CIRF
Circuit Intégré Radio Fréquence

Lecture IV

• **Receiver Architectures**

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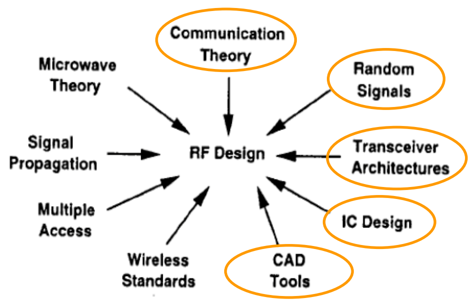
References

- B. Razavi, "RF Microelectronics", Prentice Hall, 1997.
- M. Perrott, "High Speed Communication Circuits and Systems", M.I.T.OpenCourseWare, http://ocw.mit.edu/, Massachusetts Institute of Technology, 2003.

Multidisciplinarity of radio design



B. Razavi, *RF Microelectronics*, Prentice Hall, 1998

Hostile environment

- The signal to be received and successfully detected may have a much lower amplitude than other signals very close in frequency
  - In general, many stages of filtering are required to separate the desired signal from the interferers
- The availability of suitable filters dictates the radio architecture itself
- Frequency translation is always applied, in order to process the signal at manageable (low) frequencies

Interferers

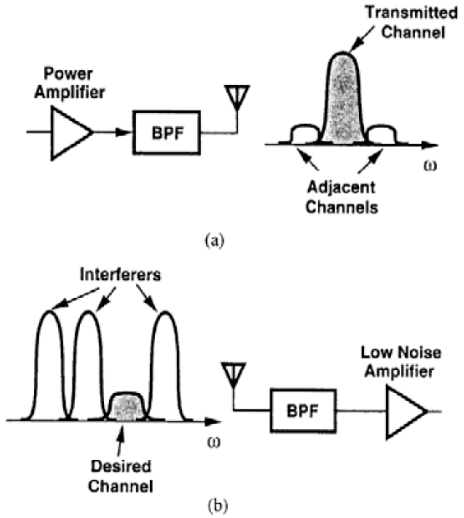


Figure 5.1 (a) Transmitter and (b) receiver front ends of a wireless transceiver.

Channel selection at RF?

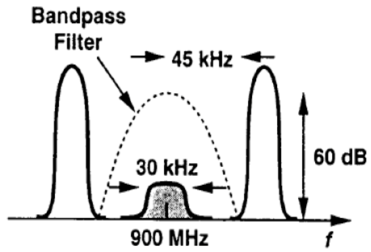


Figure 5.2 Rejection required of a hypothetical front-end bandpass filter.

Very high Q for the BPF!

$$Q = \frac{\omega_0}{BW}$$

Receive band selection

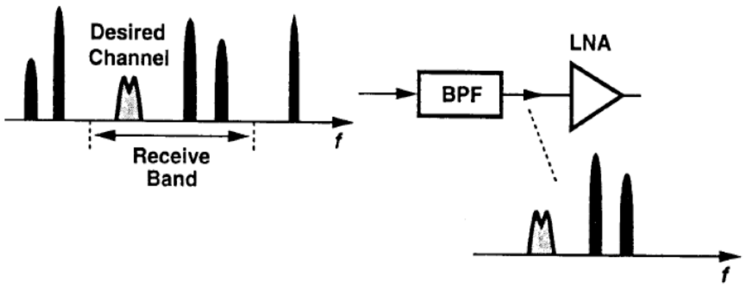


Figure 5.3 Band selection at the front end of a receiver.

Front-end nonlinearity

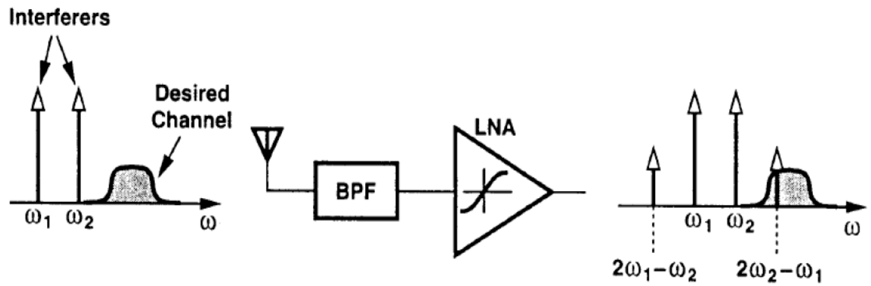
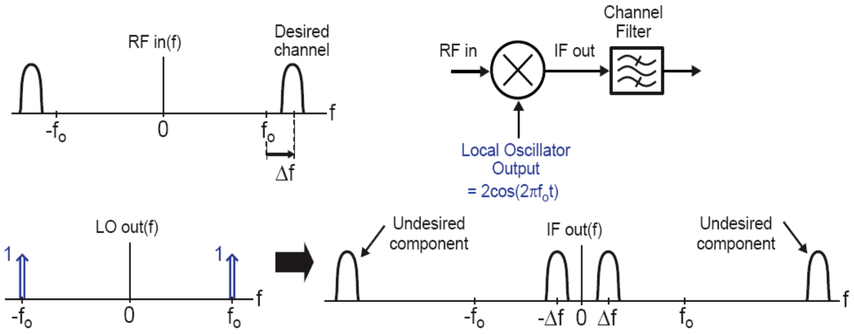


Figure 5.5 Effect of nonlinearity in the front end.

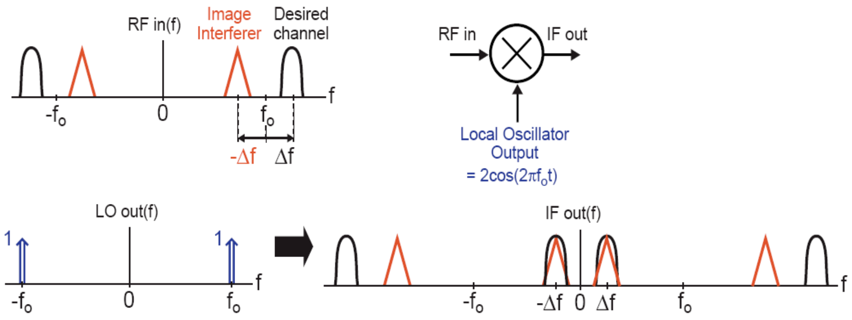
Intermodulation distortion is very critical.

