Lecture 12

of

EEE307

Electronics for Communications

Department of Electrical & Electronic Engineering

Xi'an Jiaotong-Liverpool University (XJTLU)

Friday, 6th December 2019

- Transceiver Architectures
  - AM radio receiver
  - superheterodyne receiver
  - direct conversion receiver
  - OOK transmitter & receiver

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Wireless Transceiver

(transmitter & receiver)

- To exchange information electronically or optically, it needs at least a **transmitter**, a **receiver** and a **communication channel** in between.
- To transmit and receive information using **radio waves**, there can be a number of **architectures** for the radio **transmitter** and **receiver**.
  - The **architecture** choice depends on the applications.
  - Considerations of which architecture to use include power consumption, feasibility of RF integrated circuit (IC) implementation, requirements of off-chip components, noise, linearity, etc.
  - It is overall still consideration of **performance** and **cost** trade-off.

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Wireless Transceiver

(transmitter & receiver)

- A simplified generic radio **transceiver** consists of key RF building blocks (e.g. LNA, PA, oscillator, mixer) and baseband processing circuits (e.g. ADC and DAC) for modern wireless communication.

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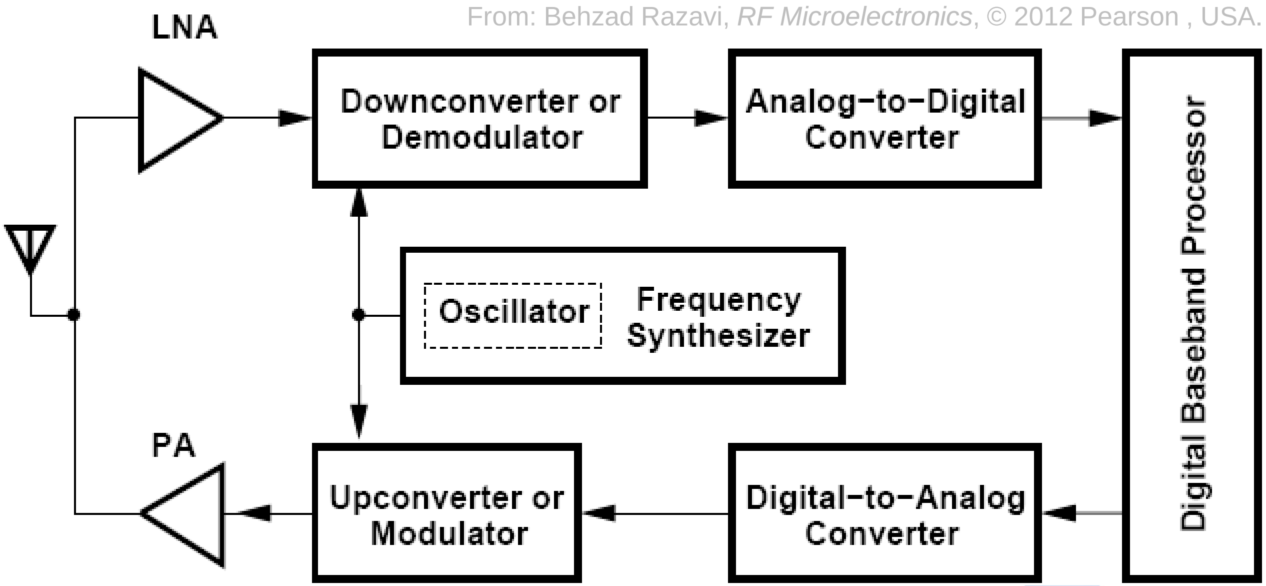

  - Such an architecture is not a must.

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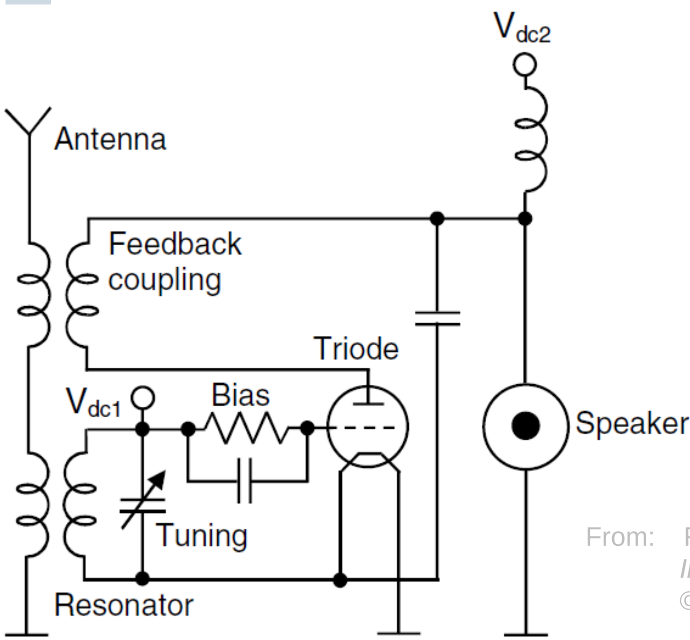
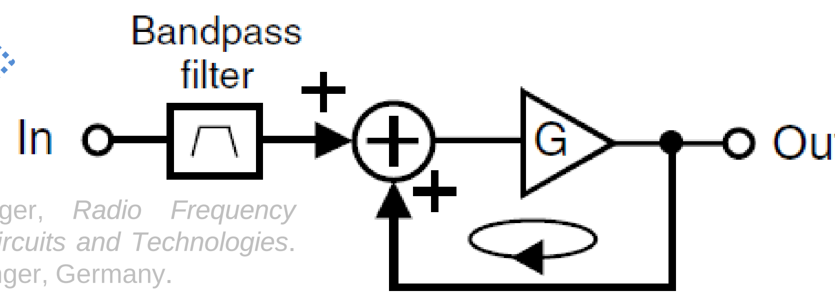
Regenerative Receiver

(architecture using minimal components)

- Before the era of solid-state transistors, vacuum tubes were used for building radio communication circuits.
  - Edward H. Armstrong invented the **regenerative receiver**.
  - Such an **receiver architecture** uses a minimal number of components. It can be very low-cost and still used in some applications today.





