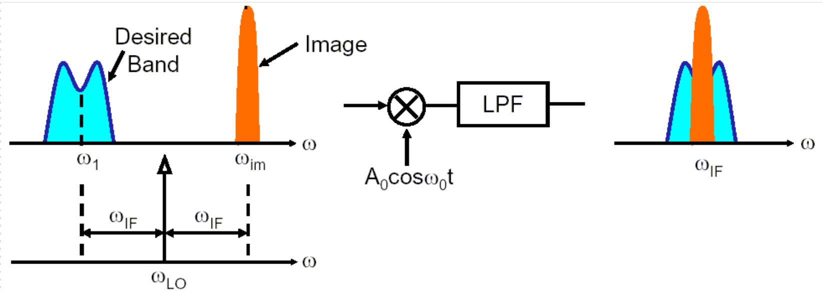
- **Signal band is translated to much lower frequency**
- **Background**
  - Filtering a narrow channel that is centered at high frequency and is accompanied by large interferers demands prohibitively high Q
  - Tradeoff between the filter loss and Q



- **Simple heterodyne down conversion**
  - Mixer (ω_o) : a multiplier
    - converts the signal(ω_1) to $\omega_2=|\omega_o-\omega_1|$ (downconversion) or $\omega_o+\omega_1$
    - High-side injection : $\omega_0 > \omega_1$
    - Low-side injection : $\omega_0 < \omega_1$
  - LPF removes high frequency signal
  - LNA precedes due to the mixer's high NF to lower NF
  - ω_0 (ω_{LO}) : generated by local oscillator
  - ω_2 (ω_{IF}) : called intermediate frequency (IF)



Problem of Image

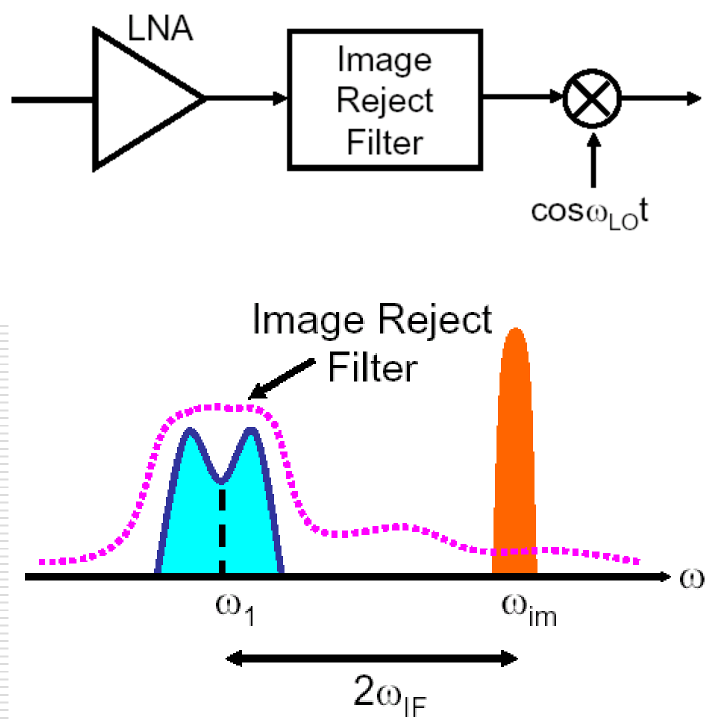


- Signal at $\omega_1 = \omega_{LO} - \omega_{IF}$ and image at $\omega_{im} = \omega_{LO} + \omega_{IF}$ translate to same frequency
- Image power may be much higher than that of desired signal
  - Image rejection required

Methods of image rejection

- Image rejection filter before mixer
- Image-reject architecture
  - Hartley architecture
  - Weaver architecture

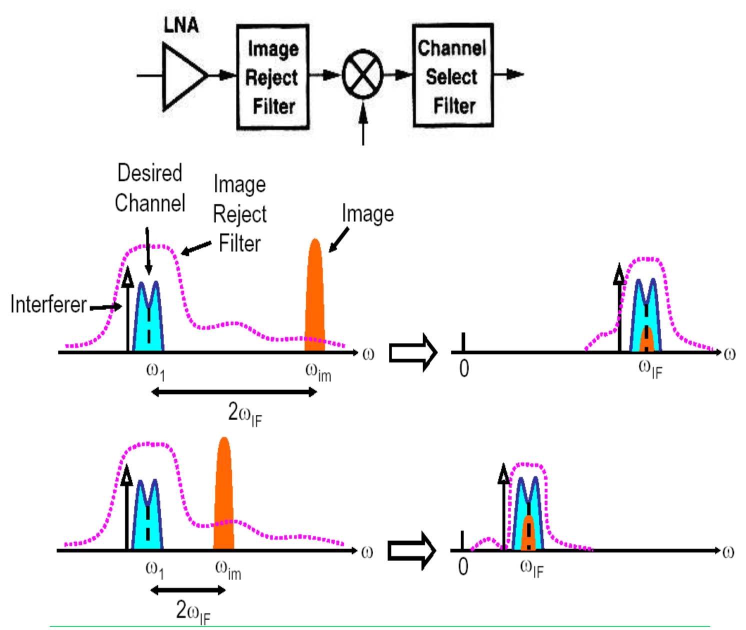
Image Rejection



- **Image-reject (IR) filter**
  - Small loss in desired band
  - Large attenuation in image band
- **Drawback of heterodyning by IR filter**
  - IR filter : usually passive, external component
    - 50ohm impedance
  - Require 50ohm output impedance for LNA
    - Need more severe trade-off between gain, NF, stability, and power dissipation

ω_{IF}

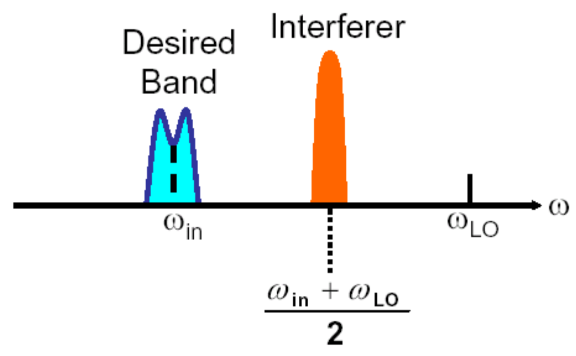
- **Comparison of high IF and low IF**
  - High IF: minimum image signal, but poor channel selection
  - Low IF: great suppression of nearby interferers, but poor image rejection
  - trade off between image rejection and channel selection (sensitivity-since image degrades the sensitivity of the receiver – and selectivity

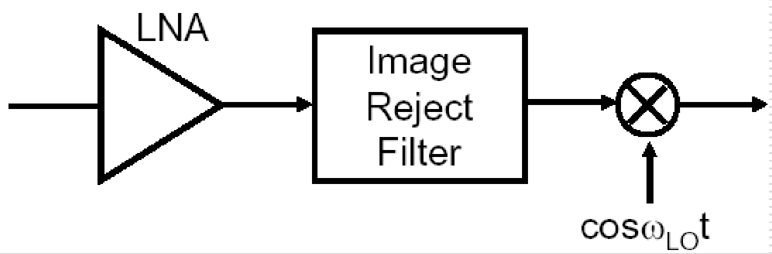


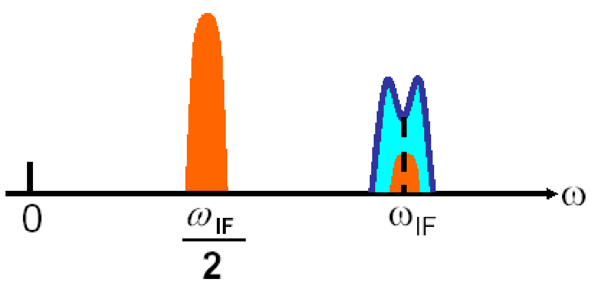
- **Choice of ω_{LO}**
  - High-side injection $\omega_{LO}>\omega_{RF}$
  - Low-side injection $\omega_{LO}<\omega_{RF}$
  - ω_{LO} determined to avoid noise from image band

Problem of half IF

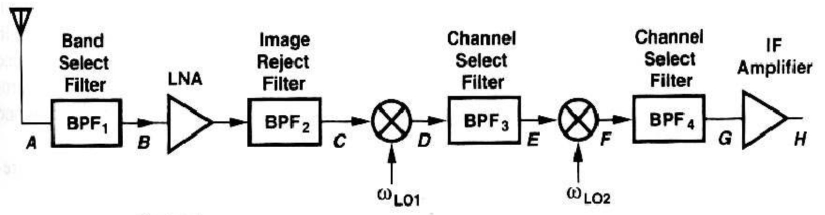
- **Problem of half IF**
  - Case 1
    - If $(\omega_{IN}+ \omega_{LO})/2$ experience 2^{nd}-order distortion by LNA -> $(\omega_{IN}+ \omega_{LO})$
    - LO contains significant 2^{nd}-order harmonics->$2\ \omega_{LO}$ then
    - $|(\omega_{IN}+ \omega_{LO})-2\ \omega_{LO}| = \omega_{IF}$
  - Case 2
    - If $(\omega_{IN}+ \omega_{LO})/2$ down converts to $\omega_{IF}/2$
    - And 2^{nd}-order distortion in the IF band (ex: IF amp), then
    - They fall into band of interest $2 * \omega_{IF}/2 = \omega_{IF}$

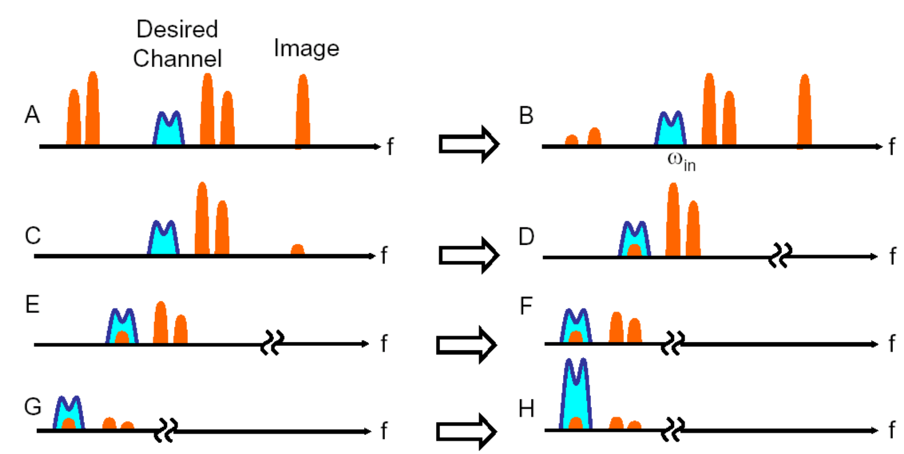






Dual-IF Topology

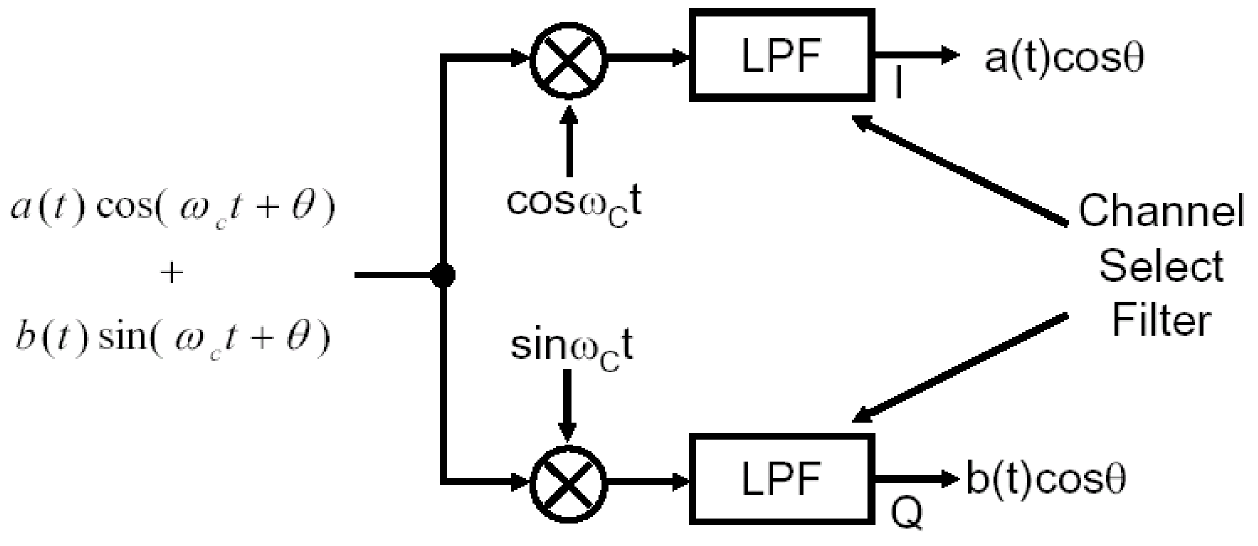




- **Newly introduce wireless applications**
  - Operating frequency goes up (900MHz, 1.8GHz, 2,4GHz,etc) with signal bandwidth stays the same (200KHz, 2MHz,etc)
  - Ratio [operating frequency/wanted signal bandwidth] goes up
  - Harder to use single stage IF receiver