Ideal Mixer Behavior



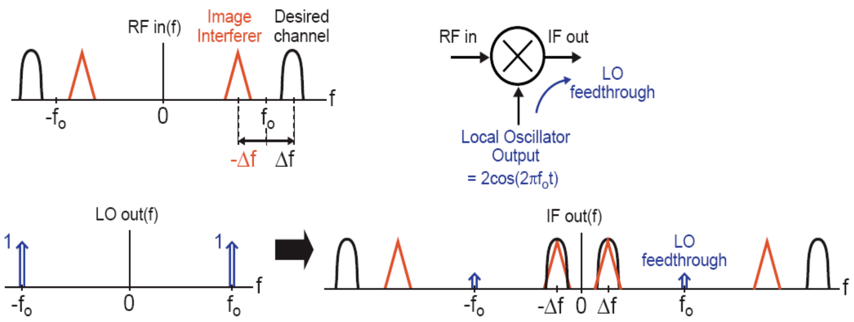
- RF spectrum converted to a lower IF center frequency
  - IF stands for intermediate frequency
    - If IF frequency is nonzero – heterodyne or low IF receiver
    - If IF frequency is zero – homodyne receiver
- Use a filter at the IF output to remove undesired high frequency components

The Issue of Aliasing



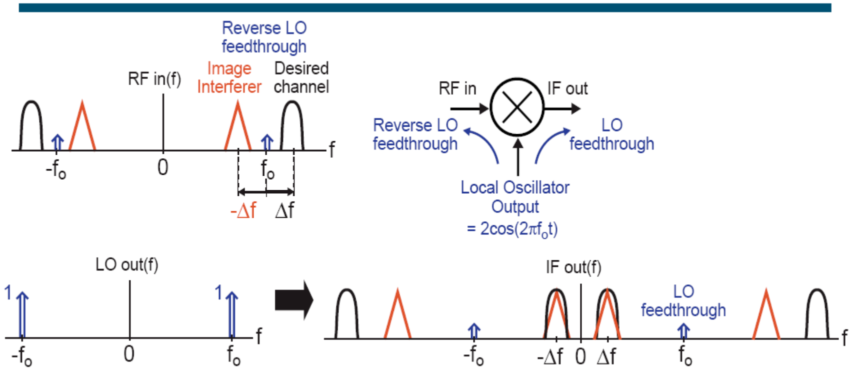
- When the IF frequency is nonzero, there is an image band for a given desired channel band
  - Frequency content in image band will combine with that of the desired channel at the IF output
  - The impact of the image interference cannot be removed through filtering at the IF output!

LO Feedthrough



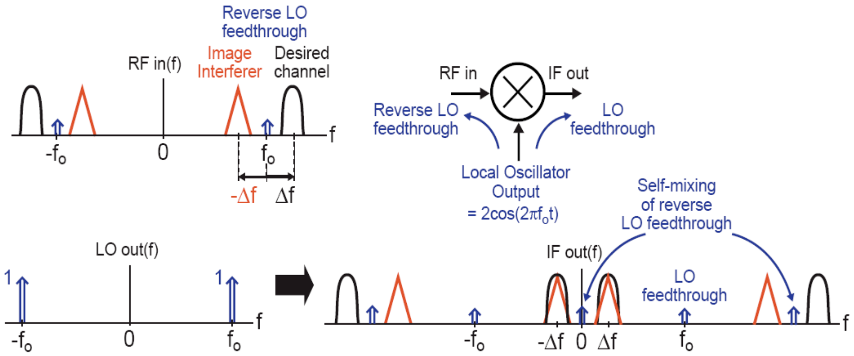
- LO feedthrough will occur from the LO port to IF output port due to parasitic capacitance, power supply coupling, etc.
  - Often significant since LO output much higher than RF signal
    - If large, can potentially desensitize the receiver due to the extra dynamic range consumed at the IF output
    - If small, can generally be removed by filter at IF output

Reverse LO Feedthrough



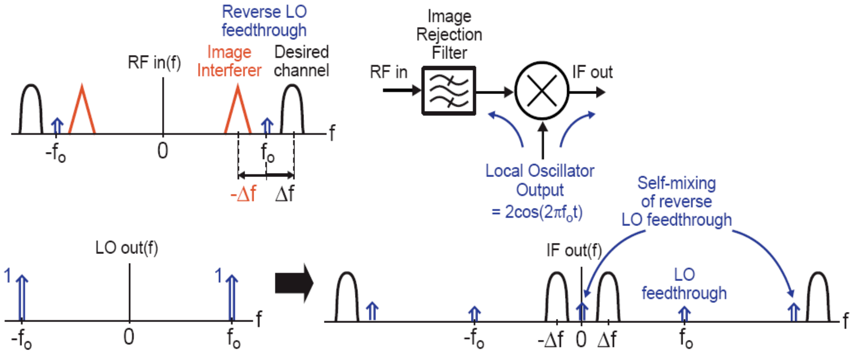
- Reverse LO feedthrough will occur from the LO port to RF input port due to parasitic capacitance, etc.
  - If large, and LNA doesn't provide adequate isolation, then LO energy can leak out of antenna and violate emission standards for radio
  - Must insure that isolate to antenna is adequate

