Communication system performance revisited

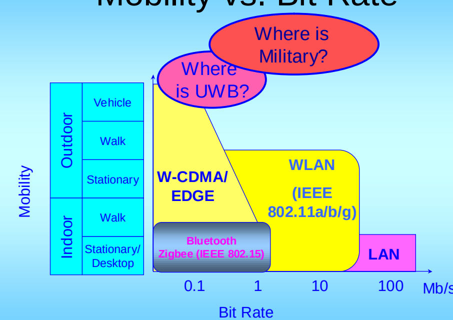
Slide from before: Performance Concerns

- DC offset
- Image rejection
- Quadrature requirements
- Noise and noise figure
- Phase noise and Jitter
- Distortion
  - Compression
  - Desensitization
  - Cross modulation
  - Intermodulation
  - IP2, IP3
  - Harmonic distortion (THD, SFDR,…)
- Bit error rate
- Data rate (bandwidth)

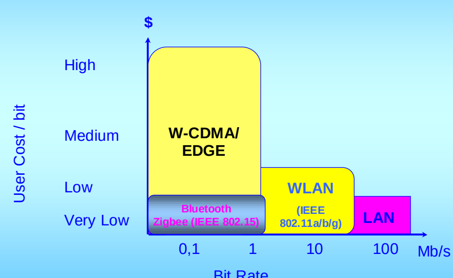
System level concerns

- Data rate (voice, text, image, video,…)
- Cost (CMOS, SiGe, …)
- Mobility (fixed, indoor, outdoor, ground vehicle, airborne, …)
- Battery life (power consumption)
- Weight (discrete, multi-chip, single chip,)
- Multi-standard support (hardware sharing)
- Security (baseband DSP)
- Quality of service (protocol, transceiver)

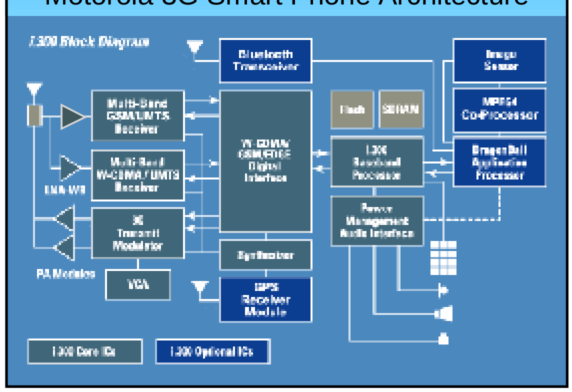
Mobility vs. Bit Rate



Cost vs. Bit Rate



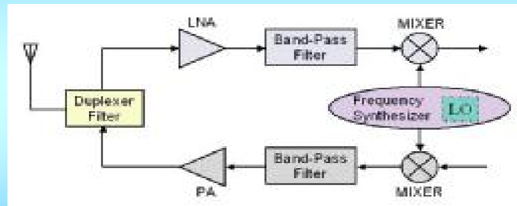
Motorola 3G Smart Phone Architecture



Transceiver performance

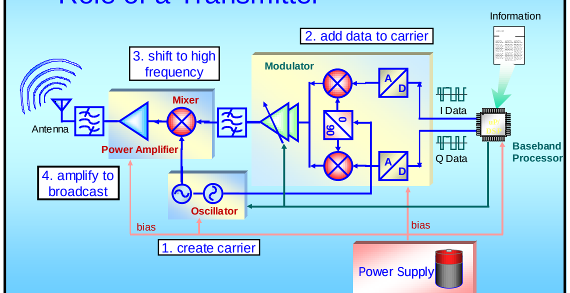
- Transceiver Overview
- Transmitter Performance Spec.
- Transmitter Architecture
- Receiver Performance Spec.
- Receiver Architecture
- Receiver Link Budget

Generic Transceiver Architecture

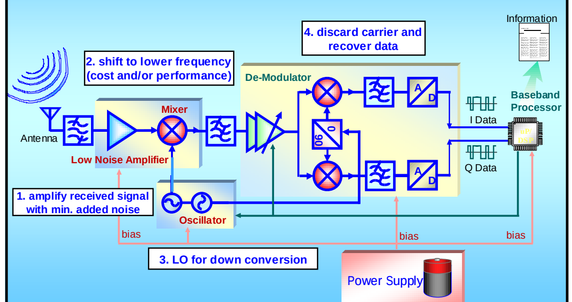


Transceiver

Role of a Transmitter

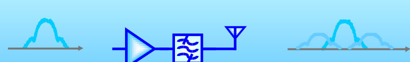


Role of a Receiver

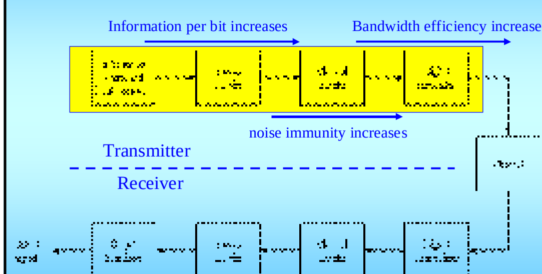


Transmitter Performance Spec.

- Output Power
- Spurious Emission
- Adjacent Channel Power Ratio; ACPR
- Frequency Stability
- Data rate
- Bandwidth efficiency
- Noise immunity



Digital Communication System:



Increasing Information

- Information in a source
  - Mathematical Models of Sources
  - Information Measures
- Compressing information
  - Huffman encoding
  - Lempel-Ziv-Welch Algorithm
  - Optimal Compression?
- Quantization of analog data
  - Scalar Quantization
  - Vector Quantization
  - Model Based Coding
    - µ-law encoding
    - Delta Modulation
    - Linear Predictor Coding (LPC)

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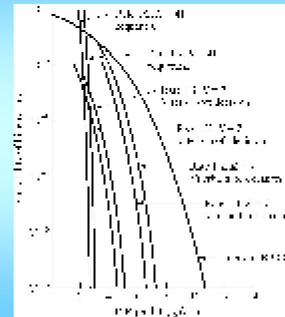
Increasing Noise Immunity

Error correction coding
Block coding
Channel coding
Adaptive feedback coding
...