Quadrature Downconversion

- **Demodulation at the 2nd IF**
  - If 2nd mixer translates the spectrum to zero frequency (base band signal)
    - No 2nd IF → "Single IF topology"
  - In-phase (I) and Quadrature (Q) components normally at the 2nd mixer

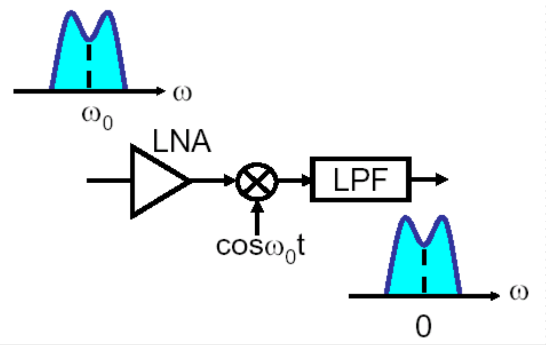


Heterodyne - Summary

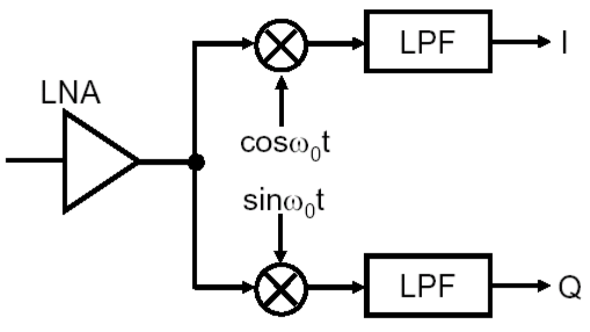
- **Dual-IF topology**
  - Resolve the trade-off between sensitivity and selectivity issue of simple heterodyne receiver
    - Partial channel selection at progressively lower center frequencies
    - Relax required Q
  - NF (sensitivity) : critical in the front
  - IIP3 (selectivity) : critical in the back end
    - Relax the IP3 requirement through the progressive compression of interferes
- **Heterodyne-summary**
  - Complex
  - Many off chip components : expensive, sensitive to external parasitic signals, higher power consumption
  - Most reliable reception technique (sensitivity and selectivity wise)

Homodyne Receivers

- Homodyne, direct conversion, zero-IF
  - RF spectrum → baseband frequency conversion
  - Simple homodyne
    - Double sideband AM
    - Double sideband
      - (+) and (-) part of spectrum



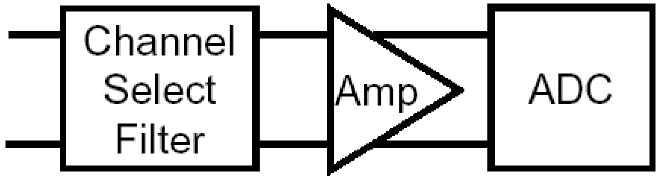
  - Homodyne with quadrature downconversion
    - FM, QPSK



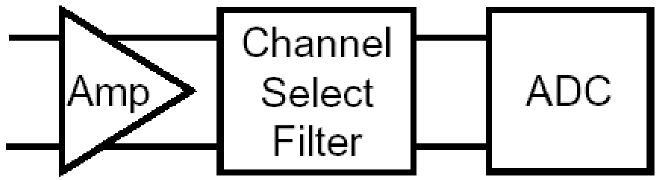
  - Advantage
    - No image
      - No IR filter
      - Simple and cheap
    - High output impedance of LNA
    - BPF can be replaced by LPF

Homodyne Receiver – Channel Selection

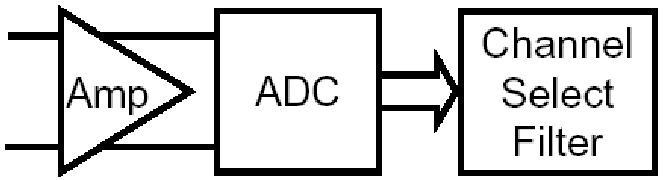
- **Rejection of out-of-channel interferers**
  - Active filter is more difficult than passive filter.
  - Active filter
    - Noise-linearity-power trade-offs



- **Out-of-channel suppression**
  - Amplifier can be nonlinear
  - ADC moderate dynamic range
  - LPF tight noise-linearity spec



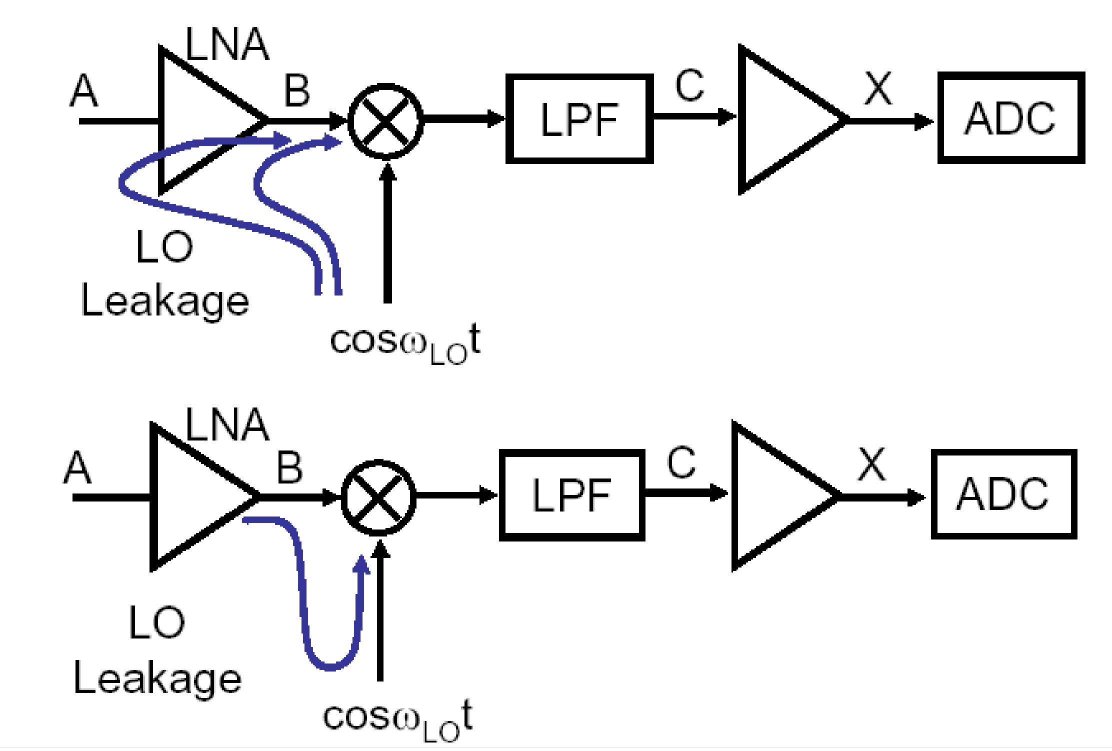
- **Amplifier should be linear**
  - Relaxed LPF noise requirement



- **Amplifier should be linear**
  - ADC high linearity and low noise

Homodyne Receiver – DC Offsets

- Homodyne → Zero-IF
  - Offset voltages at DC corrupt the signal
- Offset voltage generation
  - Self mixing
    - LO leakage
    - Strong interferer



Self-mixing

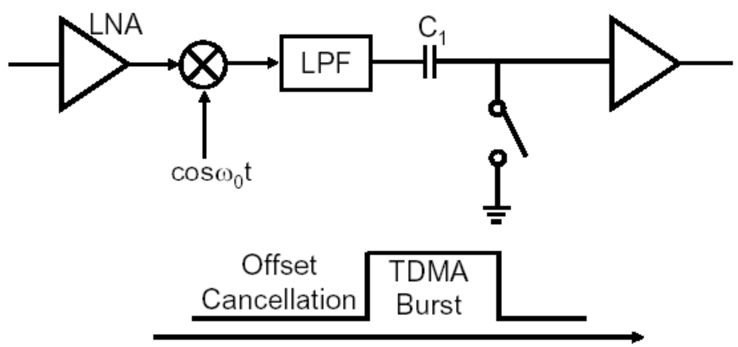
- Gain before ADC
  - 80-100 dB
- LNA/mixer gain
  - 25-30 dB
- Example
  - LO voltage peak-to-peak 0.63 V (0 dBm)
  - 60 dB LO-RF isolation (-60 dBm)
  - Gain of LNA/Mixer 30 dB (-30 dBm)
  - Offset voltage at the output of mixer ~ 10 mV
  - Signal input ~ 30 μVrms
- Problem is severe if self-mixing varies with time
  - LO signal leaks through antenna and reflected back
  - Time-varying offset is difficult to distinguish
- DC offset is not a problem in heterodyne
  - RF≠LO, no DC offset problem
  - IF is selected by BPF.