Self-Mixing of Reverse LO Feedthrough



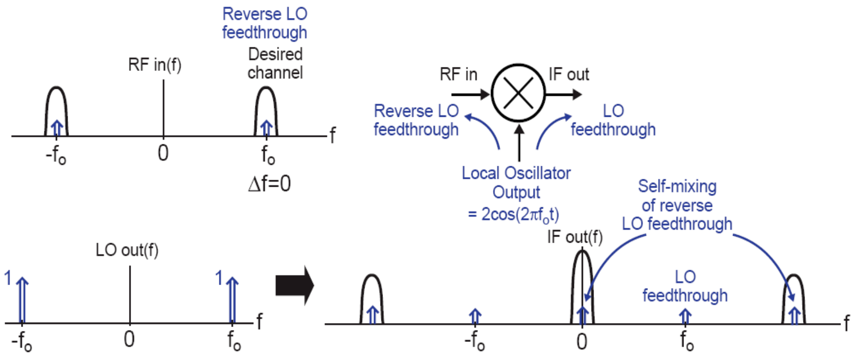
- LO component in the RF input can pass back through the mixer and be modulated by the LO signal
  - DC and $2f_o$ component created at IF output
  - Of no consequence for a heterodyne system, but can cause problems for homodyne systems (i.e., zero IF)

Removal of Image Interference – Solution 1



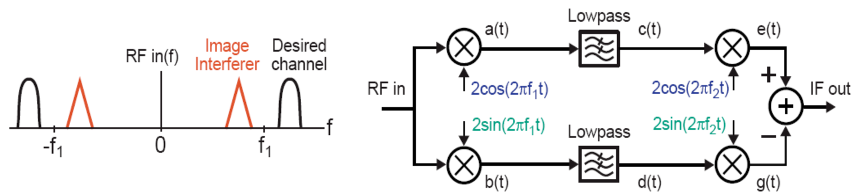
- An image reject filter can be used *before* the mixer to prevent the image content from aliasing into the desired channel at the IF output

Removal of Image Interference – Solution 2



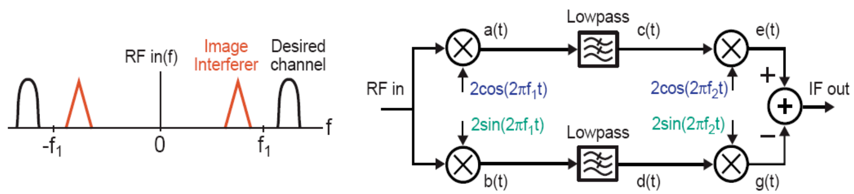
- Mix directly down to baseband (i.e., homodyne approach)
  - With an IF frequency of zero, there is no image band
- Issues – many!
  - DC term of LO feedthrough can corrupt signal if time-varying
  - DC offsets can swamp out dynamic range at IF output
  - 1/f noise, back radiation through antenna

Removal of Image Interference – Solution 3



- Rather than filtering out the image, we can cancel it out using an image rejection mixer
  - Advantages
    - Allows a low IF frequency to be used without requiring a high Q filter
    - Very amenable to integration
  - Disadvantage
    - Level of image rejection is determined by mismatch in gain and phase of the top and bottom paths
    - Practical architectures limited to 40-50 dB image rejection