Diversity
Space time diversity



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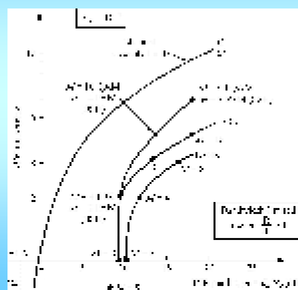
Increasing bandwidth Efficiency

- Modulation of digital data into analog waveforms
  - Impact of Modulation on Bandwidth efficiency



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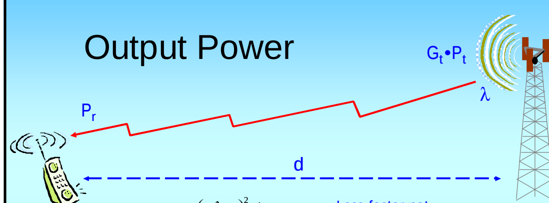
Output Power



$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \frac{1}{L}$$

Loss factor not related to propagation

$$PL = -10\log\left(\frac{P_r}{P_t}\right) = -10\log\left(G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \frac{1}{L}\right)$$

f (GHz)	D (m)	Prop Loss (dB)	Pt (dBm)	Pr (dBm)	L (dB)
2.45	10	60.23	20	-70.23	30

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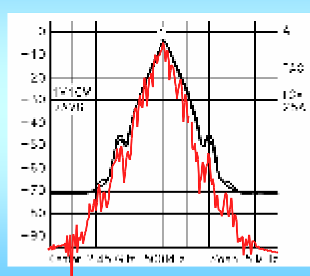
Spurious Emission



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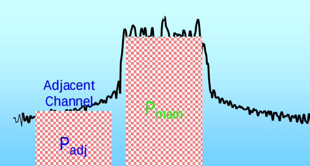
Adjacent Channel Power Ratio

- Definition depends on specification

$$ACPR = \frac{P_{adjacent}}{P_{main}}$$



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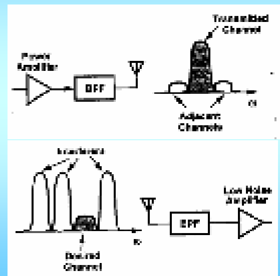
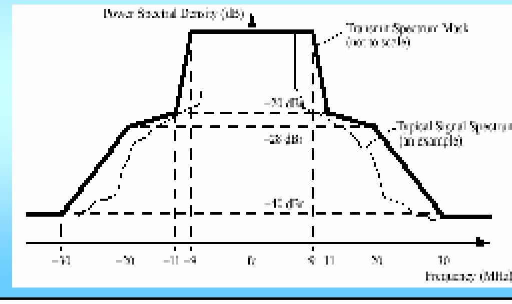
Adjacent channel reject



Transmit Specifications

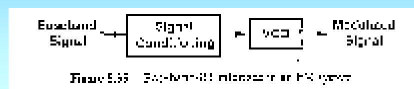
- Transmit spectrum mask

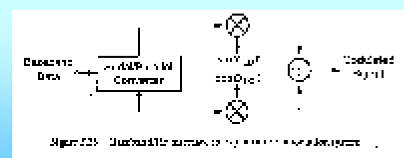


Transmitter Architecture

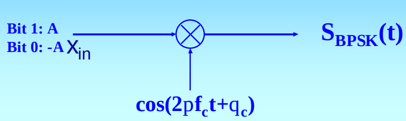
- RF/BB Interface
- Direct Conversion Transmitter
- Two-step Conversion Transmitter
- Offset PLL Transmitter

RF/BB Interface





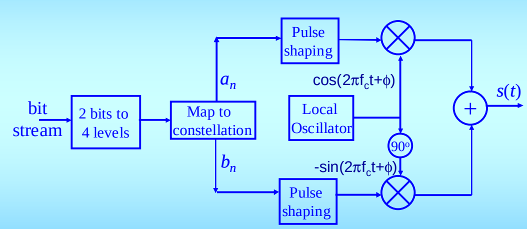
BPSK Transmitter



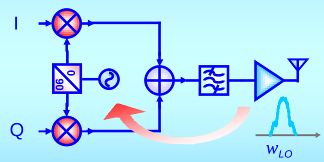
$$s_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2p f_c t + q_c) \qquad (bit\ 1)$$

$$s_{BPSK}(t) = -\sqrt{\frac{2E_b}{T_b}} \cos(2p f_c t + q_c) \qquad (bit\ 0)$$

QPSK transmitter



- Direct-conversion transmitter



Pros: less spurious synthesized
Cons: more LO pulling

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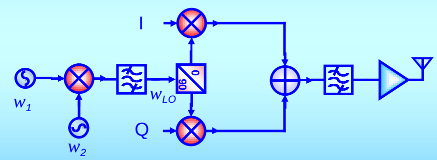
- Direct-conversion transmitter with offset LO



Pros: less LO pulling
Cons: more spurious synthesized

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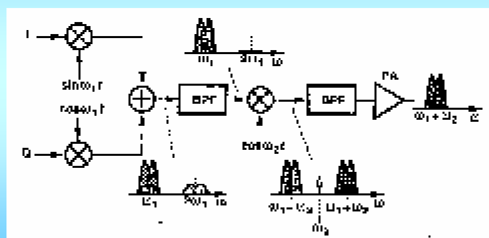
- Two-Step Transmitters



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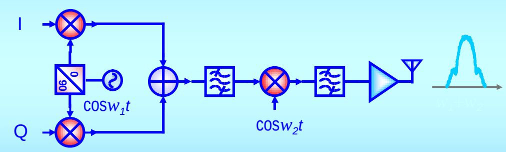
- Two-step transmitter



Pros: less LO pulling
superior IQ matching
Cons: required high-Q bandpass filter

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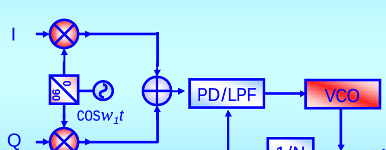
- Offset PLL transmitter



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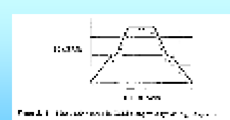
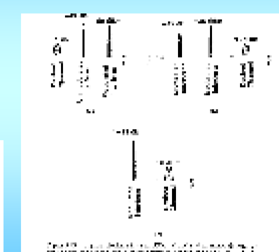
Transmitter Performance Check
1. Sensitivity and Dynamic Range
2. Unwanted Emission





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Receiver Performance Spec.