Solutions for Offset Cancellation DC-Free Coding

- **High-pass filter**
  - To remove DC component
  - Most of energy is accumulated at DC
    - Example: 200 kHz BW, 0-20 Hz removal BER>10^{-5}
  - Large capacitor required
  - Fast variation of offset voltage cannot be covered.
  - Not a good method
- **Modulation such that little energy at DC**
  - DC-free coding
  - Suitable for wideband channels
  - Example: DECT, a few kHz with no data there

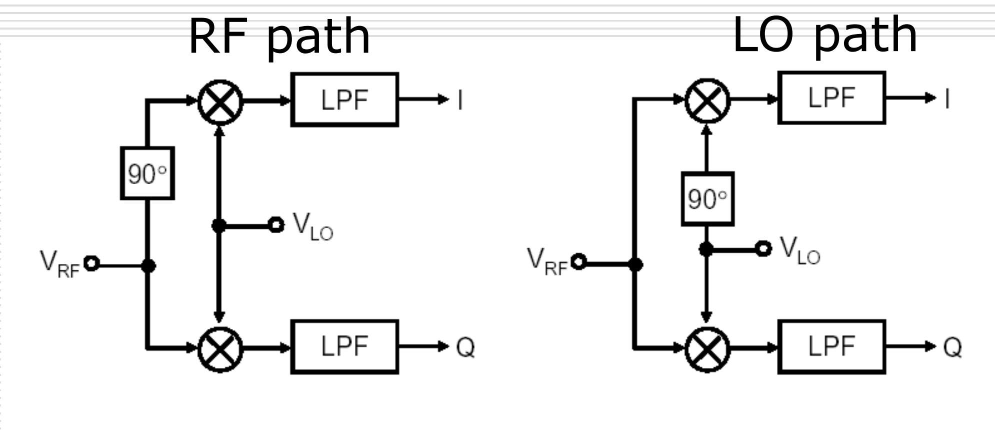
Solutions for Offset Cancellation
Offset Cancellation in a TDMA

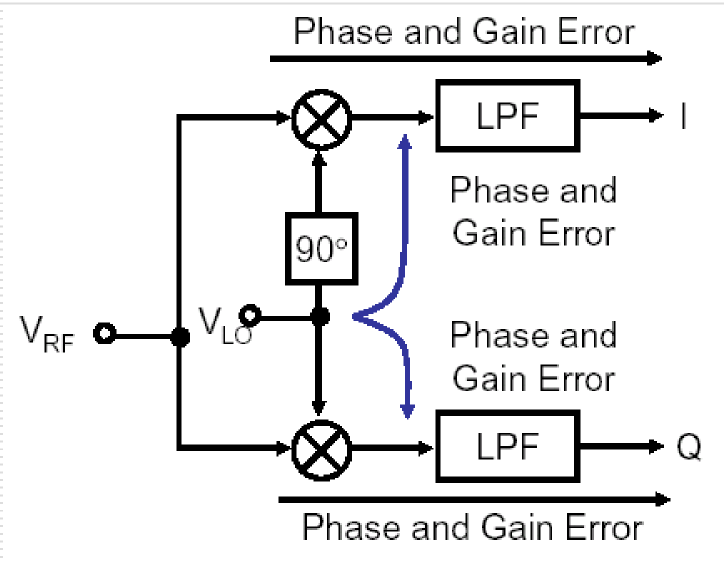
- **Digital offset cancellation**
  - C stores offset between TDMA bursts.
  - TDMA frame: a few ms
    - Offset cancellation every a few ms
      - Sufficiently fast
  - Thermal noise of S_1 is significant
    - kT/C noise
    - C_1 should be a large value.
    - Example
      - 1 μV input signal
      - 30 dB gain before offset cancellation, 32 μV
      - Noise $\sqrt{(kT/C)}$, 15 dB below signal (5.6 μV)
      - C_1> 200 pF $\sqrt{(kT/C)}$=4.5 μV
  - Interferer signal is also stored at C_1
    - Interferer signal changes fast
    - Several sampling and averaging



I/Q Mismatch

- **For phase and frequency modulation**
  - Quadrature mixing is required
  - Either RF or LO require 90° shift





  - Normally LO 90° shift
  - I/Q mismatch
    - Amplitude mismatch for I and Q LO signal
    - Phase mismatch for I and Q LO signal
    - Worse BER

Effect of I/Q Imbalance

- **Received signal** $x_{in}(t) = a\cos\omega_c t + b\sin\omega_c t$
  - a, b = ±1
- **I and Q phase of LO signal**
  - ½ for simplification
  - ε: amplitude error
  - θ: phase error

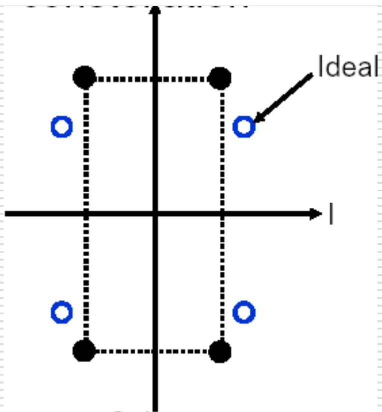
$$x_{LO,I}(t) = 2\left(1+\frac{\varepsilon}{2}\right)\cos\left(\omega_c t + \frac{\theta}{2}\right)$$

$$x_{LO,Q}(t) = 2\left(1-\frac{\varepsilon}{2}\right)\sin\left(\omega_c t - \frac{\theta}{2}\right)$$

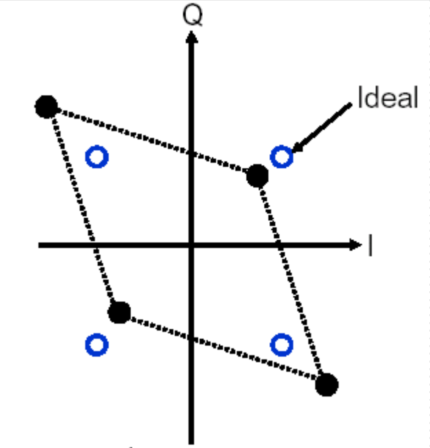
- **Baseband signal**

$$x_{BB,I}(t) = a\left(1+\frac{\varepsilon}{2}\right)\cos\left(\frac{\theta}{2}\right) - b\left(1+\frac{\varepsilon}{2}\right)\sin\left(\frac{\theta}{2}\right)$$

$$x_{BB,Q}(t) = -a\left(1-\frac{\varepsilon}{2}\right)\sin\left(\frac{\theta}{2}\right) + b\left(1-\frac{\varepsilon}{2}\right)\cos\left(\frac{\theta}{2}\right)$$



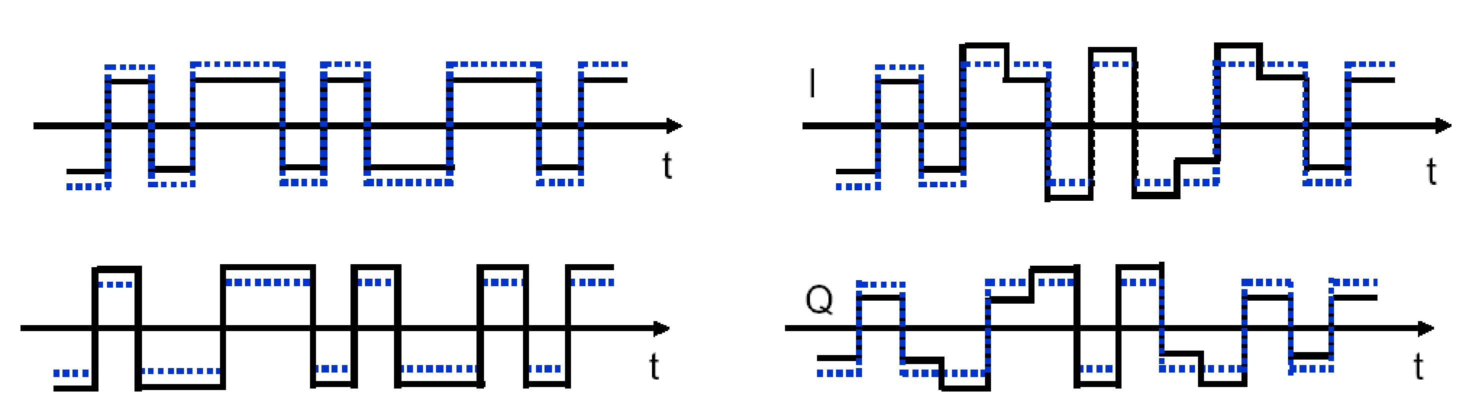
Gain error



phase error

Gain Error and Phase Error

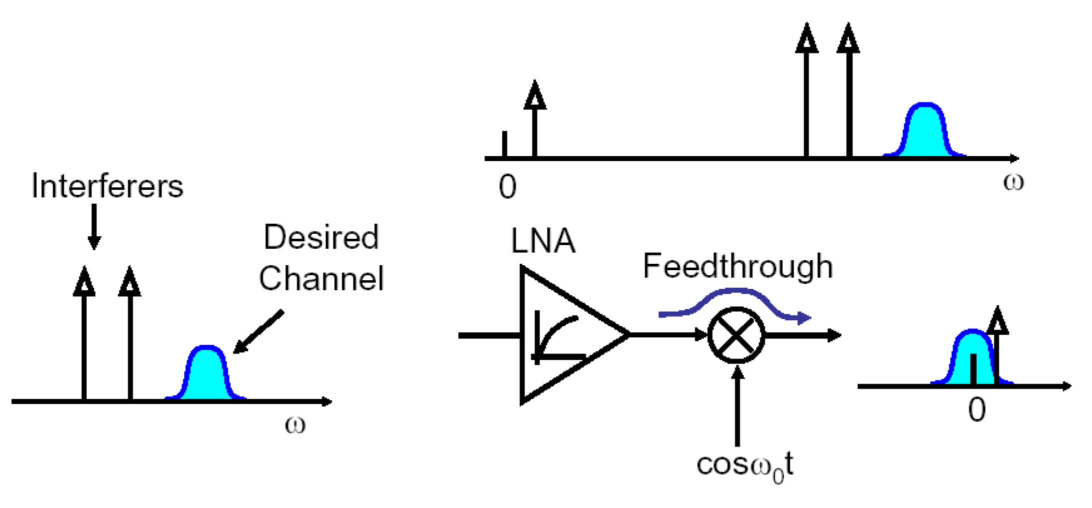
- Effect of I/Q mismatch
- Gain Error   Phase Error



- Amplitude mismatch < 1 dB
- Phase error <5°
- For heterodyne receiver, requirements are relaxed
  - Frequency is lower. Less sensitive to mismatches in parasitics
  - Signals amplified 50-60 dB before I/Q separation
    - More gain required after I/Q separation→ gain stage delay
  - Monolithic integration is better than hybrid approach.

Even Order Distortion

- **Even order distortion is important in homodyne.**
  - Signal near DC



$$y(t) = \alpha_1 x(t) + \alpha_2 x^2(t)$$

$$x(t) = A_1 \cos \omega_1 t + A_2 \cos \omega_2 t$$

$$\alpha_2 A_1 A_2 \cos(\omega_1 - \omega_2)t$$

  - 2^{nd} harmonic (even-order harmonic at low frequency)
  - RF to IF feedthrough → interferer at baseband of signal

Even Order Distortion in FSK or PSK

- **PSK or FSK signal with AM**
- **PSK or FSK signal go through fading or disturbance during transmission**

$$x_{in}(t) = (A + \varepsilon \cos \omega_m t)(a \cos \omega_c t + b \sin \omega_c t)$$

  - $\cos\omega_m t$: low freq. Amplitude modulation
  - 2nd order term $(a^2 + b^2) A\varepsilon \cos \omega_m t$
  - Even–order distortion demodulates AM
- **Mixer 2nd order distortion**
  - Mixer RF port also has the same distortion problem
- **IP2: 2nd order distortion characterization**
  - How small (or large) the 2nd order distortion is
- **Differential structure suppresses even order distortion**
  - RF component (antenna, duplexers, etc) are single ended.
  - Higher power dissipation than single ended.