Image Reject Mixer Principles – Step 1



- Note: we are assuming RF in(f) is purely real right now

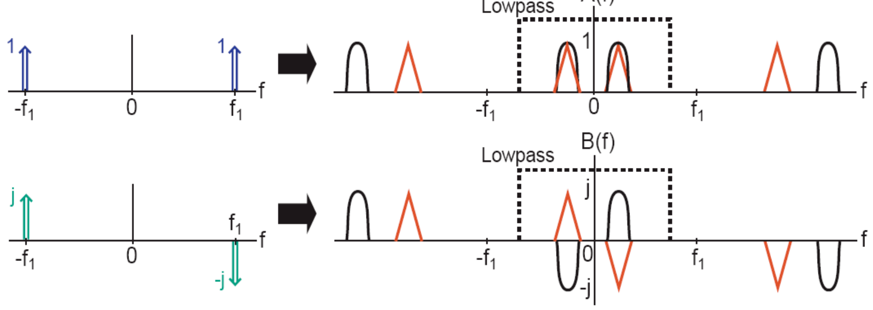


Image Reject Mixer Principles – Step 2

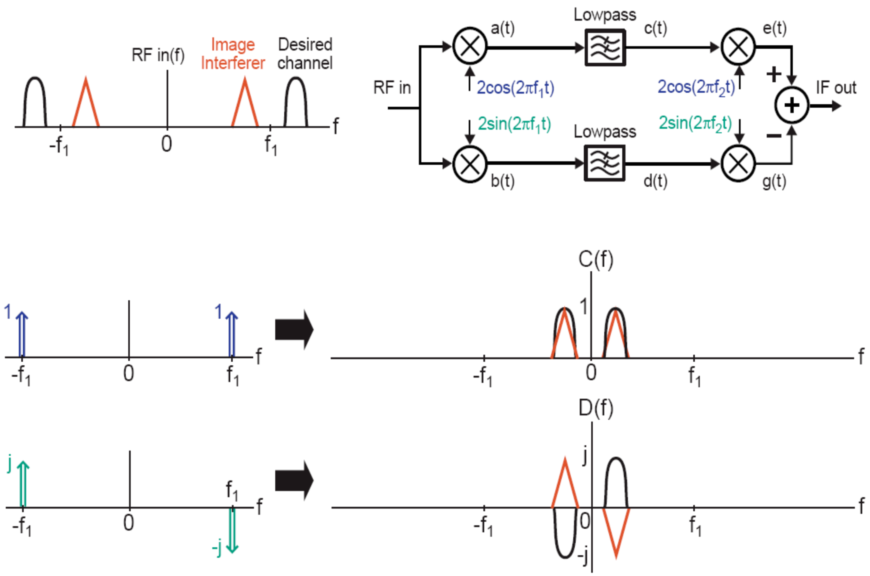


Image Reject Mixer Principles – Step 3

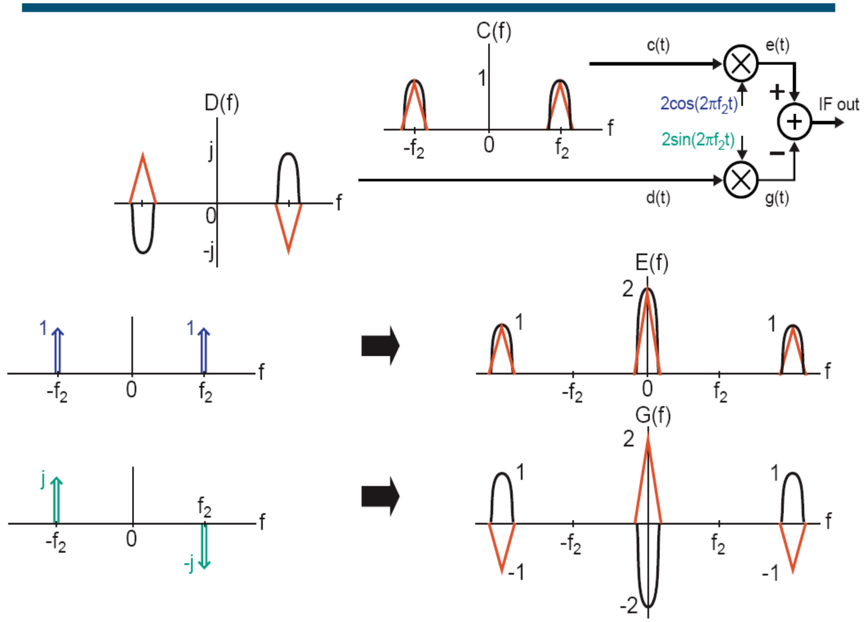


Image Reject Mixer Principles – Step 4

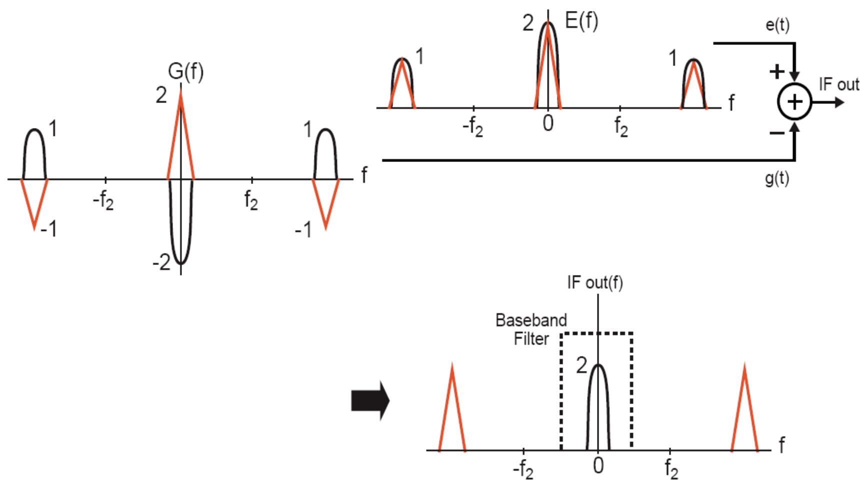
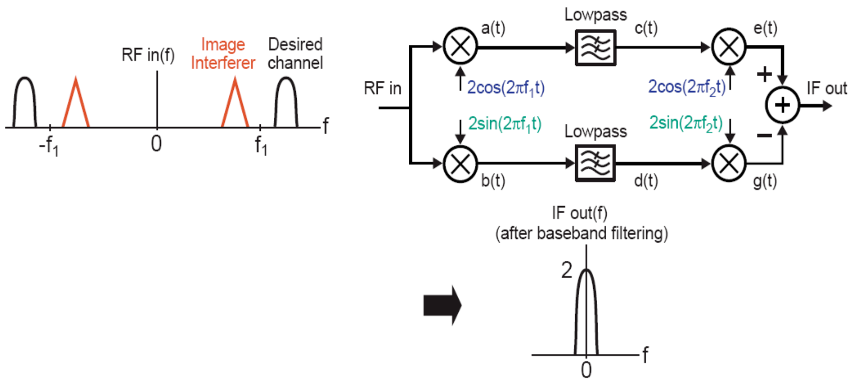
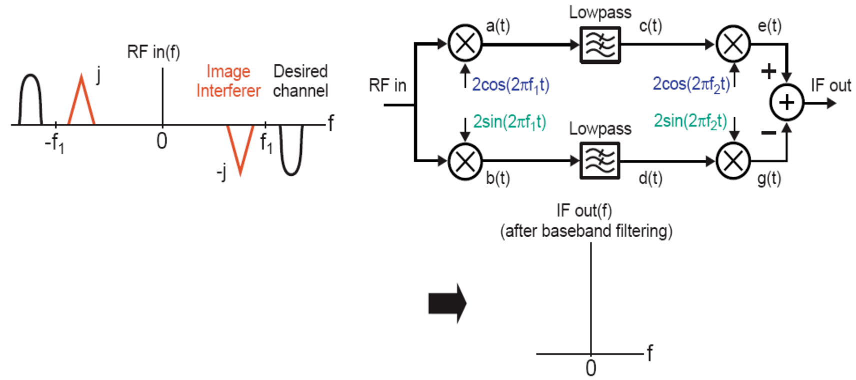


Image Reject Mixer Principles – Implementation Issues



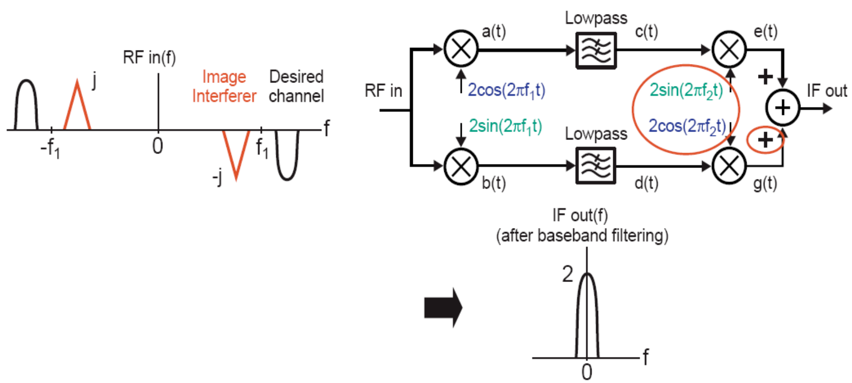
- For all analog architecture, going to zero IF introduces sensitivity to 1/f noise at IF output
  - Can fix this problem by digitizing c(t) and d(t), and then performing final mixing in the digital domain

What if RF in(f) is Purely Imaginary?