- Sensitivity
- Selectivity
- Spurious Response Rejection
- Intermodulation Rejection
- Receiver Self-quieting
- Dynamic Range

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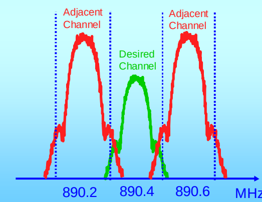
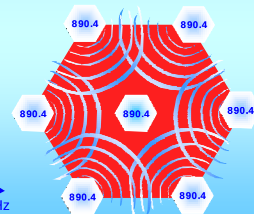
Sensitivity

- Adjacent Channel Interference
- Co-Channel Interference





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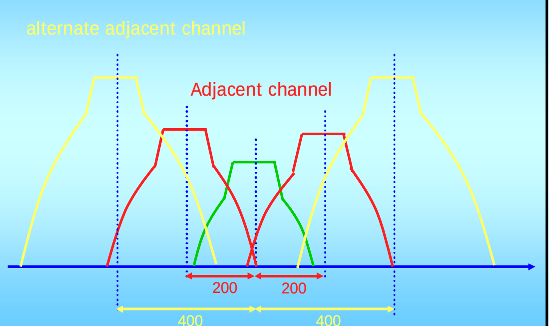
Receiver Specifications



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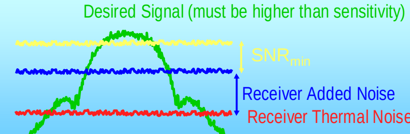
Sensitivity

$$Noise\ Floor = P_{nf}(\text{dBm}) = kTB(\text{dBm}) + F_{receiver}(\text{dB})$$

$$Sensitivity = P_{in,\min}(\text{dBm}) = kTB(\text{dBm}) + F_{receiver}(\text{dB}) + SNR_{\min}(\text{dB})$$

$$= P_{nf}(\text{dBm}) + SNR_{\min}(\text{dB})$$



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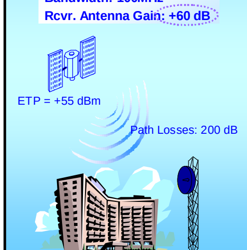
Sensitivity Example

Power to Antenna: +45 dBm
TX. Antenna Gain: +10 dB
Frequency: 10 GHz
Bandwidth: 100MHz
Rcvr. Antenna Gain: +60 dB

Transmitter:	
ETP	+ 55 dBm
Path Losses	-200 dB
Rcvr. Ant. Gain	60 dB
Power to Receiver	-75 dBm
Receiver:	
Noise Floor @ 290K	- 174 dBm/Hz
Noise in 100 MHz BW	+ 80 dB
Receiver N.F.	+10 dB
SNR min	+5 dB
Receiver Sensitivity	-79 dBm

Margin: 4 dB



How to increase Margin by 3dB ?

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Calculate Receiver Noise Figure

- Stage Thermal Noise
- Image Noise
- LO Wideband Phase Noise

$$F_{tot} = 1 + \frac{F_1 - 1}{1} + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \frac{F_4 - 1}{G_1 G_2 G_3} + \ldots$$

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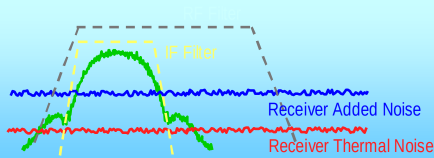
Selectivity

- IF filter rejection at the adjacent channel
- LO spurious in IF bandwidth
- Phase noise of LO



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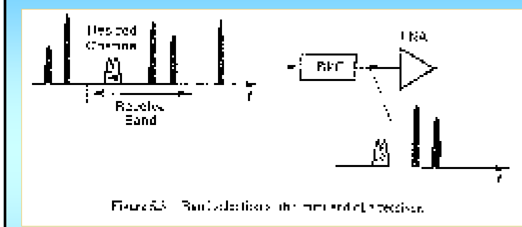

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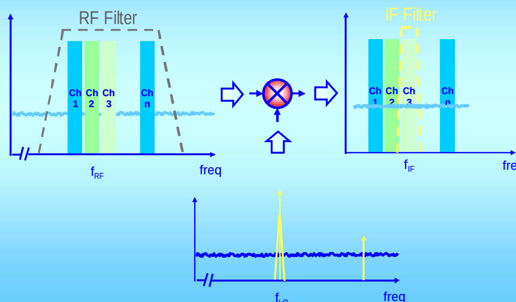
Selectivity



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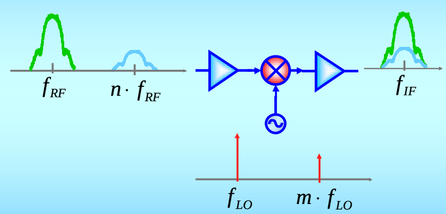
Spurious Response



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Spurious Reponses

$$IF = n \cdot RF + m \cdot LO$$

$$\frac{IF}{RF} = m \cdot \frac{LO}{RF} + n$$

$$y = \frac{IF}{RF}, \; x = \frac{LO}{RF}$$

$$y = m \cdot x + n$$

$$|m| + |n| = \text{order of spurious response}$$

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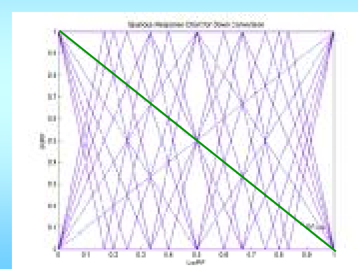
Spurious Response Chart