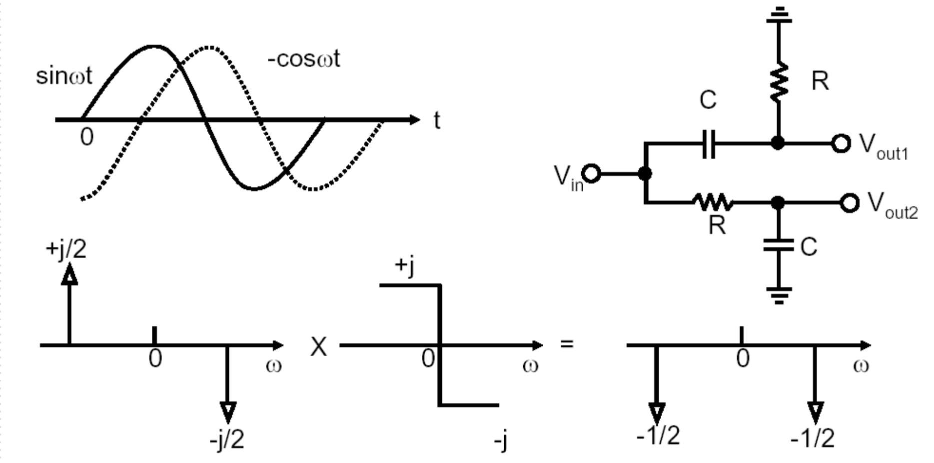
Flicker Noise and LO Leakage

- **LNA+mixer 30 dB gain: ~ 10 μV signal**
  - 1/f noise (low frequency noise) corrupts the signal.
  - Employ large size device to minimize the flicker noise at IF amplification
  - TDMA periodic offset cancellation
  - DC free coding

- **LO leakage**
  - LO leakage to antenna and received by other users using the same standard
  - FCC (Federal Communication Commission)
    - In-band LO radiation requirement ~ -50 to -80 dBm

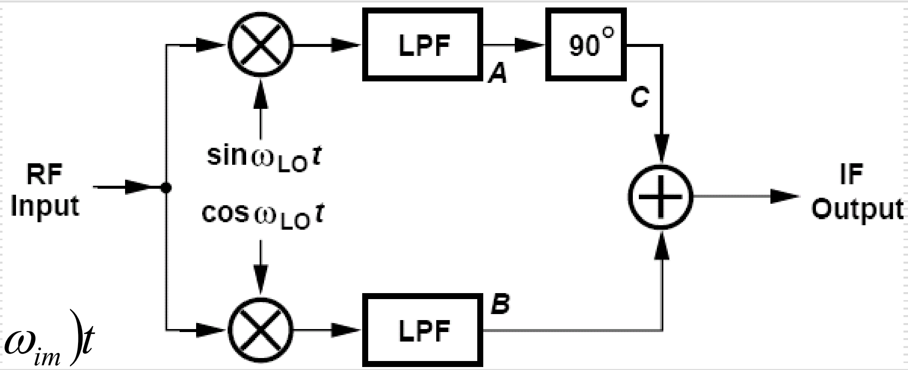
Image Reject Receiver

- **Without image-reject filter, heterodyne is a viable technology. → Image reject receiver**
- **Shift by 90° operation**
  - Multiplication of $G(\omega)=-j\ \mathrm{sgn}(\omega)$
  - Example: $\sin(\omega t) \rightarrow -\cos(\omega t)$, $\cos(\omega t) \rightarrow \sin(\omega t)$



  - 90° shift: RC-CR network
    - Phase shift of Vout1 and Vout2
      - $\pi/2-\tan^{-1}(RC\omega)$ and $\tan^{-1}(RC\omega)$ → always 90° phase shift

Hartley Architecture



- **Hartley, 1928**
- **RF input**

$$x(t) = A_{RF}\cos\omega_{RF}t + A_{im}\cos\omega_{im}t$$

- **After I/Q mixer**

$$x_A(t) = \frac{A_{RF}}{2}\sin(\omega_{LO} - \omega_{RF})t + \frac{A_{im}}{2}\sin(\omega_{LO} - \omega_{im})t$$

$$x_B(t) = \frac{A_{RF}}{2}\cos(\omega_{LO} - \omega_{RF})t + \frac{A_{im}}{2}\cos(\omega_{LO} - \omega_{im})t$$

- **Rewriting x_A**

$$x_A(t) = -\frac{A_{RF}}{2}\sin(\omega_{RF} - \omega_{LO})t + \frac{A_{im}}{2}\sin(\omega_{LO} - \omega_{im})t$$

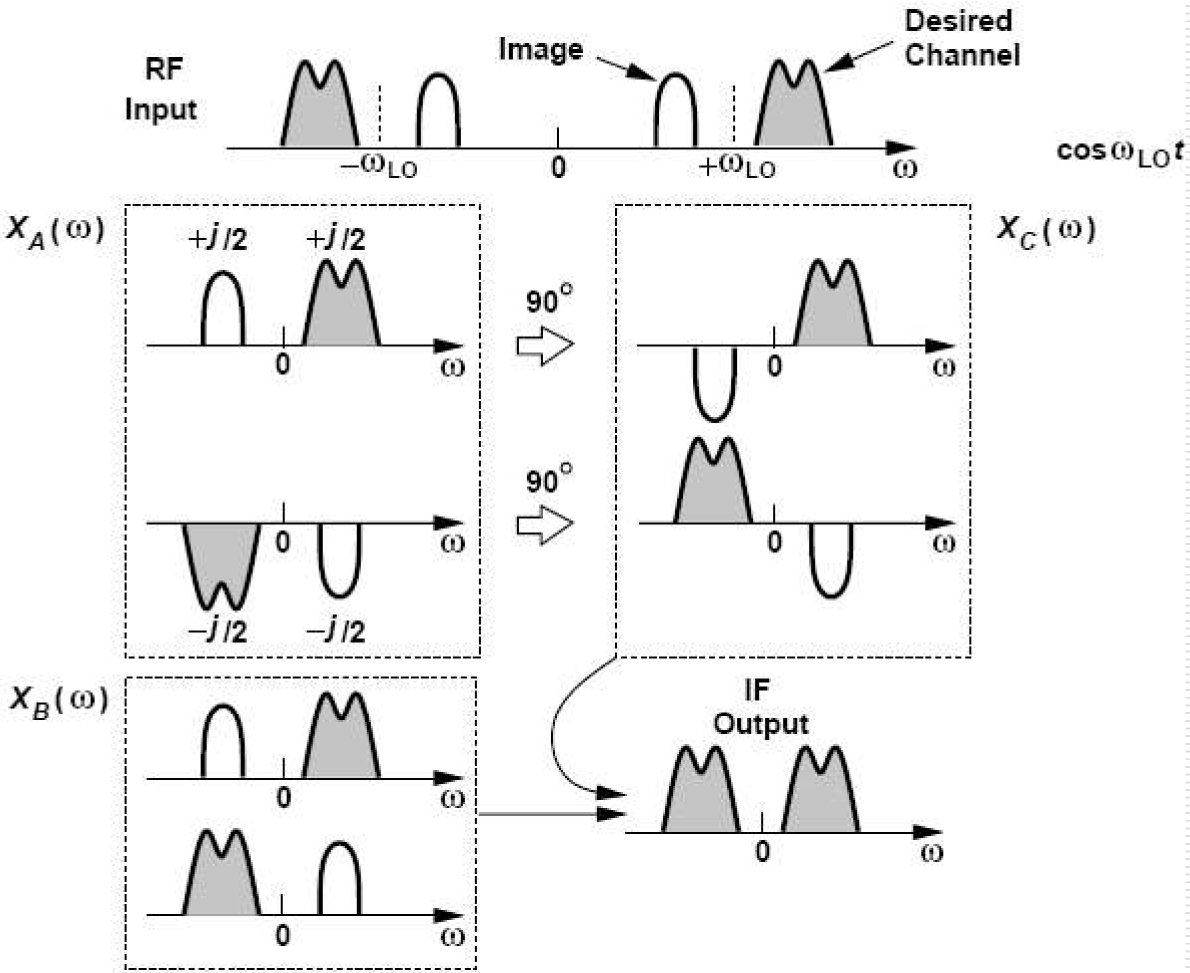
- **After 90° shift**

$$x_C(t) = \frac{A_{RF}}{2}\cos(\omega_{RF} - \omega_{LO})t - \frac{A_{im}}{2}\cos(\omega_{LO} - \omega_{im})t$$

- **Combine B and C**

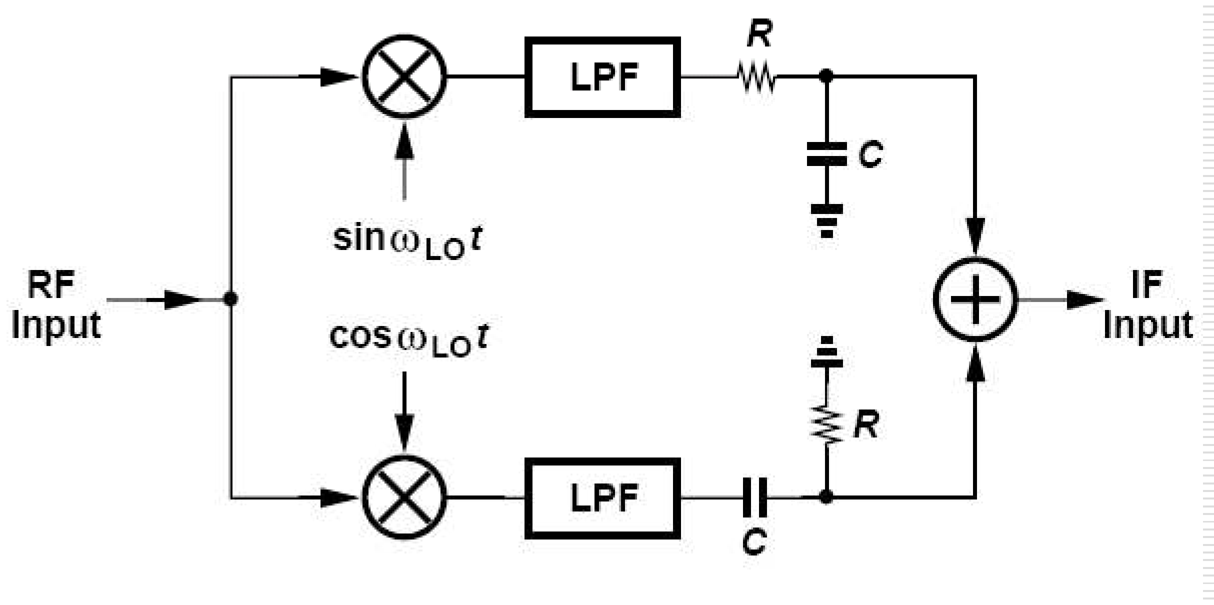
$$x_{IF}(t) = A_{RF}\cos(\omega_{RF} - \omega_{LO})t$$

Graphical Analysis of Hartley Receiver



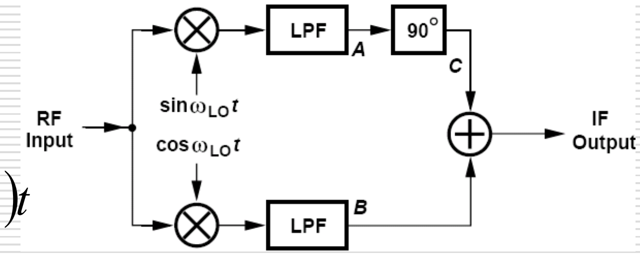
Hartley Receiver in Practice

- 90° shift → ±45° shift
- Drawback: sensitive to mismatches
  - LO mismatch: cancellation is incomplete.