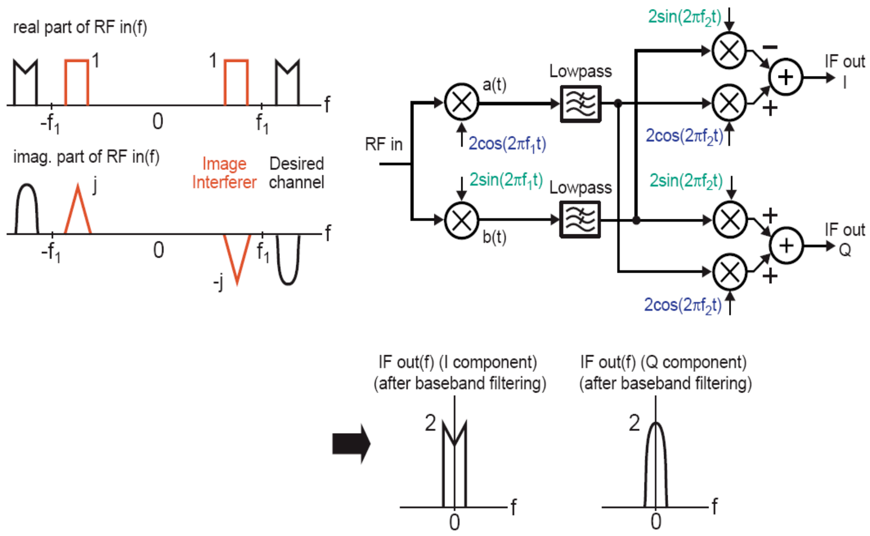
- Both desired and image signals disappear!
  - Architecture is sensitive to the phase of the RF input
- Can we modify the architecture to fix this issue?

Modification of Mixer Architecture for Imaginary RF in(f)



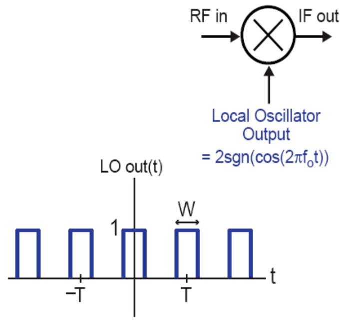
- Desired channel now appears given two changes
  - Sine and cosine demodulators are switched in second half of image rejection mixer
  - The two paths are now added rather than subtracted
- Issue – architecture now zeros out desired channel when RF in(f) is purely real

Overall Mixer Architecture – Use I/Q Demodulation



- Both real and imag. parts of RF input now pass through

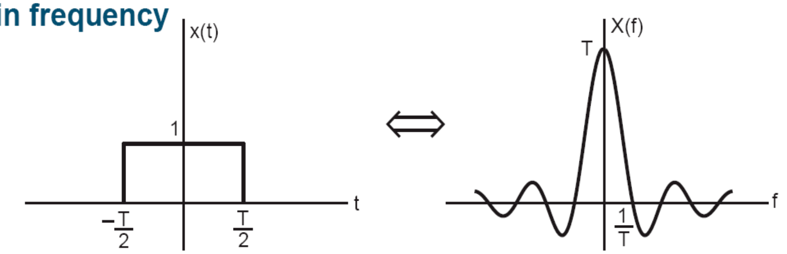
A Practical Issue – Square Wave LO Oscillator Signals



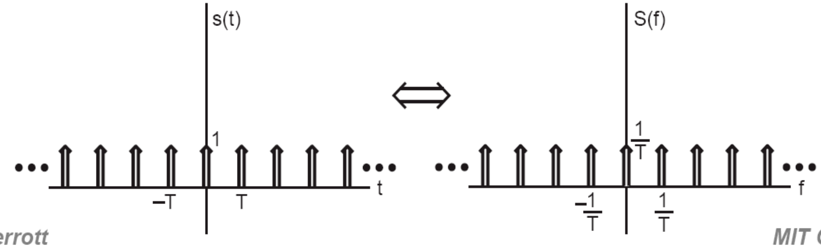
- Square waves are easier to generate than sine waves
  - How do they impact the mixing operation when used as the LO signal?
  - We will briefly review Fourier transforms (series) to understand this issue