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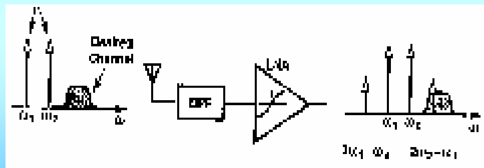
- Nonlinearity and Spurious respone



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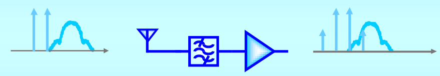
Intermodulation Rejection



$$IP3_{output} = \frac{1}{\sum_i \frac{1}{IP3_i G_{i+1} G_{i+2} \cdots G_n}} (mW)$$

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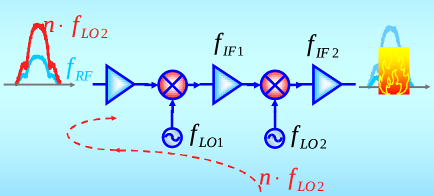
Receiver Self-quieting



$$f_{RF} = f_{LO1} + f_{IF1} = n \cdot f_{LO2}$$

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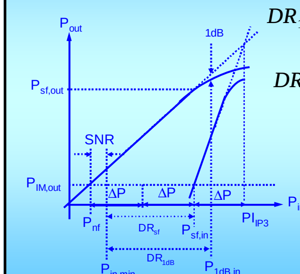
Dynamic Range



$$DR_{1dB} = P_{1dB,in} - P_{in,\min} = P_{1dB,in} - P_{nf} - SNR_{\min}$$

$$DR_{sf} = P_{sf,in} - P_{in,\min} = \frac{2P_{IIP3} + P_{IM,in}}{3} - P_{in,\min} = \frac{2P_{IIP3} + P_{nf}}{3} - P_{in,\min} = \frac{2(P_{IIP3} - P_{nf})}{3} - SNR_{\min}$$

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Receiver Architectures

- Heterodyne Receiver
- Direct Conversion Receiver
- Low-IF Receiver
- Image Reject Receiver

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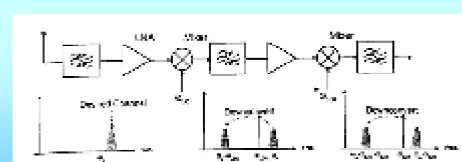
Super-heterodyne Receiver

– easy to design
– problem of image
– problem of half IF



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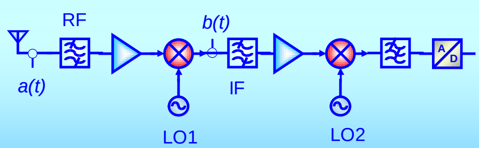
Heterodyne Receiver

- IF receiver



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Problem of Image Signal

$$a(t) = \cos(w_x t + m(t) + f)$$
$$b(t) = a(t) \cdot \cos(w_{LO} t + q)$$
$$= \cos(w_x t + m(t) + f) \cdot \cos(w_{LO} t + q)$$
$$= \frac{1}{2}\cos((w_x + w_{LO})t + m(t) + f + q)$$
$$+ \frac{1}{2}\cos((w_x - w_{LO})t + m(t) + f - q)$$

$$if \quad w_x = w_{RF} = w_{LO} + w_{IF} \Rightarrow OK$$
$$if \quad w_x = w_{image} = w_{LO} - w_{IF} \Rightarrow ?$$

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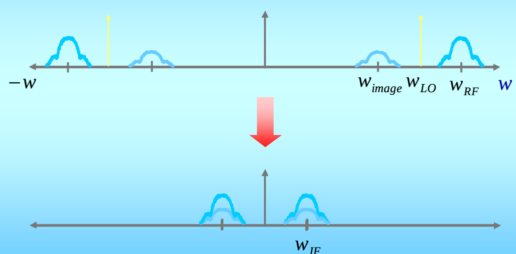
Problem of Image Signal



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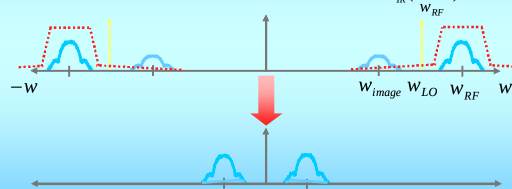
Problem of Image Signal

- One solution: Image Rejection Filter
- Image rejection ratio: $\frac{H_{IR}(w_{RF})}{H_{IR}(w_{image})} = \frac{1}{\overline{H}_{IR}(\frac{w_{image}}{w_{RF}})}$



Need ω_{RF} and ω_{LO} to be far away

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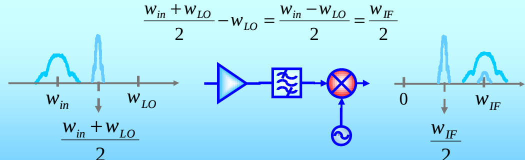
Problem of Half IF

- Second order harmonic

$$|(w_{in} + w_{LO}) - 2w_{LO}| = w_{IF}$$

$$\frac{w_{in} + w_{LO}}{2} - w_{LO} = \frac{w_{in} - w_{LO}}{2} = \frac{w_{IF}}{2}$$



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How to Select IF?

- Spurious Response
- Image Rejection v.s. Channel Selection
- Filter Availability

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Filter Availability

- Example 1
  - f_{RF}=1800MHz
  - f_{IF}=10MHz
  - Is this filter available?

$$\frac{f_{RF}}{f_{IF}} = 180 \quad Q = \frac{f_{RF}}{BW} \ge \frac{1800}{20} = 90$$

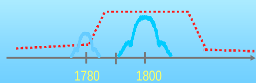

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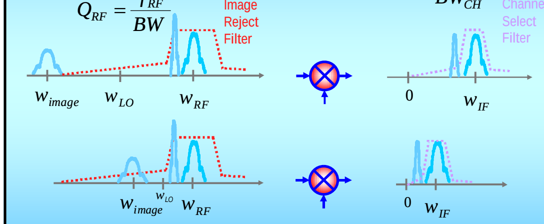
Image Rejection v.s. Channel Selection

$$Q_{RF} = \frac{f_{RF}}{BW} \qquad Q_{CH} = \frac{f_{IF}}{BW_{CH}}$$



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IF Selection

- Usually f_{RF}/f_{IF}<10
- Example 2 (Multistage IF)
  - f_{RF}=900MHz
  - f_{IF1}=250MHz
  - f_{IF2}=50MHz
  - f_{IF3}=10MHz