Mismatch Sensitivity

- **Mismatch effect**
  - At A and B



$$x_A(t) = \frac{A_{RF}A_{LO}}{2}\sin(\omega_{LO}-\omega_{RF})t + \frac{A_{im}A_{LO}}{2}\sin(\omega_{LO}-\omega_{im})t$$

$$x_B(t) = (A_{LO}+\varepsilon)\frac{A_{RF}}{2}\cos[(\omega_{LO}-\omega_{RF})t+\theta] + (A_{LO}+\varepsilon)\frac{A_{im}}{2}\cos[(\omega_{LO}-\omega_{im})t+\theta]$$

  - At C

$$x_C(t) = A_{LO}\left[\frac{A_{RF}}{2}\cos(\omega_{RF}-\omega_{LO})t - \frac{A_{im}}{2}\cos(\omega_{LO}-\omega_{im})t\right]$$

  - Signal and image

$$x_{sig}(t) = \frac{A_{RF}(A_{LO}+\varepsilon)}{2}\cos[(\omega_{LO}-\omega_{RF})t+\theta] + \frac{A_{RF}A_{LO}}{2}\cos(\omega_{LO}-\omega_{im})t$$

$$x_{im}(t) = (A_{LO}+\varepsilon)\frac{A_{im}}{2}\cos[(\omega_{LO}-\omega_{RF})t+\theta] - \frac{A_{LO}A_{im}}{2}\cos(\omega_{LO}-\omega_{im})t$$

Image Rejection Ratio (IRR)

- Image-to signal ratio at the output

$$\left.\frac{P_{im}}{P_{sig}}\right|_{out} = \frac{A_{im}^{\ 2}}{A_{RF}^{\ 2}} \frac{(A_{LO}+\varepsilon)^2 - 2A_{LO}(A_{LO}+\varepsilon)\cos\theta + A_{LO}^{\ 2}}{(A_{LO}+\varepsilon)^2 + 2A_{LO}(A_{LO}+\varepsilon)\cos\theta + A_{LO}^{\ 2}}$$

- Image-to-signal ratio at the input = A_{im}^2/A_{LO}^2

- Image Rejection Ratio (IRR)

$$IRR = \frac{(A_{LO}+\varepsilon)^2 - 2A_{LO}(A_{LO}+\varepsilon)\cos\theta + A_{LO}^{\ 2}}{(A_{LO}+\varepsilon)^2 + 2A_{LO}(A_{LO}+\varepsilon)\cos\theta + A_{LO}^{\ 2}} \approx \frac{(\Delta A/A)^2 + \theta^2}{4}$$

- IRR ~ 30-40 dB from
  - Gain mismatch (ΔA) ~ 0.2-0.6 dB
  - Phase mismatch (θ) 1-5°

Bandwidth of RC-CR Network

- $\Delta A/A$ at $f_o-\Delta f$

$$\frac{\frac{1}{sC}}{R+\frac{1}{sC}}, \quad \frac{R}{R+\frac{1}{sC}}$$

$$\frac{\Delta A}{A} = \frac{\frac{sRC-1}{sRC+1}}{\frac{1}{sRC+1}} = sRC-1 \sim \Delta\omega RC = \frac{\Delta\omega}{\omega_o}$$

Gain Mismatch from 90° phase shift

- **Equal gain only at ω_{IF} =1/RC**
- **R, C can vary with temperature or process.**

$$\frac{\Delta A}{A}=\frac{(R+\Delta R)(C+\Delta C)\omega-1}{\sqrt{1+(R+\Delta R)^2(C+\Delta C)^2\omega^2}}\Bigg/\frac{1}{\sqrt{1+(RC\omega)^2}}$$

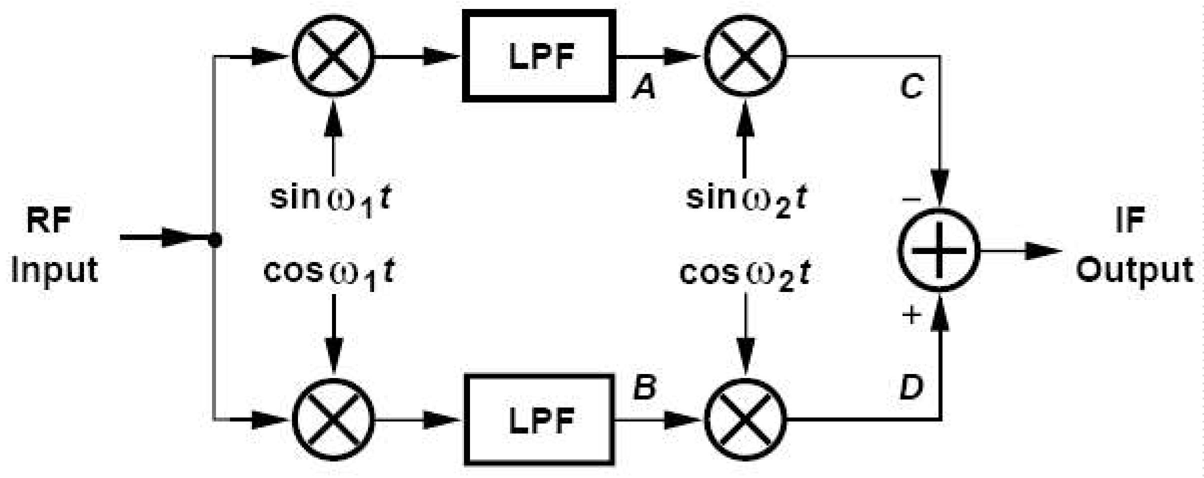
- **In the vicinity of ω_{IF}, RCω=1**

$$\frac{\Delta A}{A}\approx\frac{\Delta R/R+\Delta C/C}{\sqrt{2+\Delta R/R+\Delta C/C}}\div\frac{1}{\sqrt{2}}\approx\frac{\Delta R}{R}+\frac{\Delta C}{C}$$

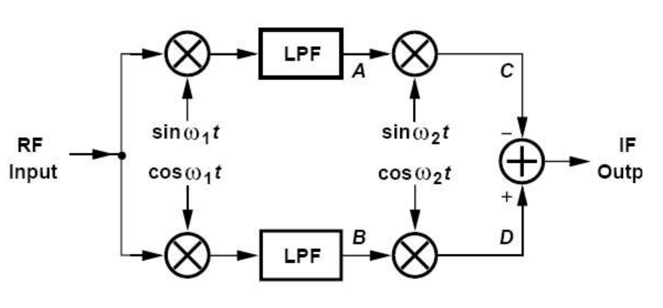
  - ΔR/R=0.2, IRR= 20 dB
- **Frequency deviation $\rightarrow$ Gain mismatch**
- **Required image rejection : 60-70 dB**
  - Additional image attenuation from front-end filter possible
- **Problems of Hartley architecture**
  - Matching requirements are more stringent than those in homodyne receivers.
  - LPF cannot suppress strong interferer $\rightarrow$ Higher linearity adder required.
  - Loss and noise problem of 90° shift

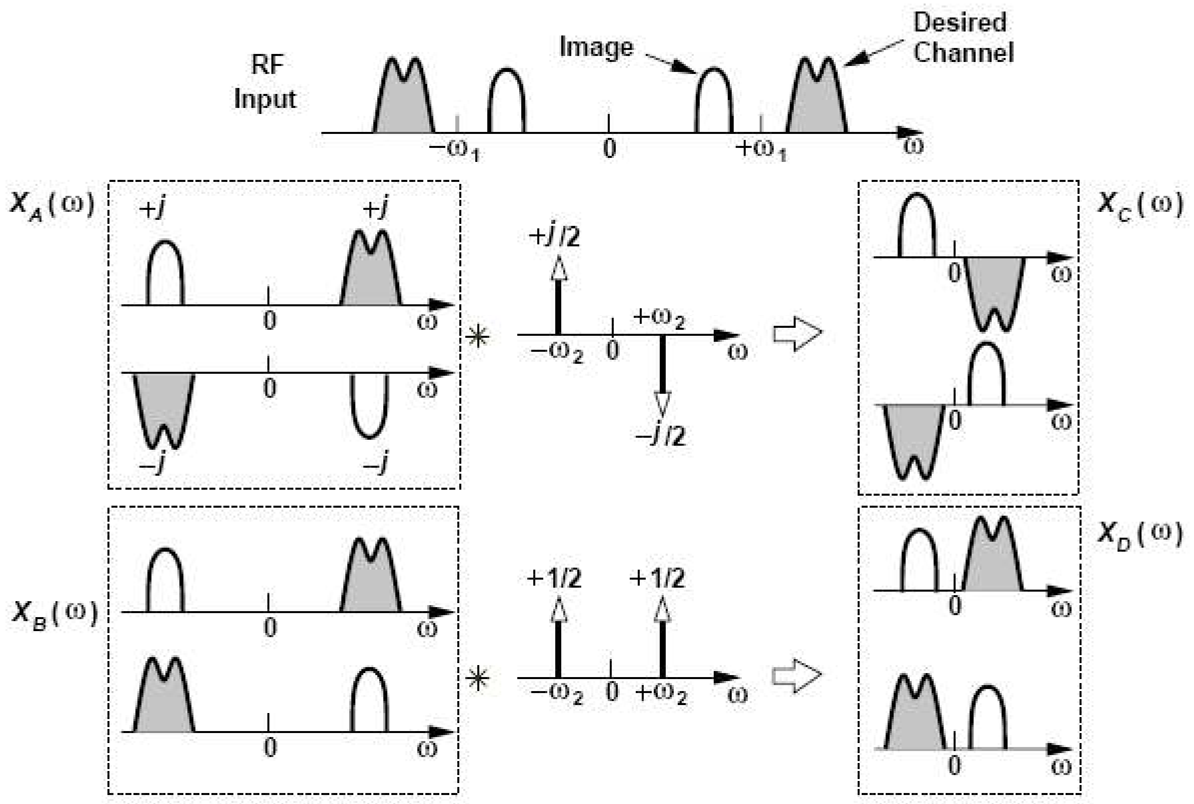
Weaver Architecture

- 90° shift in Hartley architecture → second IQ mixer in Weaver architecture



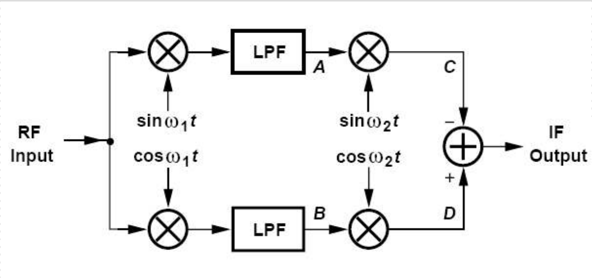
Graphical Analysis of Weaver Architecture

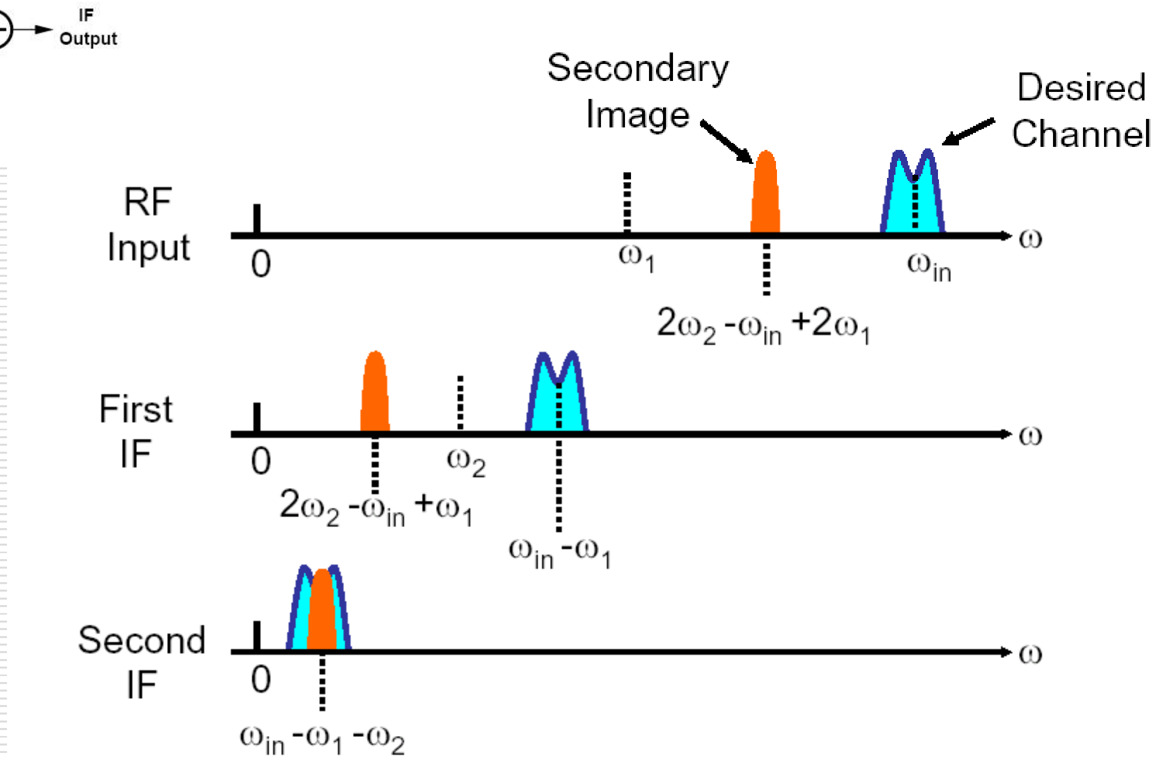




Problem of secondary image in Weaver architecture

- Secondary image is not cancelled
- $2\omega_2-\omega_{in}+2\omega_1 \rightarrow 2\omega_2-\omega_{in}+\omega_1$ (image with respect to ω_2)