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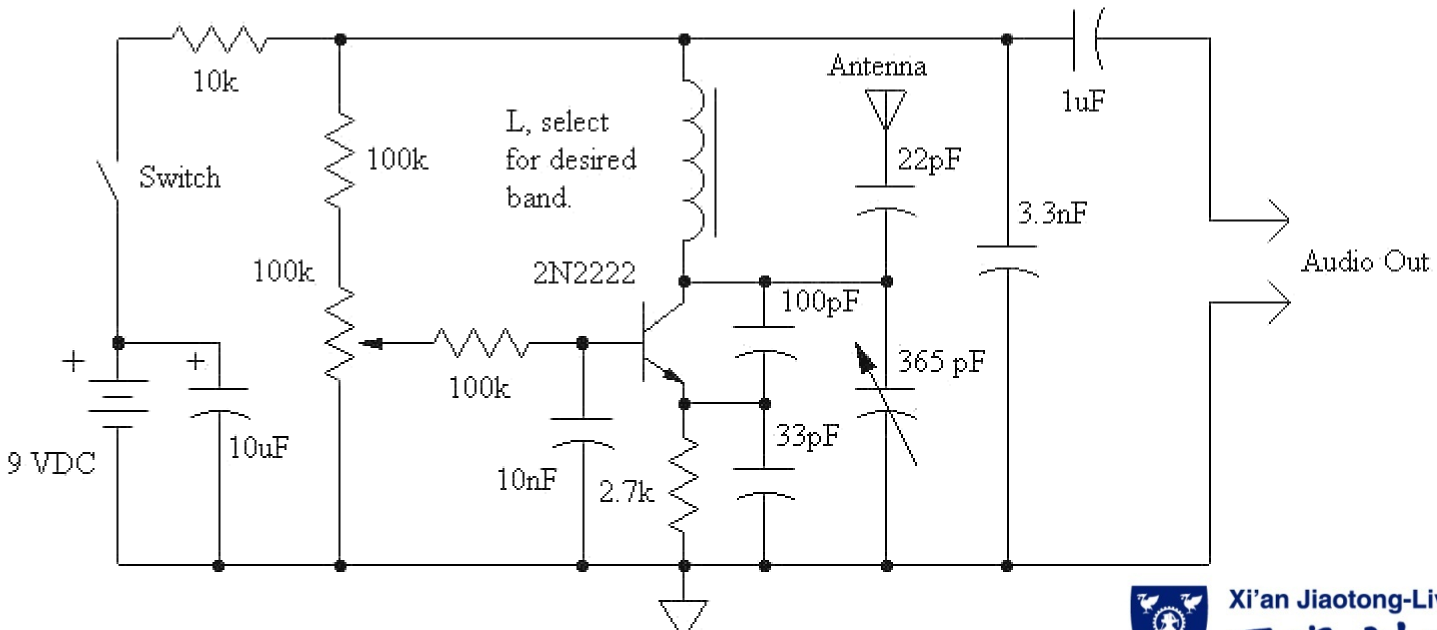
  - The **triode** is a vacuum tube version of the transistor.

Regenerative Receiver

(implemented with transistor)

- The **regenerative receiver** architecture can be implemented with solid-state transistors (one or more transistors).
  - The single transistor performs both signal detection and amplification – as a regenerative detector.

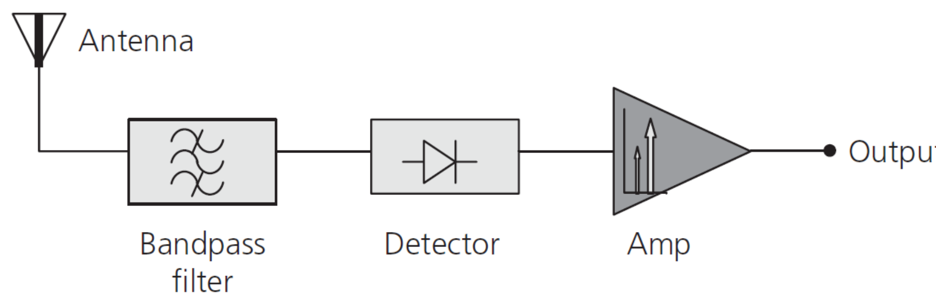


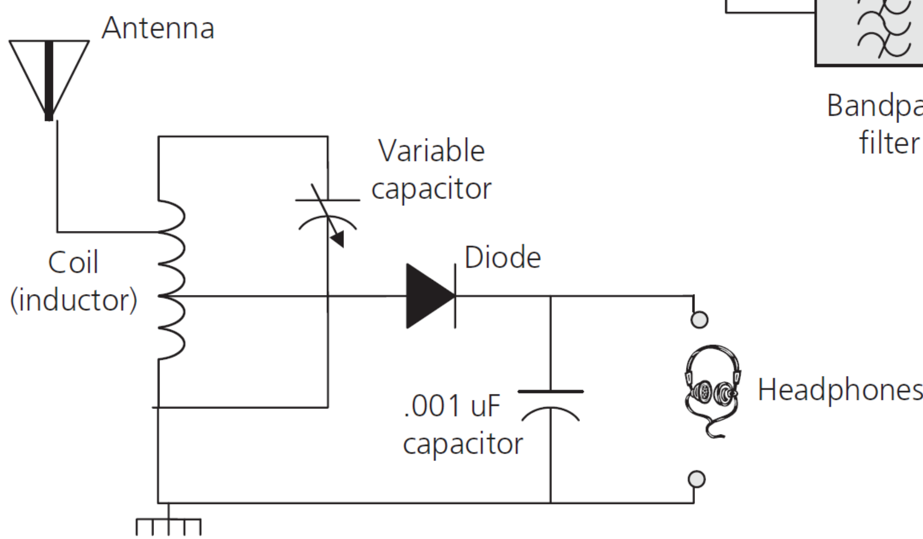
From: TechLib.com, "Regenerative Receivers" © 2017 Charles Wenzel. Available at: http://www.techlib.com/electronics/regen.html

Amplitude Modulation Receiver

(AM radio)

- An even simpler architecture is the **amplitude modulation** (AM) **receiver**.
  - No active device (e.g. transistor) is required.
  - A diode is used for the **envelope detection**.