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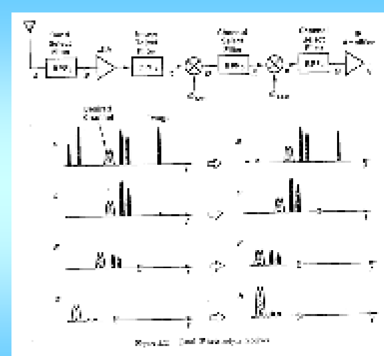

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Summary of Heterodyne Receiver

- Down converts RF to IF thus introduces image problem; avoid image signal by image reject filter
- As frequency / bandwidth increases, multi-stage IF is necessary
- Not suitable for integration due to off-chip filters
- Sensitive to external parasitic signal
- Expensive and high power consumption

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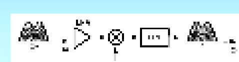
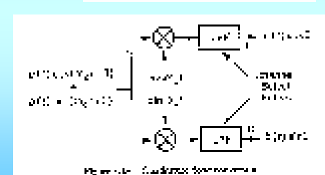
Direct Conversion Receivers

- Easy to single chip
- Channel Selection
- DC offsets
- I/Q Mismatch
- Even-Order Distortion
- Flick Noise:choose a suitable code
- LO Leakage





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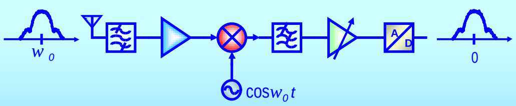
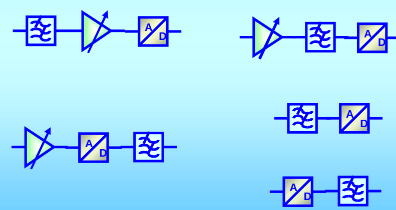
Direct Conversion Receiver

- Zero-IF Receiver



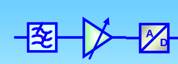
Channel Selection

- Different placement of three block

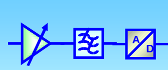


Comparison and trade-offs

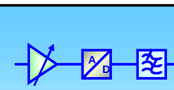
- Assume normalized input full range of +-1V for the ADC
- Input signal (signal after mixer) amplitude can range from ~<1 mV to just under 1V
- f_{RF}=1.8GHz, f_{IF}=100MHz, f_{ch}=200KHz
- Input signal is wideband but the desired signal component is narrow band (IF)
- DSP in digital domain is omnipotent



- BPF
  - Good Q(>25), excellent dynamic range
  - Blocks unwanted channels
- AGC amplifier
  - Only need to maintain in-channel linearity
  - Example gains: 1, 4, 16, 64, 250, 1000
  - Ensures v_{inADC} ¼ to full range
- ADC
  - 6 bit is sufficient, this gives at least:
  - 16 quantization levels for ¼ full range
  - Can do sub-sampling, =>low speed ADC: ADC speed >400KSPS

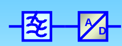


- AGC amplifier
  - Need excellent dynamic range and wand band linearity
  - Example gains: 1, 4, 16, 64, 250, 1000
  - Ensures v_{inBPF} ¼ to full range
- BPF
  - Good Q(>25), but no need for high dynamic range
  - Blocks unwanted channels
- ADC
  - 6 bit is sufficient, this gives at least:
  - 16 quantization levels for ¼ full range
  - Can do sub-sampling, => low speed ADC: ADC speed >400KSPS



- AGC amplifier
  - Need excellent dynamic range and wand band linearity
  - Example gains: 1, 4, 16, 64, 250, 1000
  - Ensures v_{inBPF} ¼ to full range
- ADC
  - 6 bit is sufficient, this gives at least:
  - 16 quantization levels for ¼ full range
  - But need high-speed ADC: ADC speed >200MSPS
- BPF
  - Implement in DSP domain

- BPF
  - Good Q(>25), excellent dynamic range
  - Blocks unwanted channels
  - But ADC input ranges from sub mV to 1V
- ADC
  - High resolution is required
  - At least 16 bits to ensure 16 quantization levels for ¼ mV weak signals
  - Narrow band allows sub-sampling, =>low speed ADC: ADC speed >400KSPS
  - Currently 16 bit 1-5MSPS ADCs available
- No AGC amplifier used



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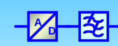
- ADC
  - ADC input ranges from sub mV to 1V
  - High resolution is required
  - At least 16 bits to ensure 16 quantization levels for ¼ mV weak signals
  - Full IF band requires high-speed ADC: ADC speed >200MSPS
  - Currently 12 bit 200MSPS ADCs available, which gives 4 quantization levels for 1mV signals
- BPF
  - Implement in DSP domain
- No AGC amplifier used



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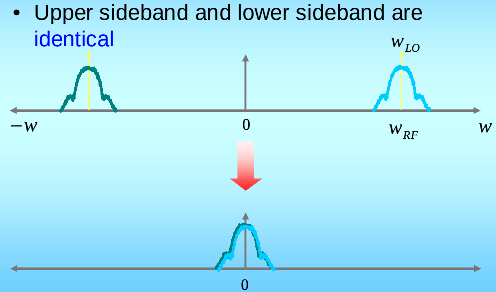
Mirror Signal

- Upper sideband and lower sideband are identical



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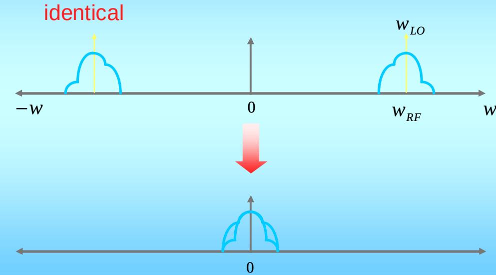
Mirror Signal