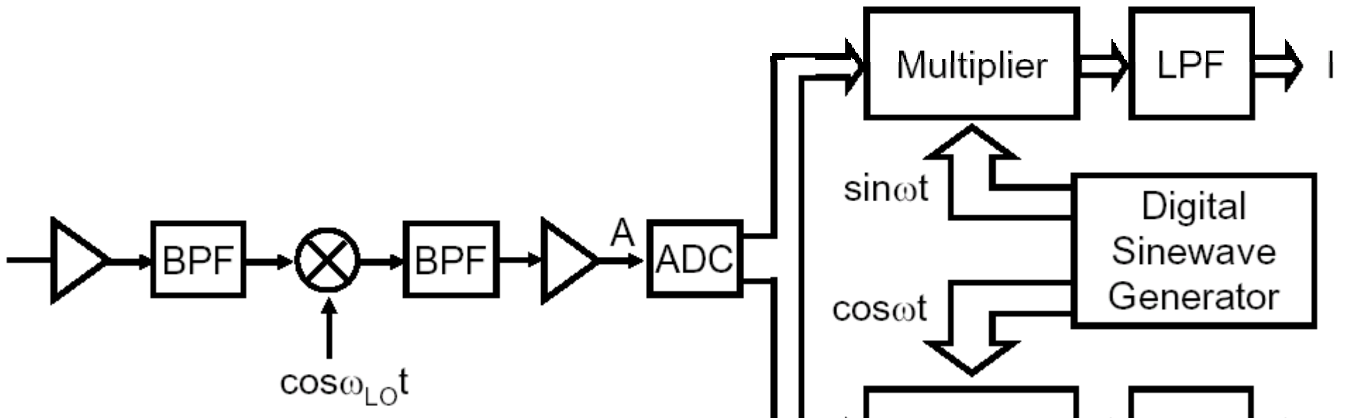


Weaver Summary

- **Weaver Architecture**
  - To solve secondary image problem
    - Final downconversion to DC
    - $\omega_1 \pm \omega_2 = \omega_{in}$
  - Incomplete image rejection due to gain and phase mismatch → Problem for both Hartley and Weaver
  - No gain imbalance from RC 90° phase shift network, but secondary image problem

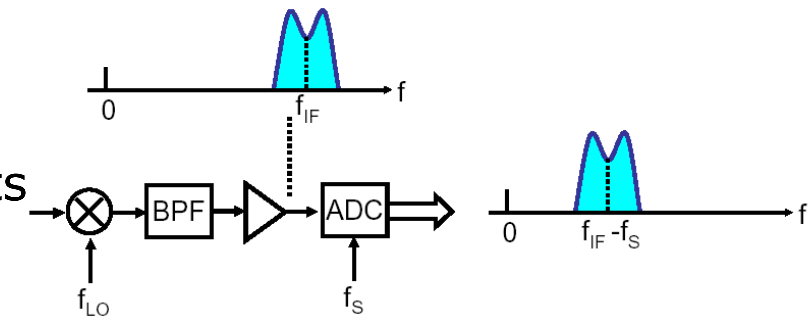
Digital-IF Receivers

- **In the dual-IF heterodyne architecture**
  - Low frequency operation can be performed in digital domain → digital-IF architecture
  - No I and Q mismatch problem



Sampling IF

- **ADC related problems**
  - Very small ADC input
    - <100 mV before ADC
  - High sampling speed
    - For IF 50 to 200 MHz, sampling rate 100 to 400 MHz
  - High dynamic range >14 bits

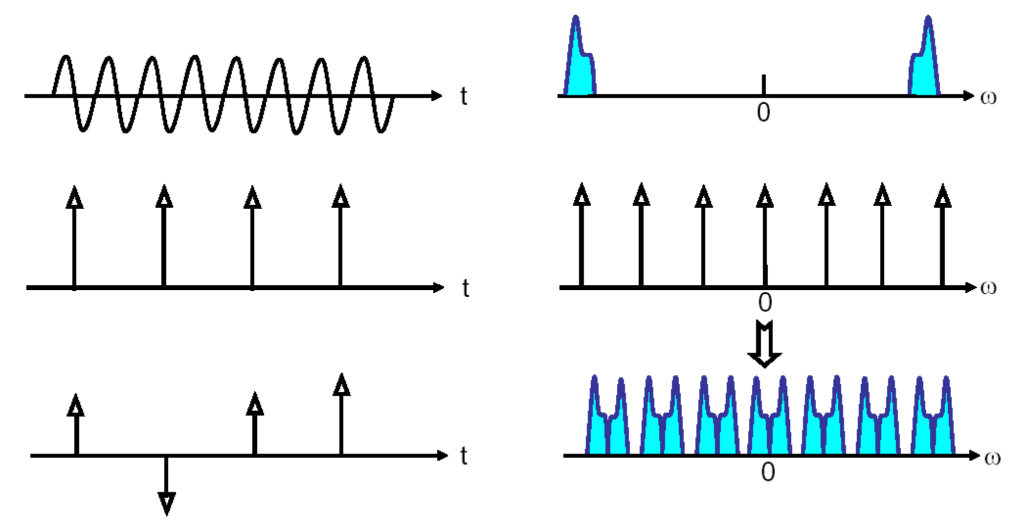


- **Sampling IF architecture**
  - ADC: sample-and-hold circuits
  - Downconversion
  - f_{IF}-f_S
    - digitized downconverted signal

- **Digital IF and Sampling IF have not been used in portable terminals yet.**

Subsampling Receivers

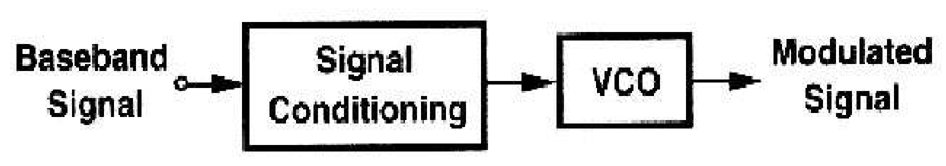
- Normally RF ~ LO, IF ~0
- Very low rate sampling of RF
  - Narrow band signal → only a small change
- Bandpass signal with bandwidth Δf
  - Sampled by a rate equal to or greater than 2Δf
  - Low frequency conversion
- No high LO required
- Drawback
  - Aliasing of noise



Contents

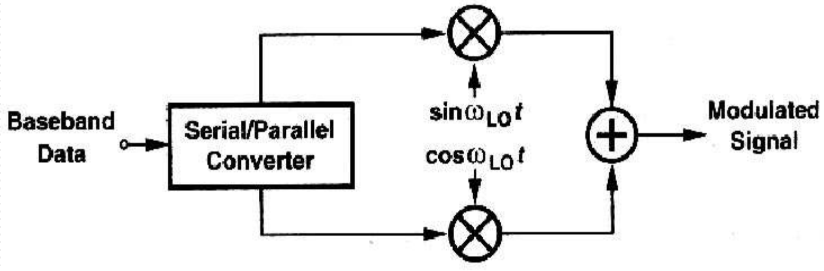
Transmitter Architectures

- **Role of Transmitter**
  - Modulation
  - Upconversion
  - Power amplification
- **Analog or digital FM system**

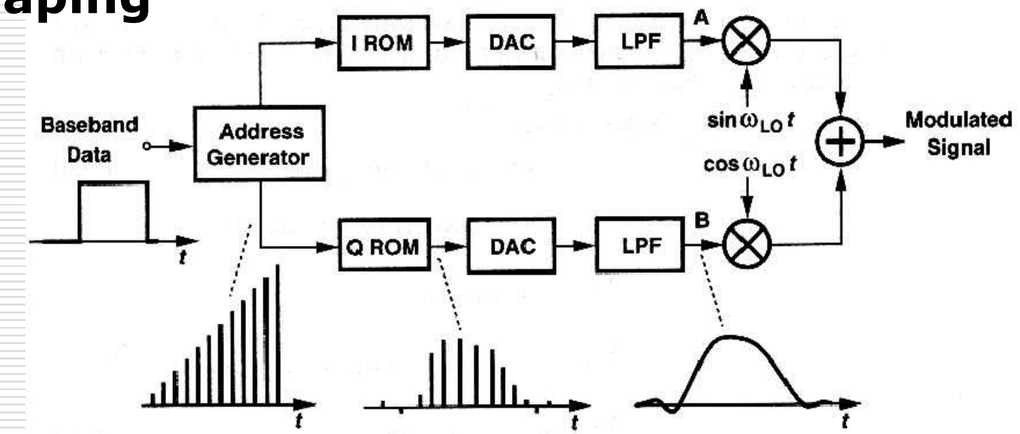


  - Base band signal directly modulates the carrier generated by VCO
  - Output spectrum depends on the amplitude and bandwidth of the modulating signal as well as the modulation index
  - Thus base band signal is first conditioned through filtering and/or variable-gain stage ->compensate for variations in VCO characteristics (VCO must be stabilized by a feedback loop)

Digital Phase Modulation Systems



- Data pulse must be shaped to minimize ISI and/or limit the signal BW
- Pulse shaping in analog domain requires bulky filters
  - Shaping by a combination of digital and analog technique
- Base band pulse shaping



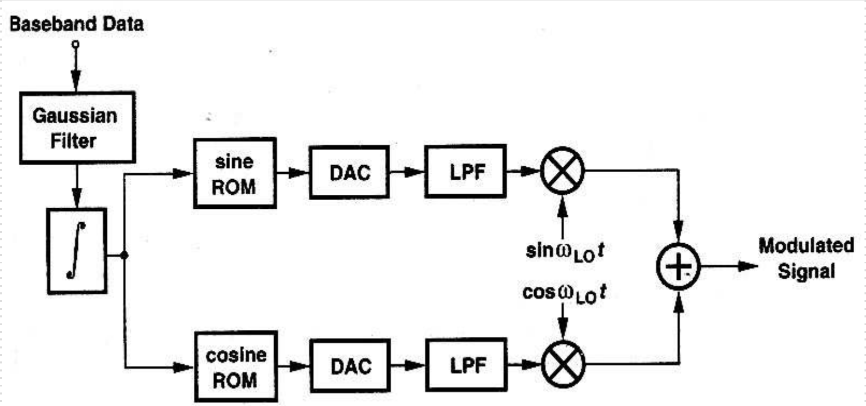
Baseband Pulse Shaping in GMSK

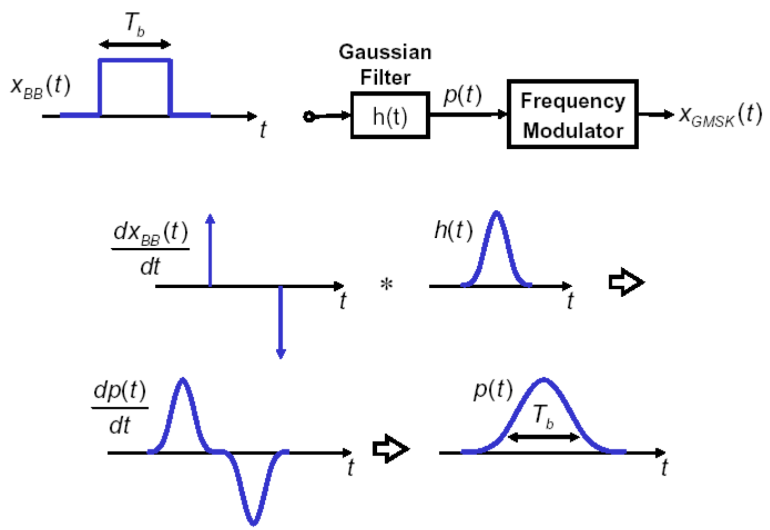
- **GMSK**

$$x_{GMSK}(t) = A\cos[\omega_c t + \phi_k(t)]$$

$$\phi_k(t) = \int \sum h(t) * p(t - kT)dt$$

  - h(t): impulse response of Gaussian filter
  - Digital implementation of filter proves more accurate than an analog counterpart