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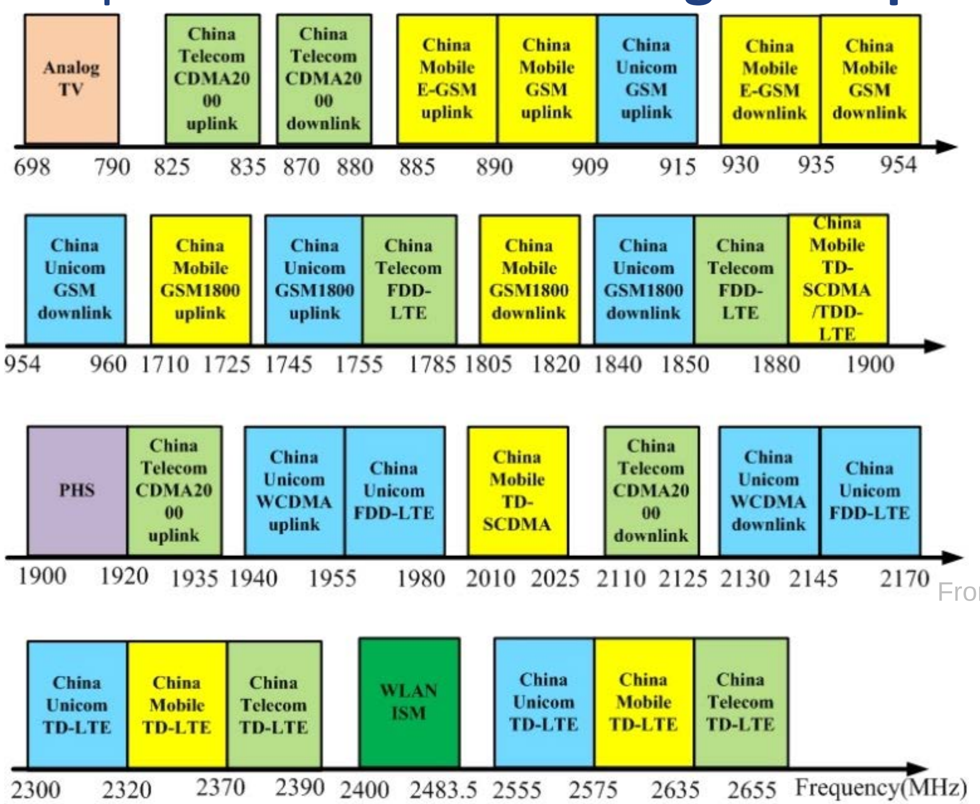
Channel Selection in Receiver

(packed wireless spectrum)

- In modern wireless communications using radio waves, **frequency channels** are very closely spaced in the usable parts of the **electromagnetic spectrum**.



- This is due to the ever increasing data traffic demand.
- Selection of the desirable frequency channels requires high-Q ***tuneable* filters**.

From: Andrey S. Andrenko *et al*., "Outdoor RF Spectral Survey: a Roadmap for Ambient RF Energy Harvesting," *2015 IEEE Region 10 Conference* (TENCON 2015)..

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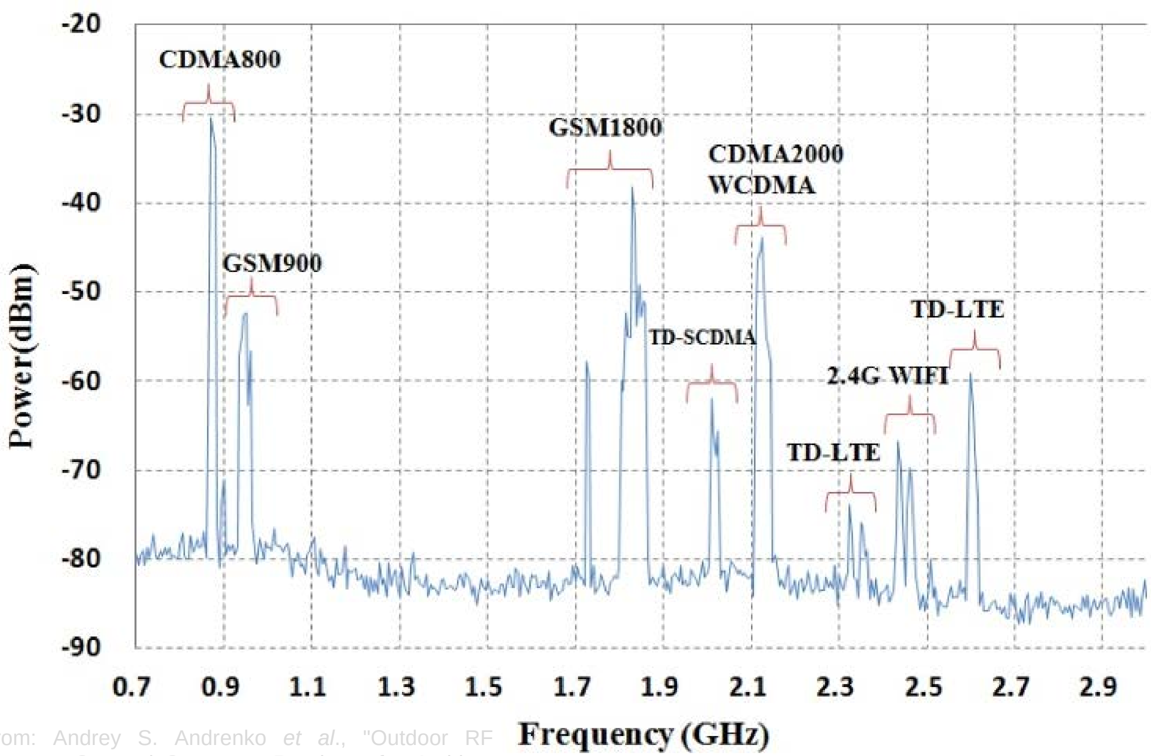
Interferer Signals

(signals of other frequency channels)

- The antenna receives **radio waves** of several different frequency channels with varying signal strength.
  - Signals of other frequency channels are **interferers**.



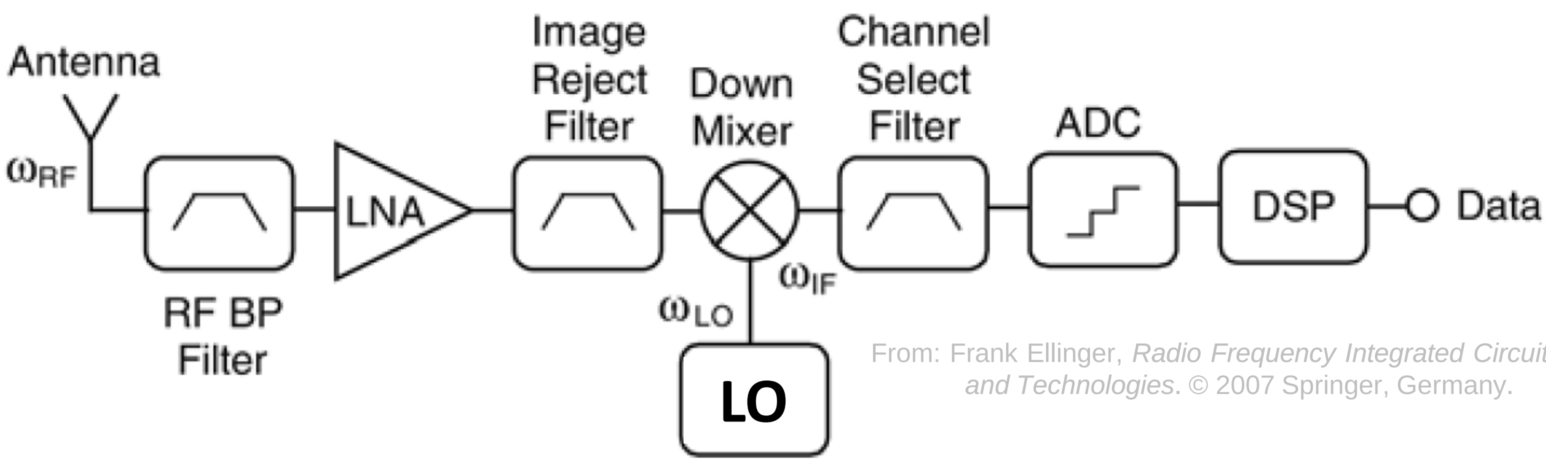
From: Andrey S. Andrenko *et al.*, "Outdoor RF Spectral Survey: a Roadmap for Ambient RF Energy Harvesting," *2015 IEEE Region 10 Conference* (TENCON 2015)..