Two Important Transform Pairs

- Transform of a rectangle pulse in time is a sinc function in frequency

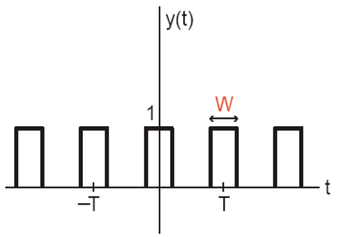


- Transform of an impulse train in time is an impulse train in frequency

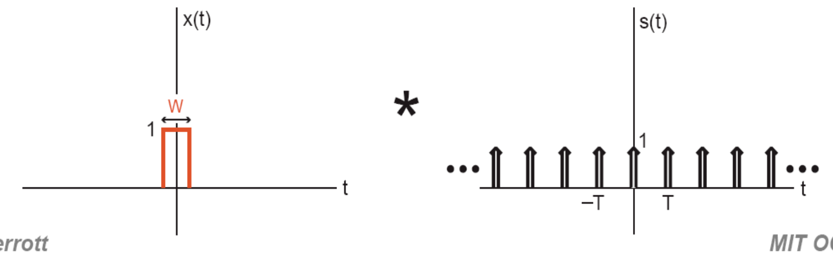


Decomposition of Square Wave to Simplify Analysis

- Consider now a square wave with duty cycle W/T

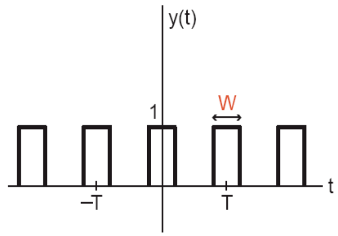


- Decomposition in time

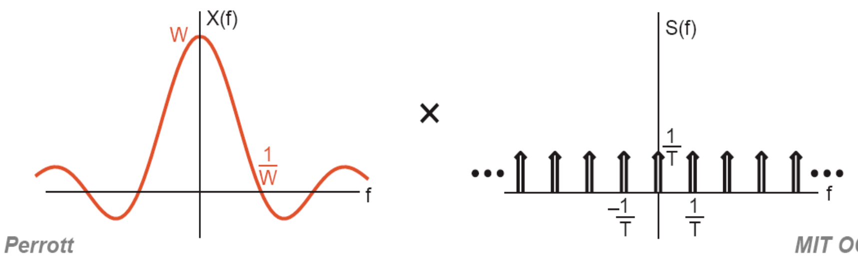


Associated Frequency Transforms

- Consider now a square wave with duty cycle W/T

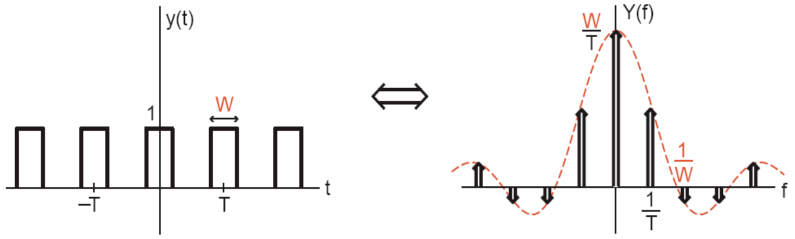


- Decomposition in frequency



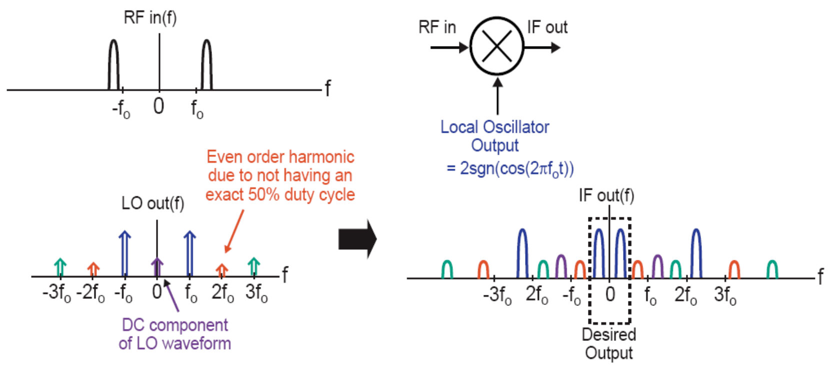
Overall Frequency Transform of a Square Wave

- Resulting transform relationship



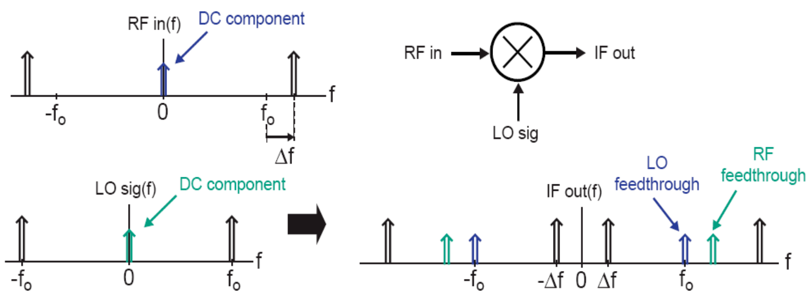
- Fundamental at frequency 1/T
  - Higher harmonics have lower magnitude
- If W = T/2 (i.e., 50% duty cycle)
  - No even harmonics!
- If amplitude varies between 1 and -1 (rather than 1 and 0)
  - No DC component

Analysis of Using Square-Wave for LO Signal



- Each frequency component of LO signal will now mix with the RF input
  - If RF input spectrum sufficiently narrowband with respect to f_o, then no aliasing will occur
- Desired output (mixed by the fundamental component) can be extracted using a filter at the IF output

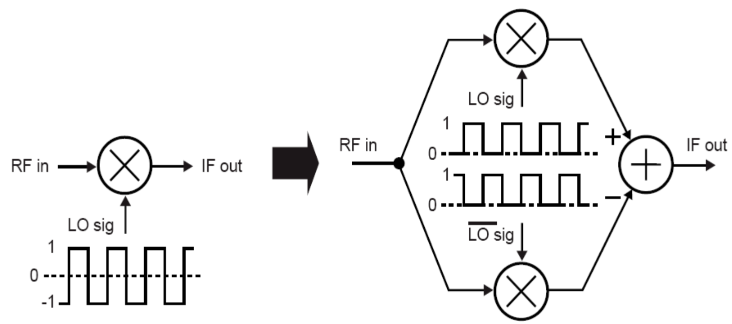
The Issue of Balance in Mixers



- A balanced signal is defined to have a zero DC component
- Mixers have two signals of concern with respect to this issue – LO and RF signals
  - Unbalanced RF input causes LO feedthrough
  - Unbalanced LO signal causes RF feedthrough
- Issue – transistors require a DC offset

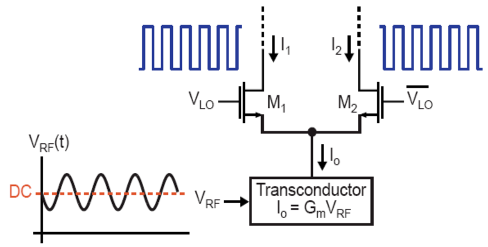
Achieving a Balanced LO Signal with DC Biasing