Cf. Fig. 3.44

Cross-talk Issue

- **Induced by phase and gain mismatch of I and Q path**

$$v_I = V_0 \sin \omega_{in} t \qquad v_Q = V_0 \cos \omega_{in} t$$

$$\begin{aligned} v_{out}(t) &= V_0 \sin \omega_{in} t \sin \omega_{LO} t + V_0 \cos \omega_{in} t \cos \omega_{LO} t \\ &= V_0 \cos(\omega_{in} - \omega_{LO}) t \end{aligned}$$

- **Under mismatch**

$$\begin{aligned} v_{out}(t) &= V_0 \sin \omega_{in} t \sin \omega_{LO} t + V_0 (1+\varepsilon) \cos \omega_{in} t \cos(\omega_{LO} t + \theta) \\ &\approx \frac{V_0}{2}[1 + (1+\varepsilon)\cos\theta]\cos(\omega_{in} - \omega_{LO})t - \frac{V_0}{2}(1+\varepsilon)\sin\theta \sin(\omega_{LO} - \omega_{in})t \\ &+ \frac{V_0}{2}[-1 + (1+\varepsilon)\cos\theta]\cos(\omega_{in} + \omega_{LO})t - \frac{V_0}{2}(1+\varepsilon)\sin\theta \sin(\omega_{LO} + \omega_{in})t \end{aligned}$$

- **Measure of I/Q imbalance**

$$\frac{Power|_{(\omega_{LO}+\omega_{in})}}{Power|_{(\omega_{LO}-\omega_{in})}} \cong \frac{1 - (1+\varepsilon)\cos\theta + \varepsilon}{1 + (1+\varepsilon)\cos\theta + \varepsilon}$$

- **Crosstalk can be negligible if above yields -30dB**

PA/Antenna Interface

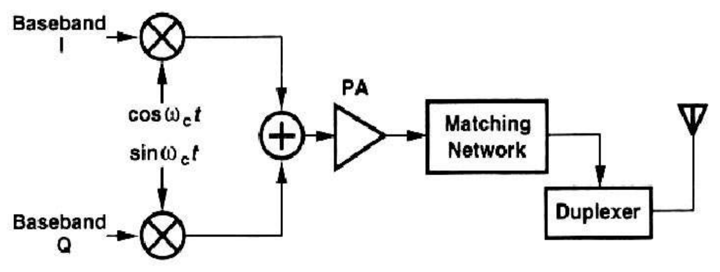
- **Transmitter → duplex filter or TDD switch → antenna**

- **Loss of duplex filter ~ 2 to 3 dB**
  - 30 to 50 % loss
  - 1 W power amplifier (PA) → more than 300 mW loss

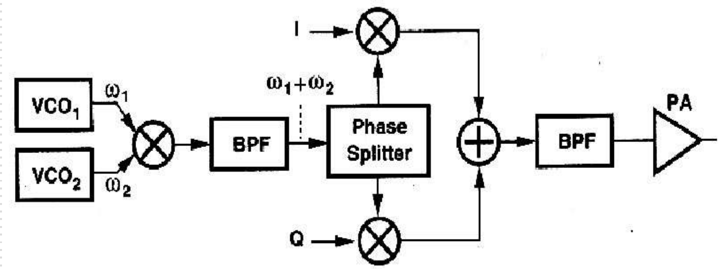
- **Loss of TDD switch ~ 0.5 to 1 dB**
  - Better efficiency than FDD

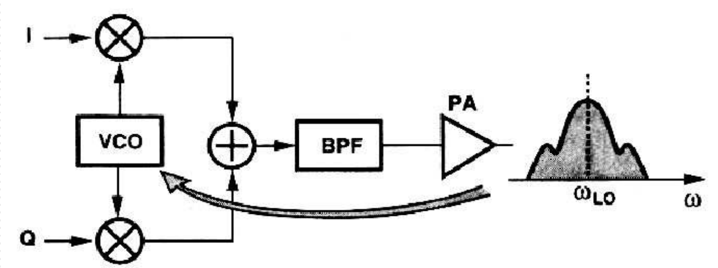
Direct Conversion Transmitters

- Direct conversion
  - RF frequency = LO frequency



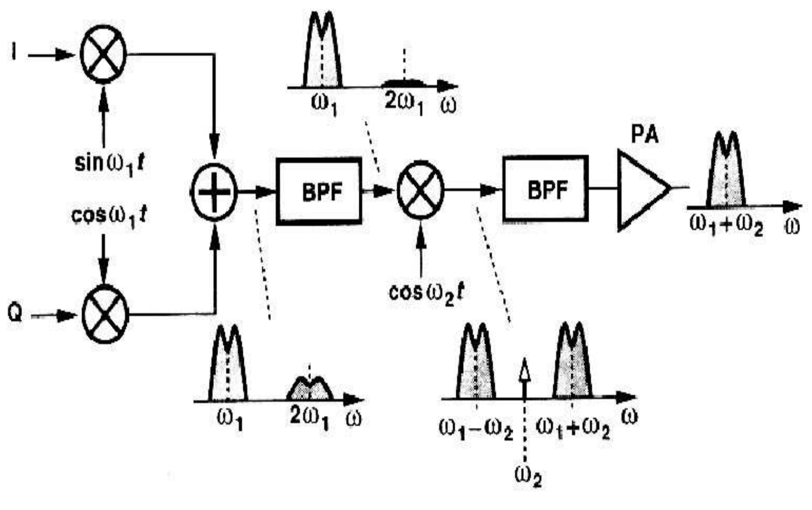
  - BPF after mixer to suppress harmonics
- Mixer noise is less critical
  - Since baseband signal is sufficiently strong
- Drawback
  - Disturbance of LO by the power amplifier – injection pulling
- Alleviating LO pulling
  - Offset LO frequency
    - Carrier frequency is equal to $\omega_1+\omega_2$ far from either ω_1 or ω_2





Two-Step Transmitters

- **Two-step architecture**
  - Circumventing the problem of LO pulling



- **Advantages**
  - Since I/Q modulation performed at lower frequencies, I/Q matching is superior
    - Less crosstalk
  - Channel filter may be used at the 1st IF to limit the transmitted noise and spurs in adjacent channel
- **Difficulty**
  - 2nd BPF require 50-60dB rejection
    - Require off-chip component

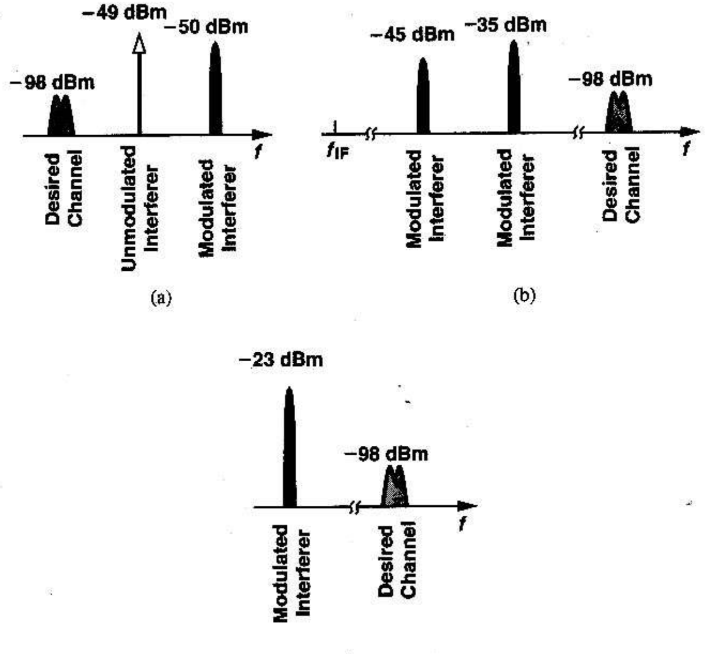
Contents

Transceiver Performance Tests

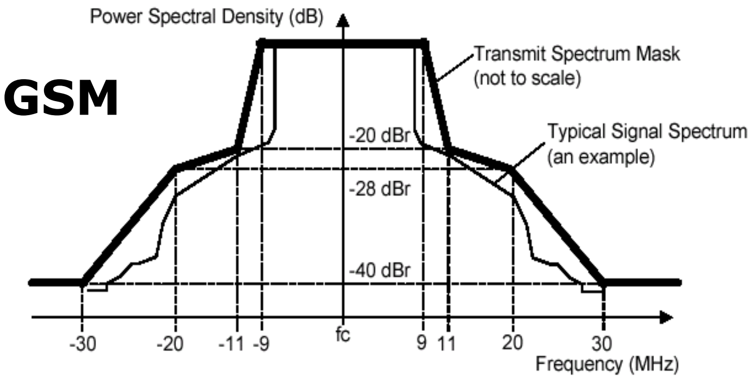
- **Sensitivity – NF requirements**
  - MDS: minimum detectable signal
  - GSM standard
    - Required MDS -120 dBm
    - SNR 9-12dB for 10^{-3} BER
  - P_{mds}=-174dBm+10logB+NF+SNR
  - NF= 7-10 dB
- **A common test examines the response of the system to blocking signals by measuring**
    - In-band intermodulation
    - Out-of-band intermodulation
    - Second-order intermodulation
    - Cross modulation
    - Reciprocal mixing (char 7)

Transceiver Performance Tests

- **Receiver Requirements**
  - In-band intermodulation (a)
    - C/(N+I) > 9 dB
    - C: carrier, N: noise, I: intermodulation
  - Out-of-band and second-order intermodulation (b)
    - C/(N+I) > 9 dB
  - Cross modulation (c)
    - C/(N+I) > 9 dB
- **Unwanted emissions**
  - Wireless standard and FCC regulation require "modulation mask".
  - ACP: adjacent channel power
  - IS-54: ACP -26dBc
  - IS-95: ACP -42dBc