- The stronger the signal and the closer frequency of the interferer are, the more easily the desired signal can be corrupted after downconversion.

Superheterodyne Receiver

(channel selection)

- It is very difficult above ≈100 MHz to have tunable filters of excellent frequency selectivity (quantified by $Q = f_c/\Delta f$) to pass RF signals of specific frequency channels.
- The **superheterodyne receiver** was invented as a solution for channel selection by a **local oscillator** of variable ω_{LO}.



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- Note: "**hetero**" means different (as $\omega_{LO} \neq \omega_{RF}$); "**dyne**" (meaning power or force) implies mixing.

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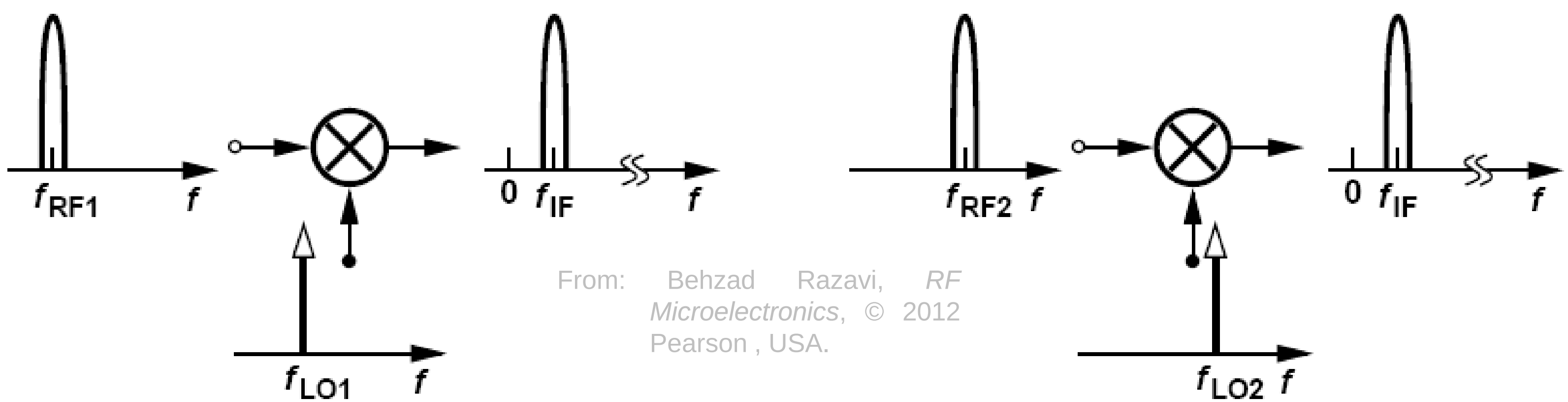
Superheterodyne Receiver

(variable LO frequency for channel selection)

- In the **superheterodyne receiver**, the RF signals of different frequency channels within the same band are downconverted to an **intermediate frequency** (IF).
  - This is **frequency translation** achieved by a mixer.



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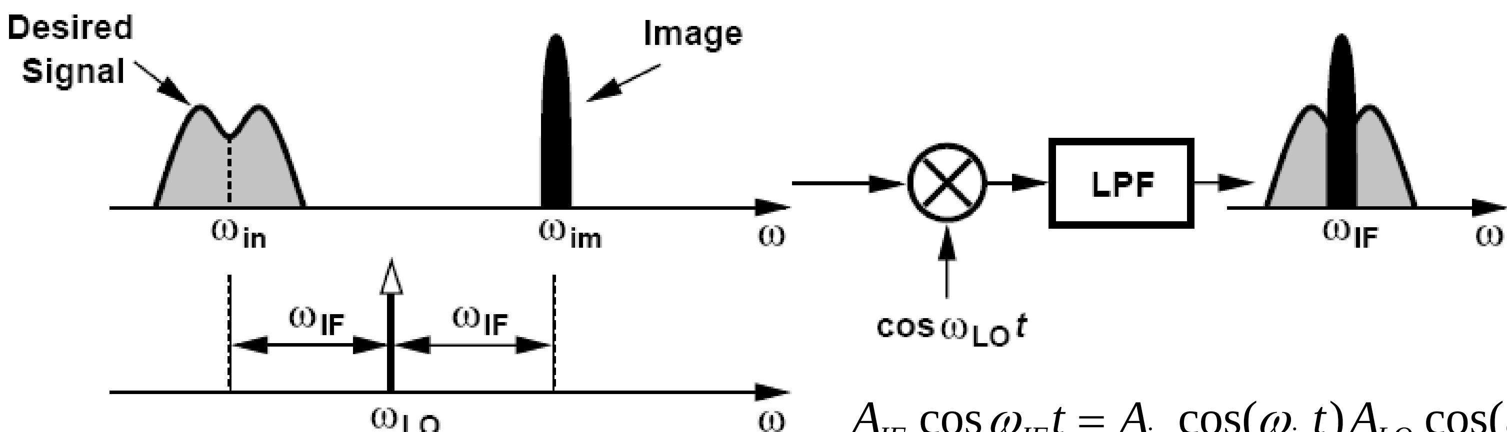
  - It is common to have a *fixed* **IF** while the **local oscillator** (LO) frequency is varied to ***downconvert*** the desired frequency channel to the *fixed* **IF**.