- Upper sideband and lower sideband are not identical



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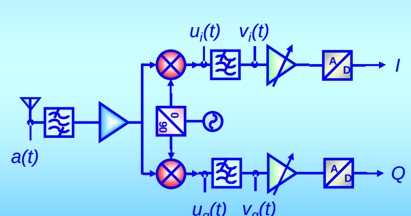
Mirror Signal Suppression

- Quadrature Down Conversion



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Quadrature Conversion

$$a(t) = \cos(w_{RF}\,t + m(t) + f)$$
$$u_i(t) = a(t)\cdot\cos(w_{LO}\,t + q)$$
$$u_q(t) = a(t)\cdot\sin(w_{LO}\,t + q)$$
$$v_i(t) = \tfrac{1}{2}\cos(m(t) + f - q)$$
$$v_q(t) = \tfrac{-1}{2}\sin(m(t) + f - q)$$
$$\frac{v_q(t)}{v_i(t)} = \tan(-m(t) + q - f)$$
$$m(t) = -\tan^{-1}\left(\frac{v_q(t)}{v_i(t)}\right) + q - f$$

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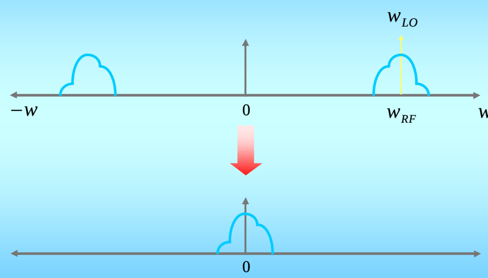
Quadrature Down Conversion



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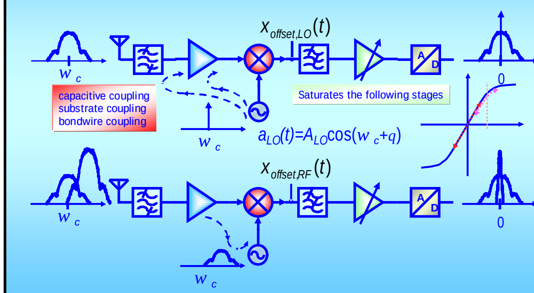
DC Offset (Self-mixing)



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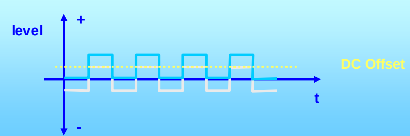
DC Offset (Self-mixing)

$$x_{offset,LO}(t) = A_{crosstalk}(\omega)\cdot a_{LO}(t)\cdot a_{LO}(t)$$
$$= A_{crosstalk}(\omega)\cdot A_{LO}\cos(\omega_c t+\theta)\cdot A_{LO}\cos(\omega_c t+\theta)$$
$$= \tfrac{1}{2}\cdot A_{crosstalk}(\omega)\cdot A_{LO}^2\left(1+\cos 2(\omega_c t+\theta)\right)$$

$$x_{offset,interferer}(t) = A_{crosstalk}(\omega)\cdot a_{interferer}(t)\cdot a_{interferer}(t)$$
$$= A_{crosstalk}(\omega)\cdot A_{interferer}^2\cos^2(\omega_c t+m(t)+\varphi)$$
$$= \tfrac{1}{2}\cdot A_{crosstalk}(\omega)\cdot A_{interferer}^2\left(1+\cos 2(\omega_c t+m(t)+\varphi)\right)$$



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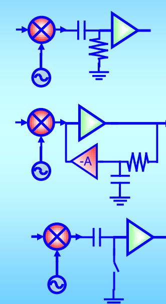
DC Offset Cancellation

- Capacitive Coupling
  - Requires a large capacitor
- Negative Feedback
  - Nonlinear
- TDMA Offset Cancellation
  - Requires a large capacitor



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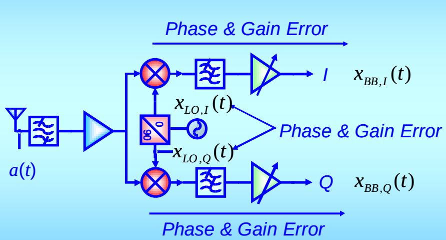
I/Q Mismatch



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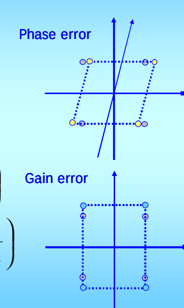
I/Q Mismatch

$$a(t) = A\cos\left(w_c t + m(t) + f\right)$$
$$x_{LO,I}(t) = \left(1+\frac{e}{2}\right)\cos\left(w_c t+\frac{q}{2}\right)$$
$$x_{LO,Q}(t) = \left(1-\frac{e}{2}\right)\sin\left(w_c t-\frac{q}{2}\right)$$
$$x_{BB,I}(t) = \frac{A}{2}\left(1+\frac{e}{2}\right)\cos\left(m(t)+f-\frac{q}{2}\right)$$
$$x_{BB,Q}(t) = -\frac{A}{2}\left(1-\frac{e}{2}\right)\sin\left(m(t)+f+\frac{q}{2}\right)$$



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

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

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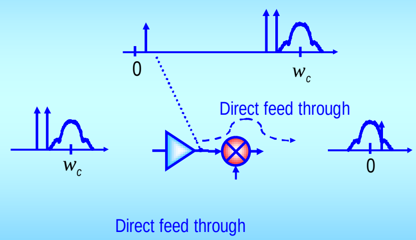
Even-Order Distortion



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Summary of Direct Conversion Receiver

- No need for imager reject filter
- Suitable for monolithic integration with baseband
- DC offsets due to crosstalk of input ports of mixer
- Even order IM direct feed through to baseband
- Quadrature down conversion suppresses mirror
- I/Q mismatch due to mismatches in parasitics
- Low power consumption attributed to less hardware

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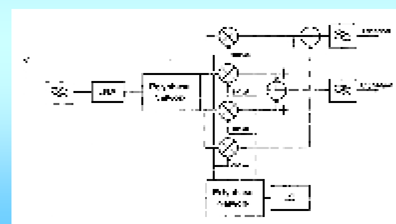
Low-IF Receivers