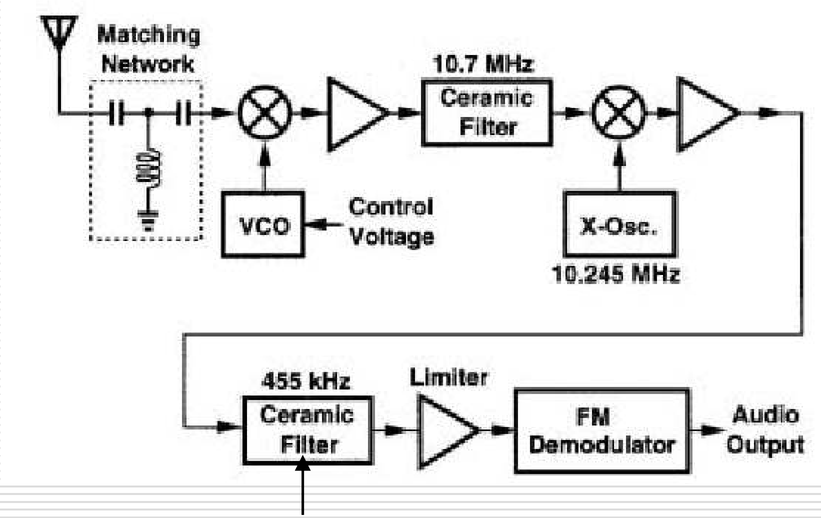


GSM



Contents

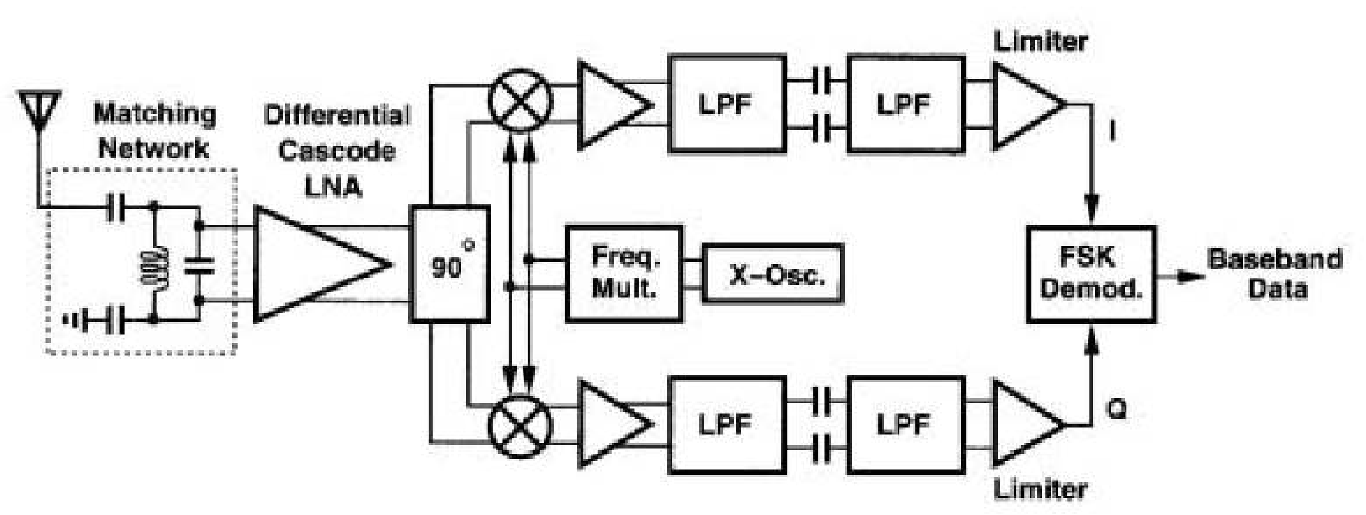
Motorola FM single-chip receiver MC3362



Channel Selection

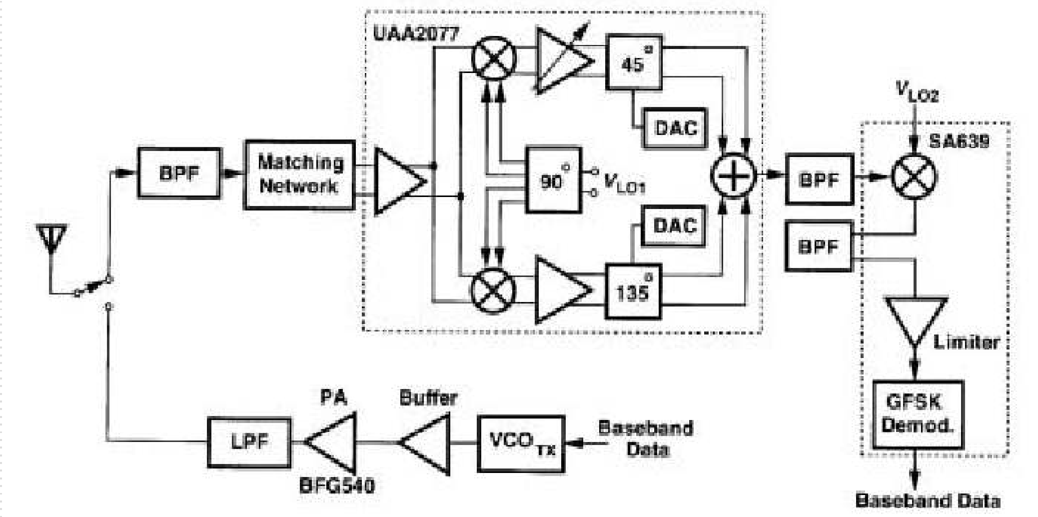
- **Walkie-talkie, first-generation cordless phone**
  - No LNA used for simplicity
- **Dual IF Conversion**
  - 50MHz→10.7MHz → 455kHz
- **25 external components**
- **2V supply voltage, 5 mA**
- **20dB SNR for 0.7μV_{rms} input**

Philips UAA2080T single-chip receiver



- Homodyne:470MHz LO generated by 78.3MHz crystal x3
- 30 external components
- 2V, 3mA
- -125dBm sensitivity for BER=0.03, 1.2kb/s

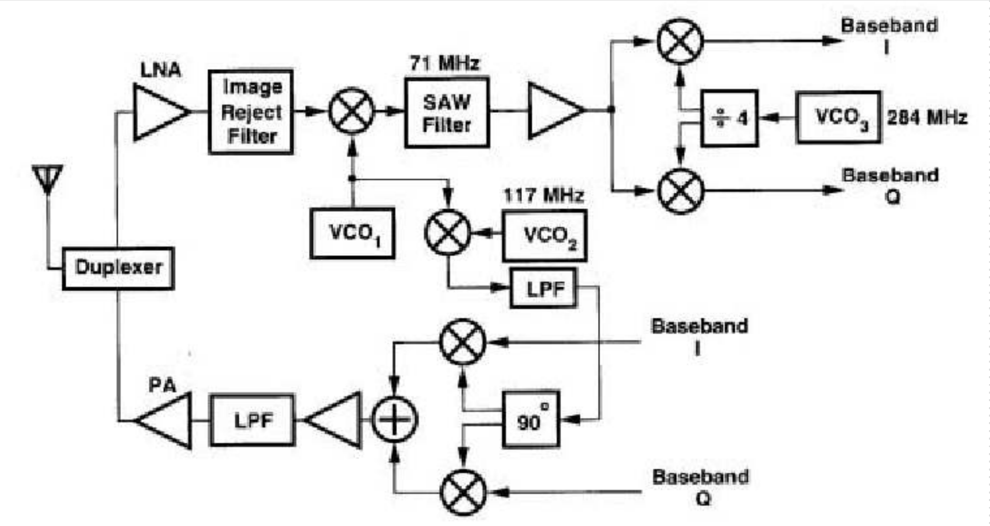
Philips's DECT Receiver



- **Dual IF receiver**
  - 1880-1900MHz → 110MHz → 9.8MHz
- **TDD**
- **Direct-conversion transmitter**
  - Open-loop GFSK modulation
- **PA pulling effect on VCO locking**

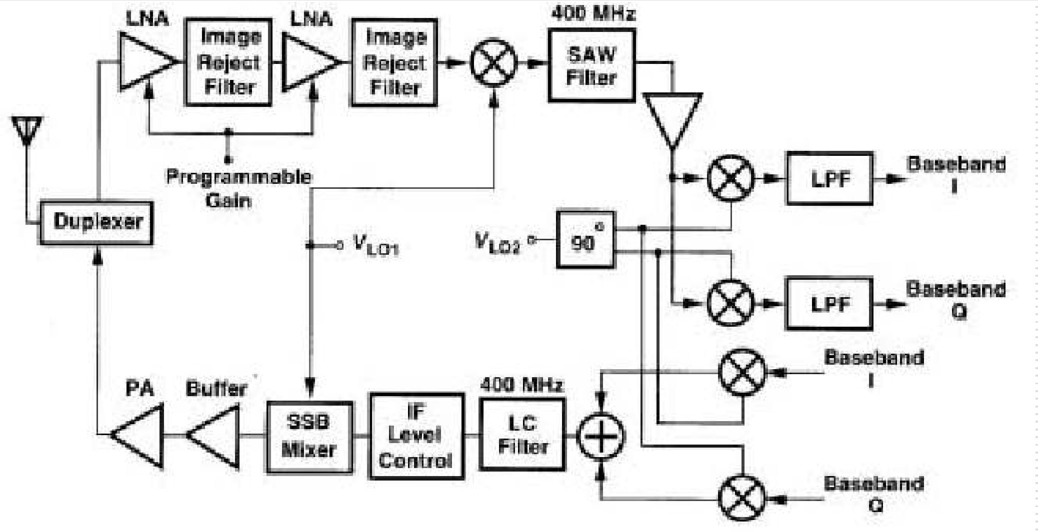
Lucent GSM

- **Receiver**
  - 890-915MHz(TX),935-960MHz(RX) → 71MHz
- **Transmitter**
  - Direct conversion
  - LO: addition of VCO1 and VCO2 to avoid VCO pulling
- **IQ LO generation by divide-by-4**
- **2.7V 60mA**



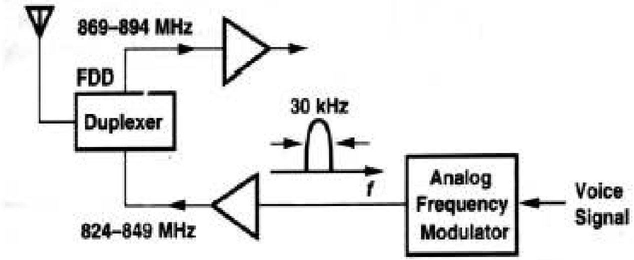
Philips GSM chip Set

- 890-915MHz(TX),935-960MHz(RX) → 400MHz
- Variable gain LNA +21 to -38 dB
- 1300MHz LO1

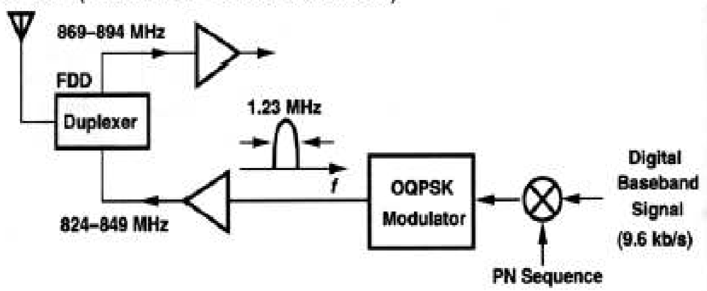


Receiver Architectures

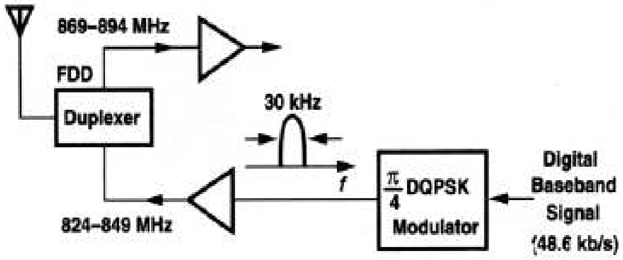
- AMPS (Advanced Mobile Phone Services)



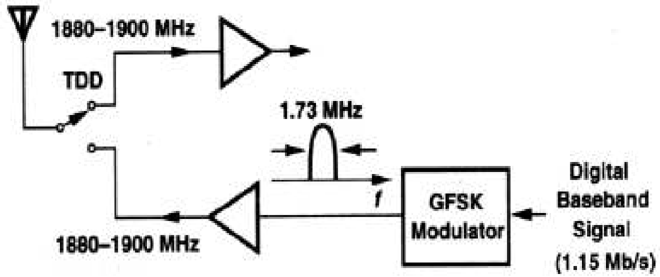
- IS-95 (Interim Standard 95)



- NADC (North American Digital Standard) - USDC



- DECT (Digital European Cordless Telephone)



- GSM (Global System for Mobile Comm.)