Superheterodyne Receiver

(image interferer signal)

- In the **superheterodyne receiver**, the frequency translation achieved by downconversion mixing also applies to an interferer signal at the **image** position about the LO frequency.

$$\omega_{im} = \omega_{in} + 2\omega_{IF} = 2\omega_{LO} - \omega_{in}$$



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$$A_{IF}\cos\omega_{IF}t = A_{in}\cos(\omega_{in}t)A_{LO}\cos(\omega_{LO}t)$$
$$+ A_{img}\cos(\omega_{img}t)A_{LO}\cos(\omega_{LO}t)$$

- Such an ***image*** **interferer signal** can also be downconverted to the same **IF**.

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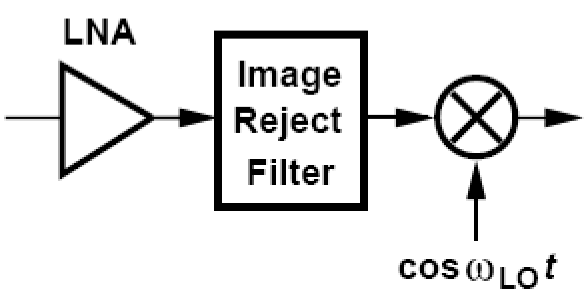
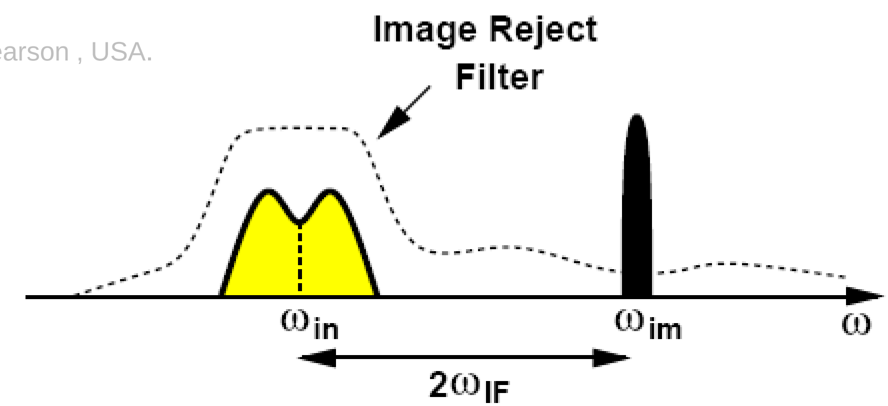
Superheterodyne Receiver

(image rejection filter)

- An **image rejection filter** is typically used between the low-noise amplifier (LNA) and the downconversion mixer to much attenuate the image interferer signal.

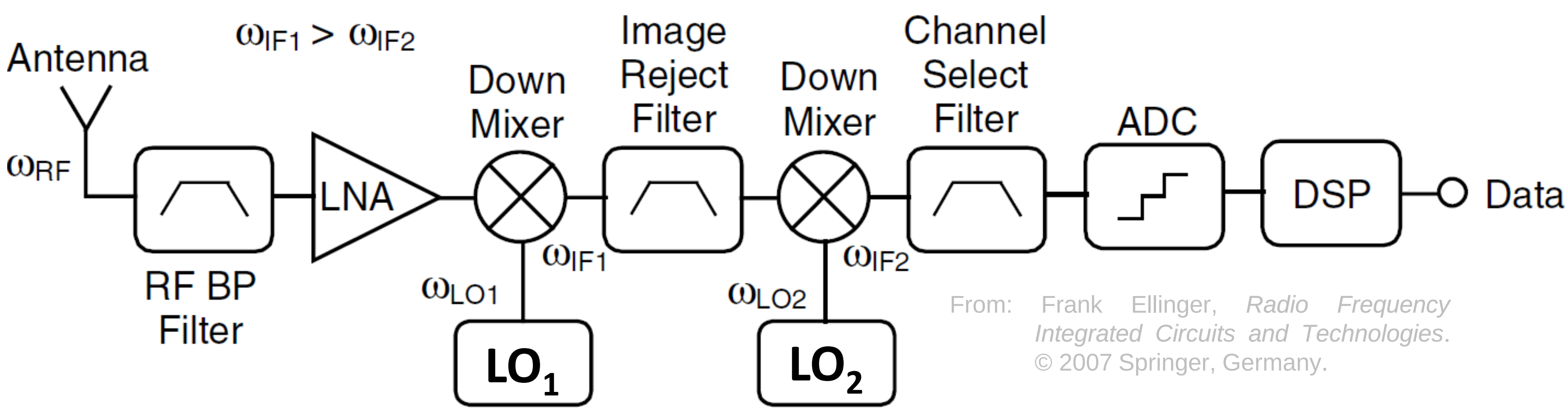




  - As a result, the downconverted image interferer signal is much weaker, depending on how good the **frequency selectivity** of the **image rejection filter** is.
  - The desired signal is less corrupted at IF.

Superheterodyne Receiver
(double conversion)

- To further minimise the effect of the interferer signals on corrupting the desired signal at IF, double downconversion can be used in the **superheterodyne receiver**.



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- Such double downconversion also eases the requirements of high frequency selectivity in the filters.
- Two LOs and two mixers are needed.
- What is the trade-off then?

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Superheterodyne Receiver

(band-pass filters)

- It can be seen the usefulness of **band-pass filters** (BPFs) in the **superheterodyne receiver**.