- Combine two mixer paths with LO signal 180 degrees out of phase between the paths



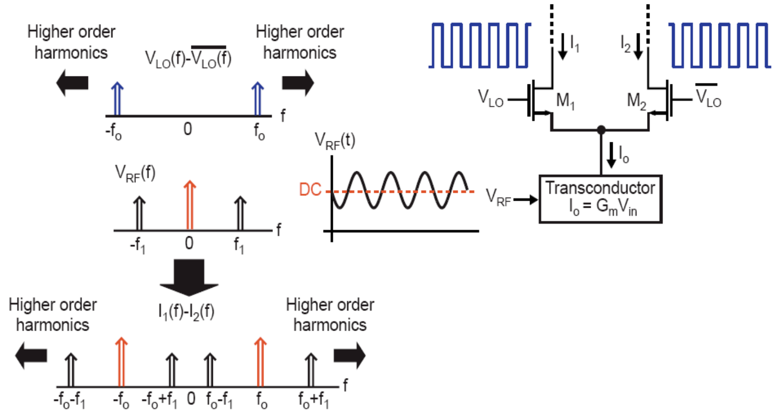
  - DC component is cancelled

Single-Balanced Mixer



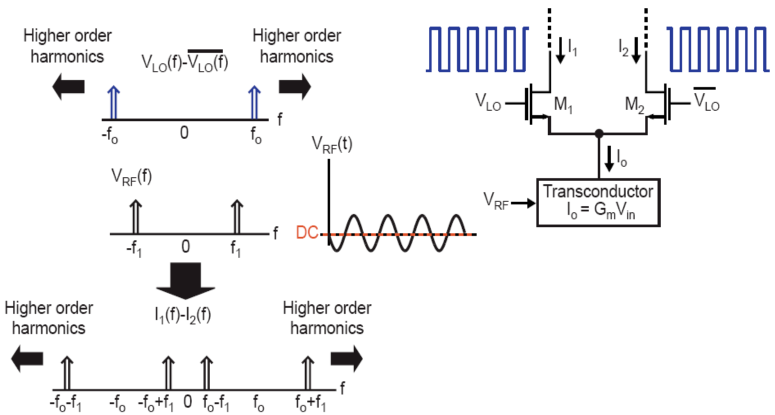
- Works by converting RF input voltage to a current, then switching current between each side of differential pair
- Achieves LO balance using technique on previous slide
  - Subtraction between paths is inherent to differential output
- LO swing should be no larger than needed to fully turn on and off differential pair
  - Square wave is best to minimize noise from M_1 and M_2
- Transconductor designed for high linearity

LO Feedthrough in Single-Balanced Mixers



- DC component of RF input causes very large LO feedthrough
  - Can be removed by filtering, but can also be removed by achieving a zero DC value for RF input

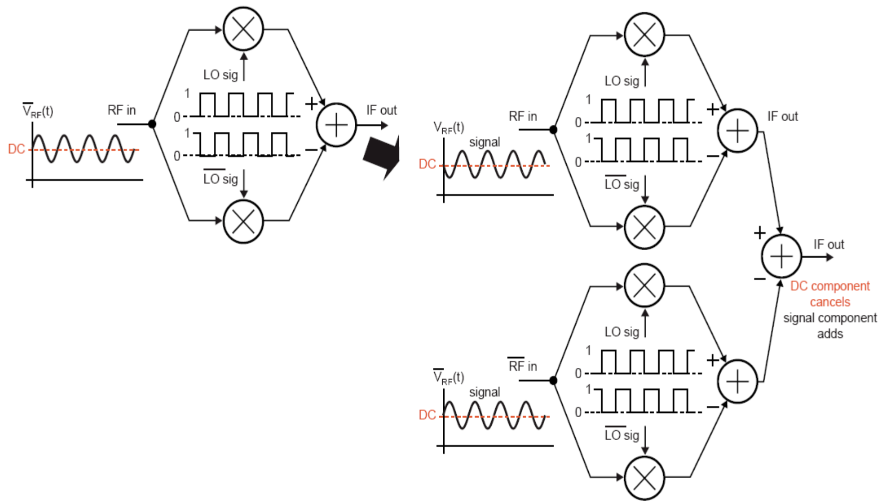
Double-Balanced Mixer



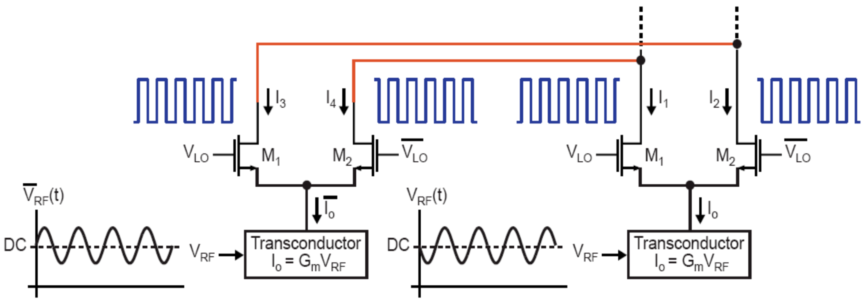
- DC values of LO and RF signals are zero (balanced)
- LO feedthrough dramatically reduced!
- But, practical transconductor needs bias current