- Possible way to implant digital IF
- Low-IF cause image reject problem



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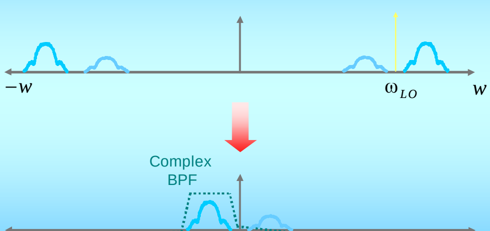
Low-IF Down Conversion



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Mirror Signal Suppression (1)

Image Reject Receiver

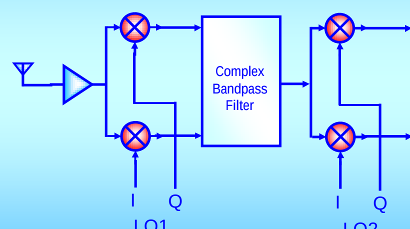

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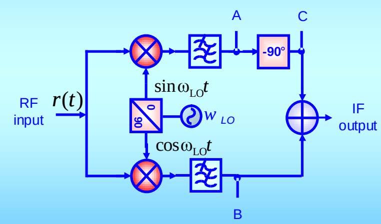
Image Reject Receiver

- Hartley Architecture



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$$r(t) = A_{RF}\cos w_{RF}t + A_{im}\cos w_{im}t$$

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

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

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

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

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

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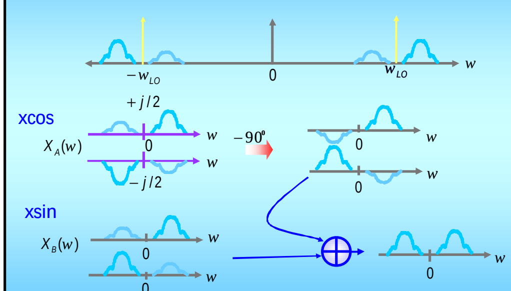
Graphical interpretation in spectral domain



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IQ error effect

- Ideal IQ: image completely rejected
- If signal and image not single tone, 90º shift is not exact
- Local oscillator's sine and cosine not matched in magnitude and phase
- 90o phase shifter may have both gain and phase error
- All lead to incomplete image rejection

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IPR Evaluation and IRR – LO error

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

$$x_B(t) = (A_{LO} + e)\frac{A_{RF}}{2}\cos[(w_{LO} - w_{RF})t + q] + (A_{LO} + e)\frac{A_{im}}{2}\cos[(w_{LO} - w_{im})t + q]$$

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

$$x_{sig}(t) = \frac{(A_{LO} + e)A_{RF}}{2}\cos[(w_{LO} - w_{RF})t + q] + \frac{A_{LO}A_{RF}}{2}\cos(w_{LO} - w_{RF})t$$

$$x_{im}(t) = \frac{(A_{LO} + e)A_{im}}{2}\cos[(w_{LO} - w_{im})t + q] - \frac{A_{LO}A_{im}}{2}\cos(w_{LO} - w_{im})t$$

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

Input image power ratio

$$IRR = \frac{(A_{LO} + e)^2 - 2A_{LO}(A_{LO} + e)\cos q + A_{LO}^2}{(A_{LO} + e)^2 + 2A_{LO}(A_{LO} + e)\cos q + A_{LO}^2}$$

$$= \frac{(1 + \frac{\Delta A}{A})^2 - 2(1 + \frac{\Delta A}{A})\cos q + 1}{(1 + \frac{\Delta A}{A})^2 + 2(1 + \frac{\Delta A}{A})\cos q + 1}$$

$$IRR \approx \frac{\left(\Delta A/A\right)^2 + q^2}{4}$$

θ in radians

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90 degree phase shift

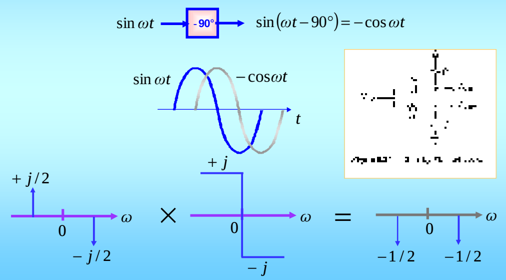
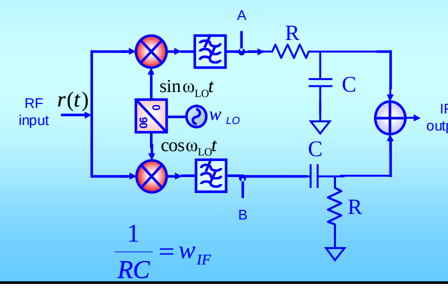


Image Reject Receiver

- Hartley Architecture



Gain Mismatch Due to RC errors:

$$\frac{\Delta A}{A} = \frac{(R+\Delta R)(C+\Delta C)w - 1}{\sqrt{1+(R+\Delta R)^2(C+\Delta C)^2 w^2}} \div \frac{1}{\sqrt{1+R^2C^2w^2}}$$

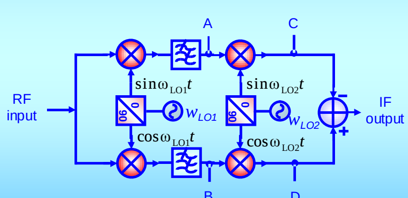
$$\frac{\Delta A}{A} \approx \frac{\Delta R/R + \Delta C/C}{\sqrt{2+\Delta R/R + \Delta C/C}} \div \frac{1}{\sqrt{2}}$$

$$\approx \frac{\Delta R}{R} + \frac{\Delta C}{C}$$

- Check IEL for “polyphase filter” or “image reject filter”
  - All suffer from error due to frequency mismatch if signal is not pure single tone
- For 90º phase shifter for LO, there are several alternatives
  - Differential ring oscillators with even # of delay stages
  - D-FF based phase delays
  - Double-integrator based oscillators
  - Delay-locked loops
  - Phase-locked loops