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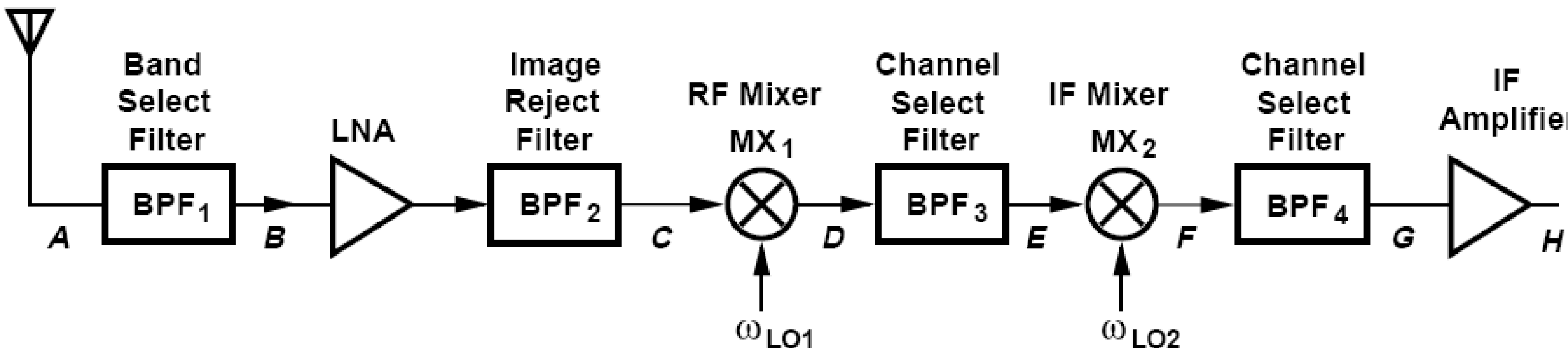
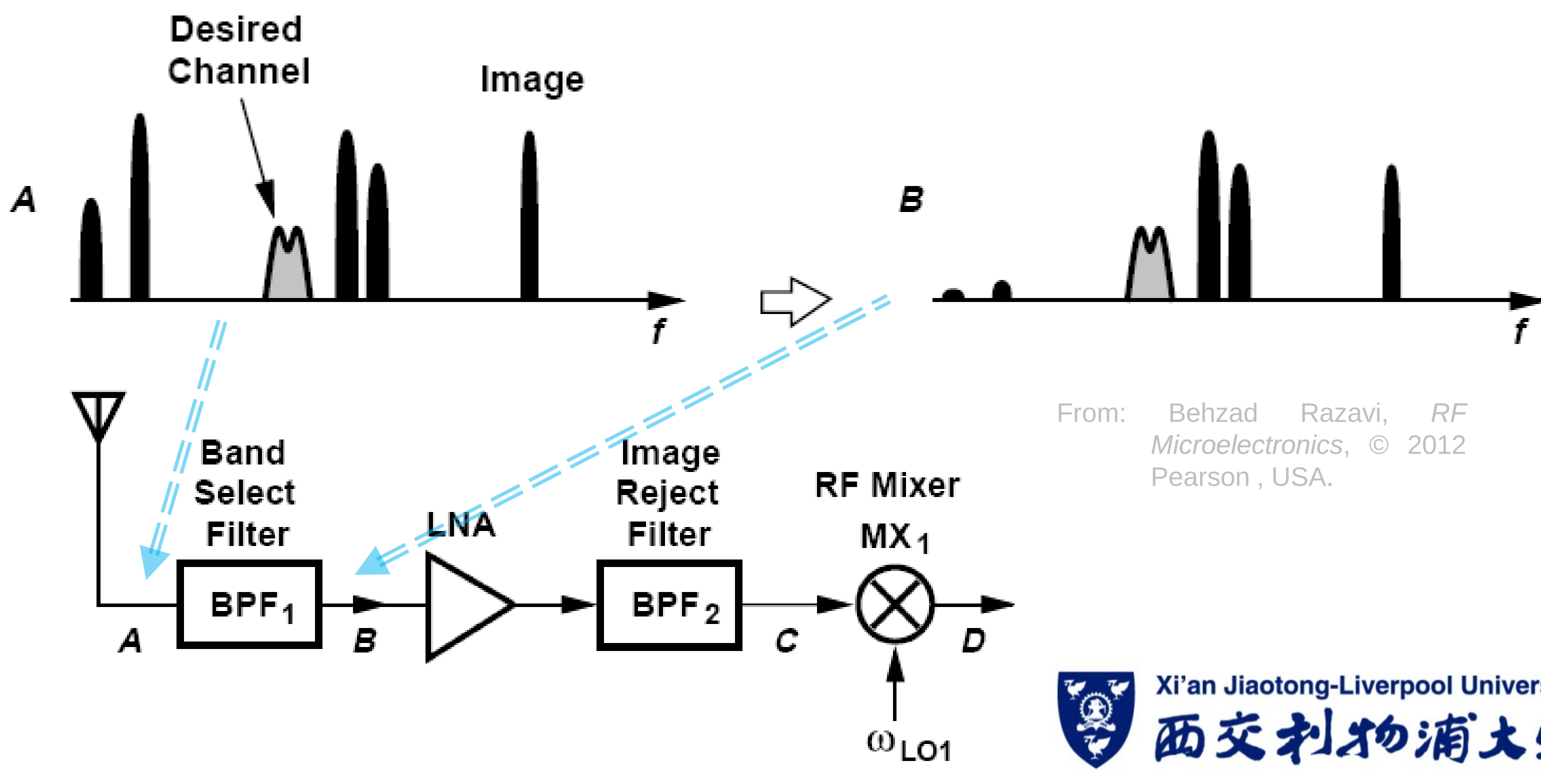


  - They can be used before the LNA for frequency band selection, before the downconversion mixer for filtering the image interferer signal, channel selection after the downconversion.
  - The **band-select filter** may not be LC filters but of the **surface-acoustic wave** (**SAW**) type.

Superheterodyne Receiver

(filtering interferer signals at different frequencies)

- The **band-pass filters** at different stages in the **superheterodyne receiver** remove interferer signals at different frequency locations away from the desired signal.