Achieving a Balanced RF Signal with Biasing

- Use the same trick as with LO balancing

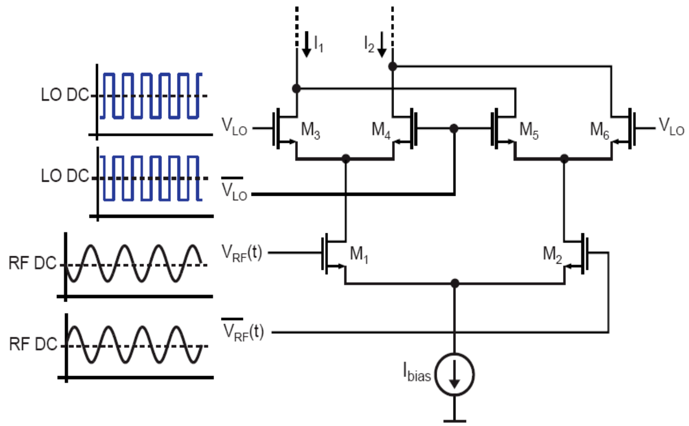


Double-Balanced Mixer Implementation

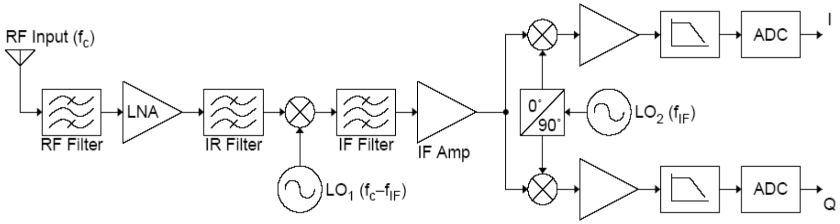


- Applies technique from previous slide
  - Subtraction at the output achieved by cross-coupling the output current of each stage

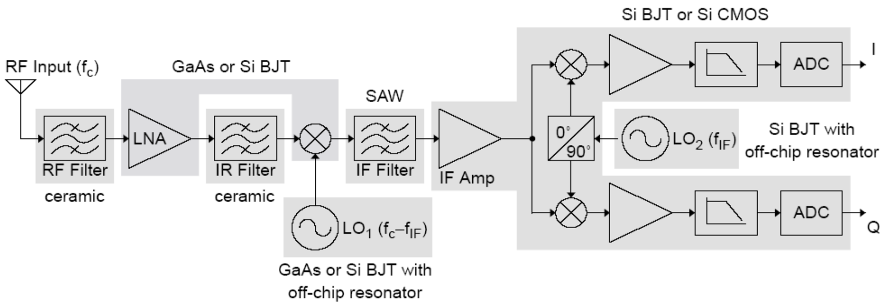
Gilbert Mixer



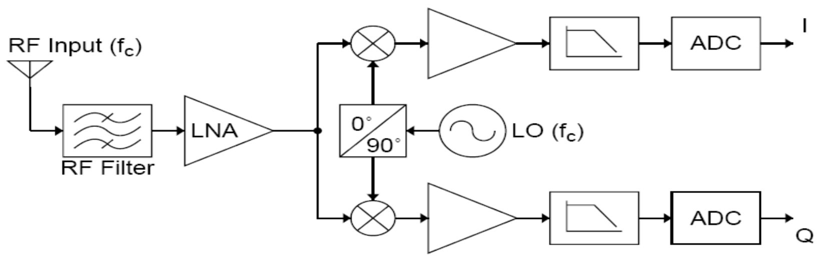
- Use a differential pair to achieve the transconductor implementation
- This is the preferred mixer implementation for most radio systems!



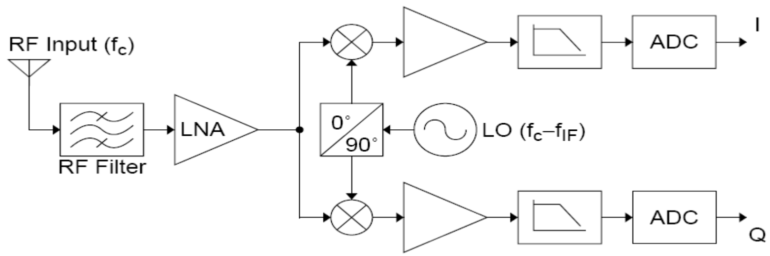
Heterodyne architecture block diagram.



: Heterodyne architecture implementation.



Direct-conversion architecture block diagram.



Low-IF architecture block diagram.

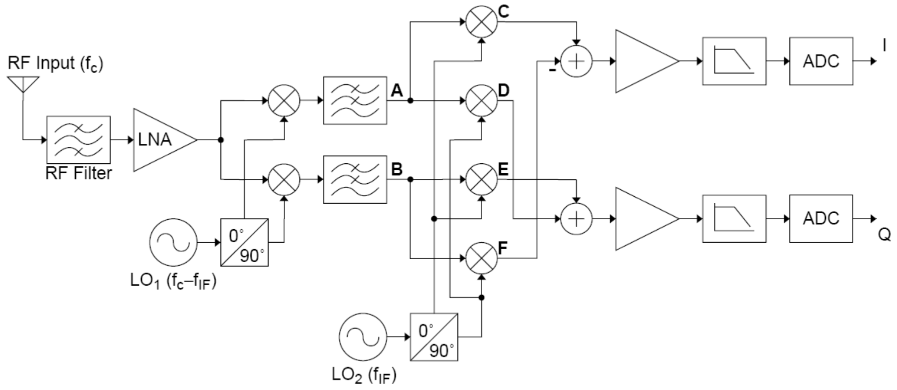


Image-reject (Weaver) architecture block diagram.

	advantages	disadvantages	design guidelines
heterodyne	• excellent sensitivity and selectivity performance	• large number of discrete components	• use this architecture when all else fails
direct-conversion	• minimal number of RF components	• dc offsets and flicker noise	• for wideband signaling schemes, dc offsets can be removed with a high-pass filter using on-chip capacitors and resistors
image-reject	• facilitates integration of low phase noise LO	• large number of RF components • dc offsets and flicker noise • image-rejection is limited by gain and phase mismatches	• fixed-frequency first LO facilitates the use of a wideband PLL for VCO phase noise suppression • tunable low-frequency second LO for channel selection
low-IF	• minimal number of RF components • avoids problems associated with dc offsets and flicker noise	• ADC sampling frequency must be at least $f_{IF} + f_{sig}$ • image-rejection is limited by gain and phase mismatches	• narrowband signaling schemes relax ADC sampling requirement • requires relaxed image-rejection requirements at small frequency offsets from the desired signal • if $f_s = 4f_{IF}$, the digital downconversion circuitry becomes trivial