Image Reject Receiver

- Weaver Architecture



$$x(t) = A_{RF}\cos[w_{RF}t + q_1] + A_{im}\cos[w_{im}t + q_2]$$

$$x_A(t) = \frac{A_{RF}}{2}\sin[(w_{LO1} - w_{RF})t - q_1] + \frac{A_{im}}{2}\sin[(w_{LO1} - w_{im})t - q_2]$$

$$= -\frac{A_{RF}}{2}\sin[(w_{RF} - w_{LO1})t + q_1] + \frac{A_{im}}{2}\sin[(w_{LO1} - w_{im})t - q_2]$$

$$x_B(t) = \frac{A_{RF}}{2}\cos[(w_{LO1} - w_{RF})t - q_1] + \frac{A_{im}}{2}\cos[(w_{LO1} - w_{im})t - q_2]$$

$$= \frac{A_{RF}}{2}\cos[(w_{RF} - w_{LO1})t + q_1] + \frac{A_{im}}{2}\cos[(w_{LO1} - w_{im})t - q_2]$$

$$x_C(t) = x_A(t)\sin w_{LO2}t$$
$$= -\frac{A_{RF}}{4}\cos\left[(w_{RF} - w_{LO1} - w_{LO2})t + q_1\right]$$
$$+ \frac{A_{im}}{4}\cos\left[(w_{LO1} - w_{im} - w_{LO2})t - q_2\right]$$

$$x_D(t) = x_B(t)\cos w_{LO2}t$$
$$= \frac{A_{RF}}{4}\cos\left[(w_{RF} - w_{LO1} - w_{LO2})t + q_1\right]$$
$$+ \frac{A_{im}}{4}\cos\left[(w_{LO1} - w_{im} - w_{LO2})t - q_2\right]$$

$$x_{output}(t) = x_D(t) - x_C(t) = \frac{A_{RF}}{2}\cos\left[(w_{RF} - w_{LO1} - w_{LO2})t + q_1\right]$$

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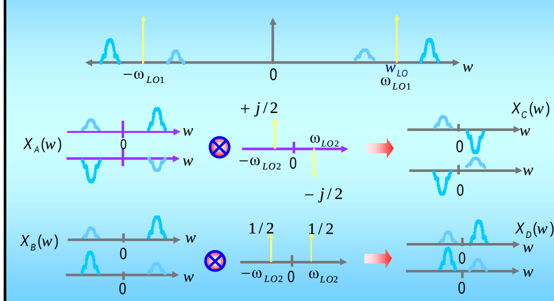
Weaver Architecture



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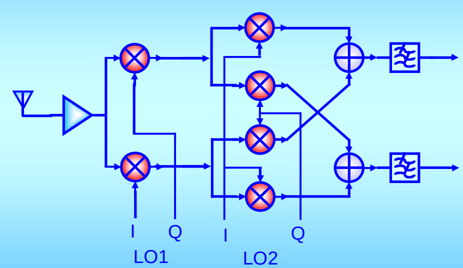
Quadrature Weaver Architecture



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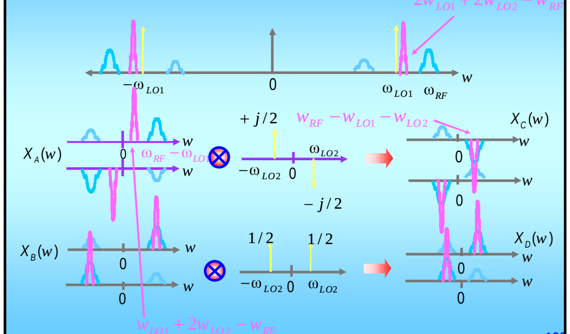
Weaver Architecture



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Receiver Link Budget Analysis

- Noise Figure Calculation
- IP3 Calculation
- Image Rejection Calculation
- Frequency Planning

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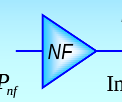
Noise Figure Calculation

$$SNR_{\min} = \frac{E_s}{N_0}\cdot\frac{R_{symbol}}{BW} \Rightarrow SNR_{\min}(dB) = \frac{E_s}{N_0}(dB) + 10\log\left(\frac{R_{symbol}}{BW}\right)$$

SNR_{in} $SNR_{\min}$

RF input



Baseband

Input noise power : P_{nf}
$= -174dBm + 10\log BW$

Input referred noise floor
$= -174dBm + 10\log BW + NF$

Standard	Bandwidth	10log(BW)	Sensitivity(dBm)	Noise Floor (dBm)	SNRin(dB)	NF(dB)	SNRmin(dB)
DECT	1.70E+06	62.30	-83.00	-111.50	28.50	18.20	10.3
GSM	2.00E+05	53.01	-102.00	-120.79	18.79	9.79	9
WLAN	2.00E+06	63.01	-80.00	-110.79	30.79	15.69	15.1

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IP3 Calculation

Input referred npoise

$$DR_{sf} = \frac{2(P_{IIP3} - P_{nf})}{3} - SNR_{\min}$$

$$P_{IIP3} = \frac{3}{2}\left(DR_{sf} + SNR_{\min}\right) + P_{nf}$$

$$P_{-1dB} \approx P_{IIP3} - 10$$

Standard	DR	SFDR	IIP3	Pmax	Bandwidth	10log(BW)	Sensitivity(dBm)
Bluetooth	50.00	36.57	-10.00	-20.00	1.00E+06	60.00	-70.00
GSM	87.00	61.67	-5.00	-15.00	2.00E+05	53.01	-102.00
WLAN	76.00	52.30	6.00	-4.00	2.00E+06	63.01	-80.00

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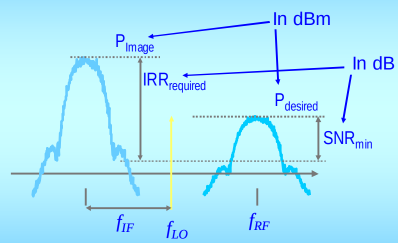
Image Rejection Calculation



$$IRR_{required} = P_{image} - P_{desired} + SNR_{\min}$$

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