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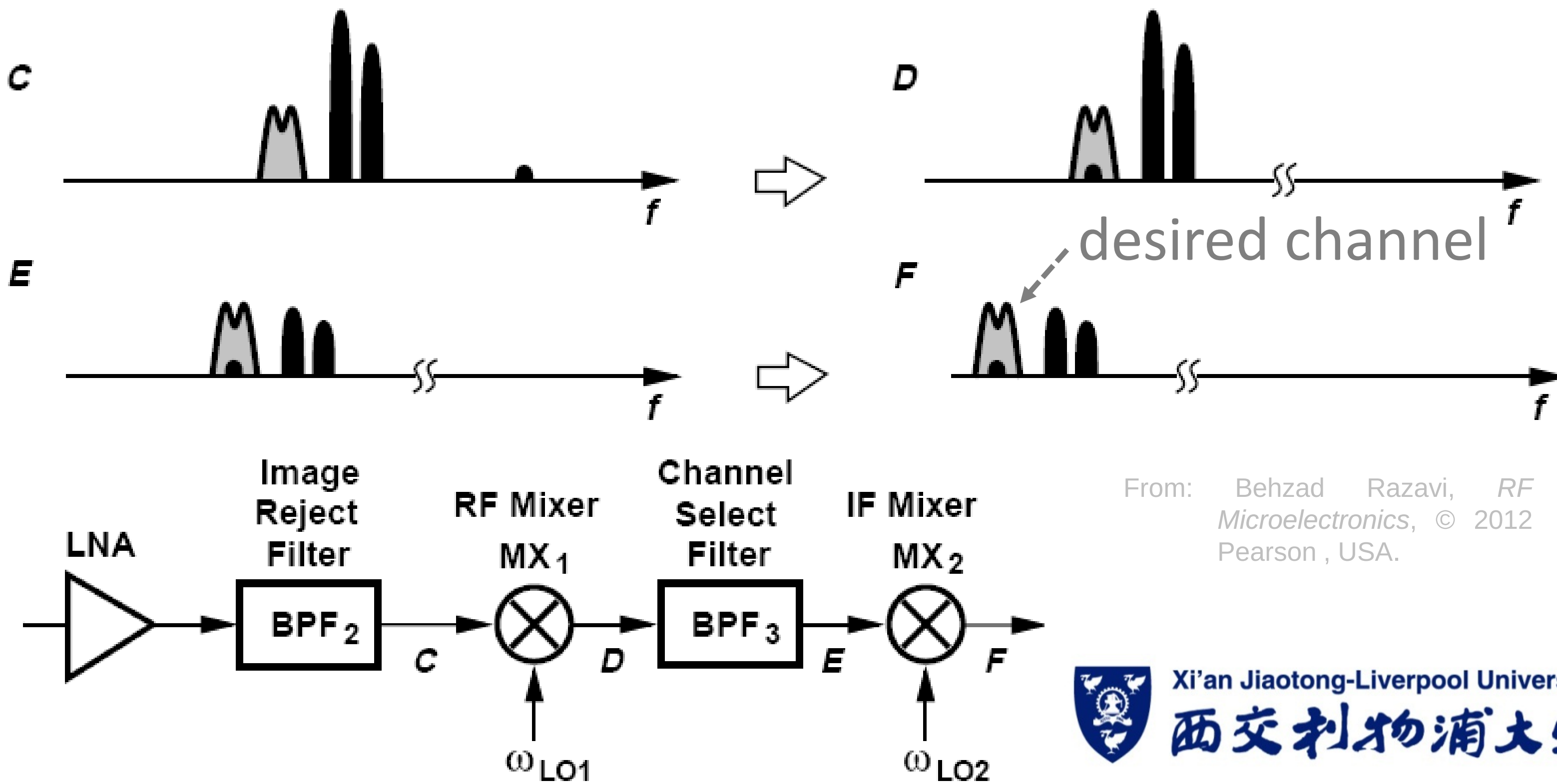
Superheterodyne Receiver

(filtering interferer signals at different stages)

- The interferer signals at frequencies close to that of the desired signal cannot be filtered initially.
  - It is because of the **frequency selectivity** requirement.



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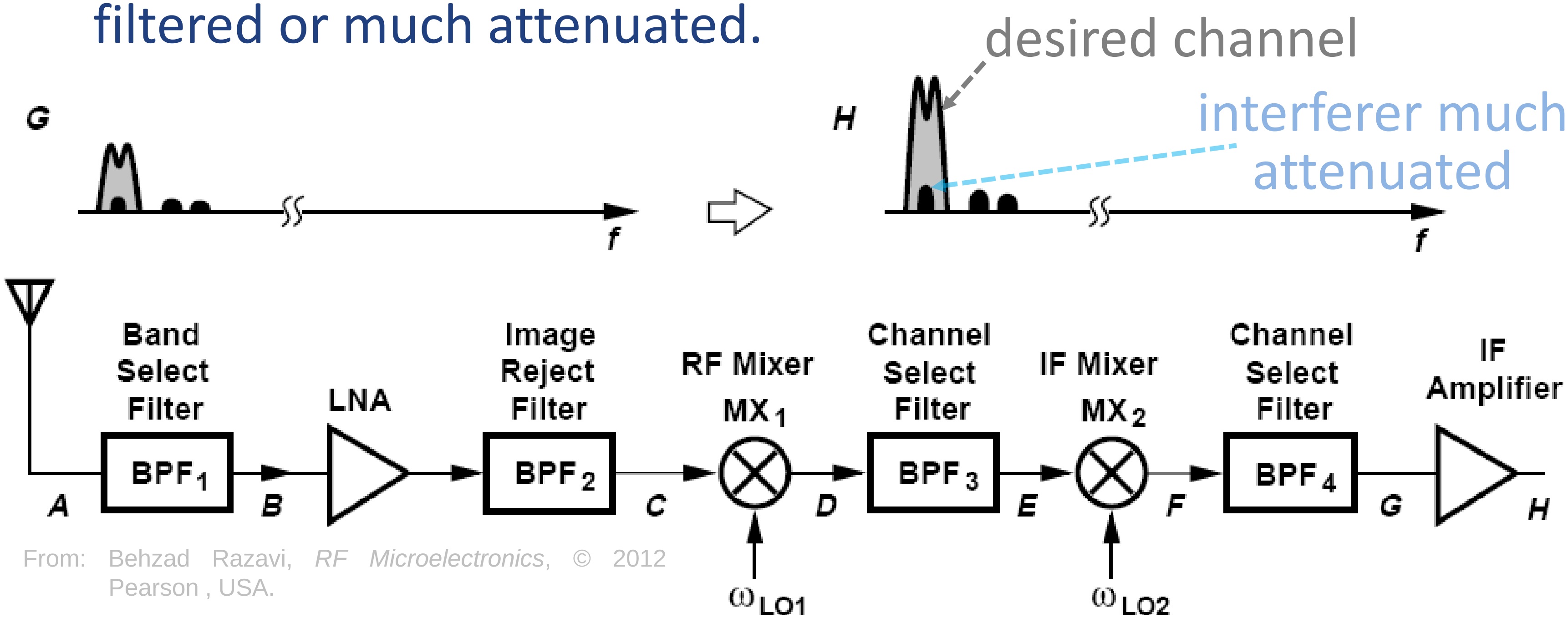
Superheterodyne Receiver

(desired signal selected at IF stage)

- ❑ At the IF stage in the **superheterodyne receiver**, the desired signal is selected and amplified, with the interferers either filtered or much attenuated.



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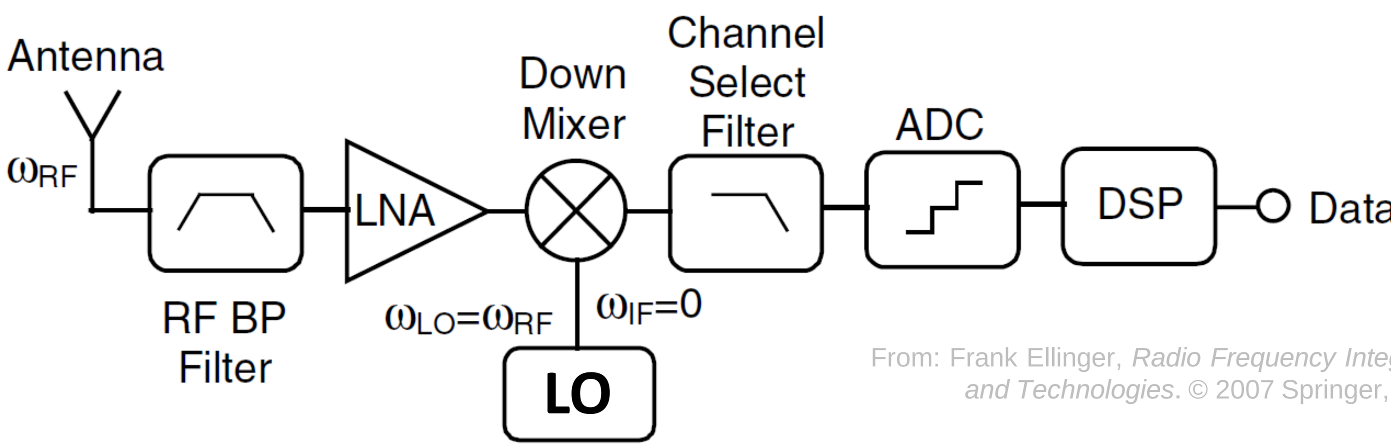
- ➢ Modern heterodyne receivers have zero 2nd IF. Bulky off-chip passive filters are avoided.

Direct Conversion Receiver

(zero intermediate frequency)

- The problem with the **image interferer signal** can also be resolved using a simple **receiver architecture** by *directly downconverting* the desired signal to the baseband.
  - This is called **direct conversion** (or homodyne) **receiver**.
  - With the direct downconversion, it has zero IF.



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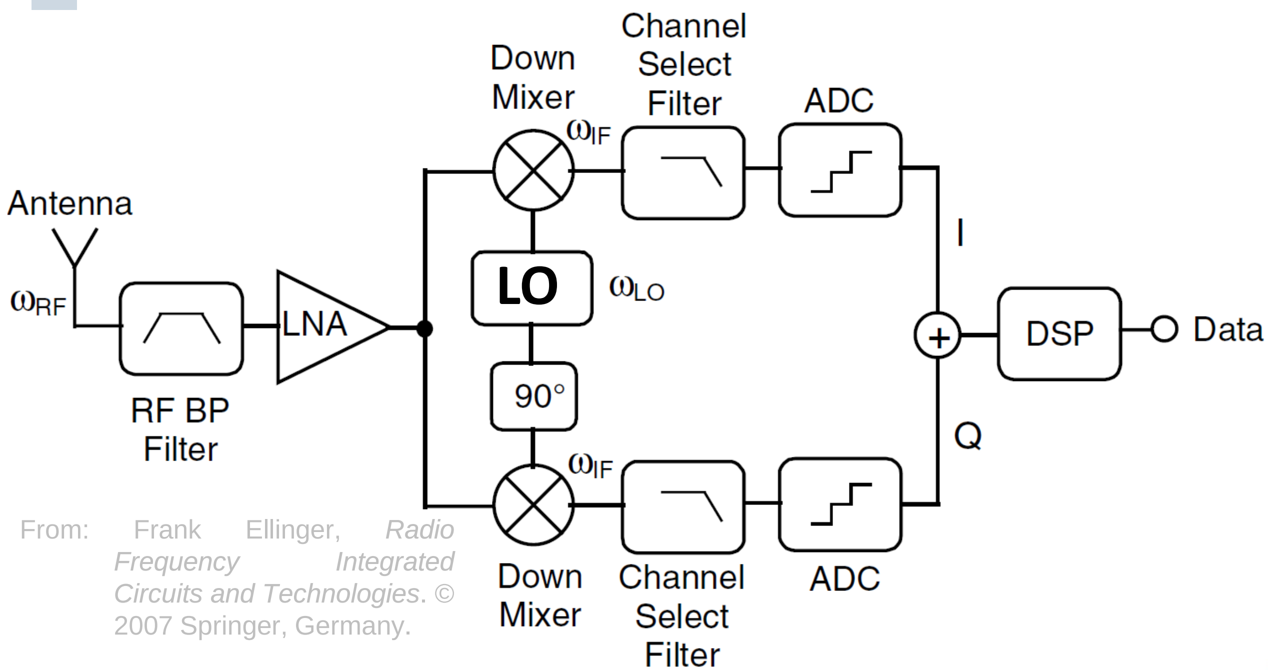
  - Such an architecture allows highly integrated and low cost realization of transceivers.

Direct Conversion Receiver

(transmitter & receiver)

- In the **direct conversion receiver**, two LO signals in **quadrature** with each other are used to drive two downconversion mixers for demodulation consideration.



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- This is to accommodate the *arbitrary* phase difference between the RF and LO signals. (Note $\omega_{LO} = \omega_{RF}$)

- Such an architecture suffers from other problems (e.g. DC offset, flicker noise)

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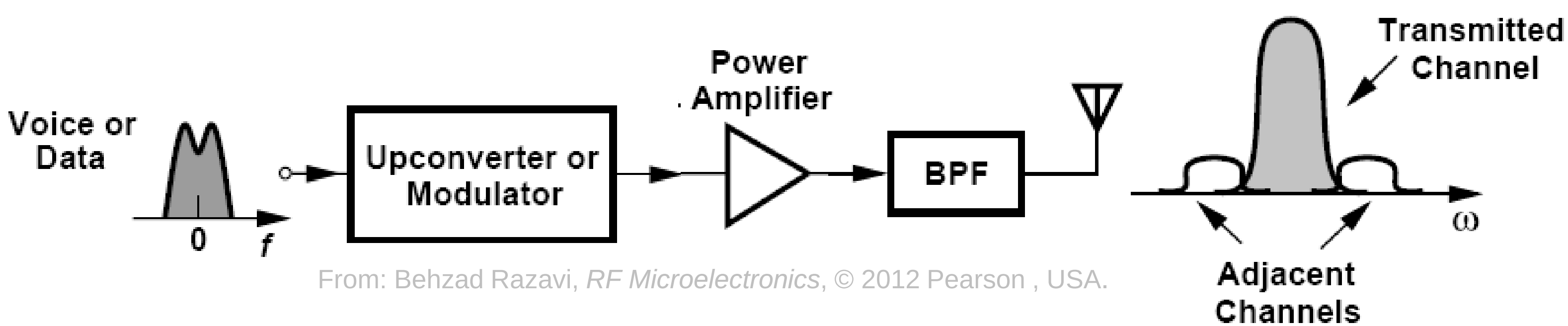
Radio Transmitter

(inverse of receiver architecture)

- In the case of the radio **transmitter**, the architectures are generally the inverse of the corresponding receiver architecture.
  - As it is a cascade of an LNA and downconversion mixers in the radio receiver, in the **radio transmitter** it is a cascade of upconversion mixers and a power amplifier.



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  - The transmitter performs modulation, upconversion and power amplification.

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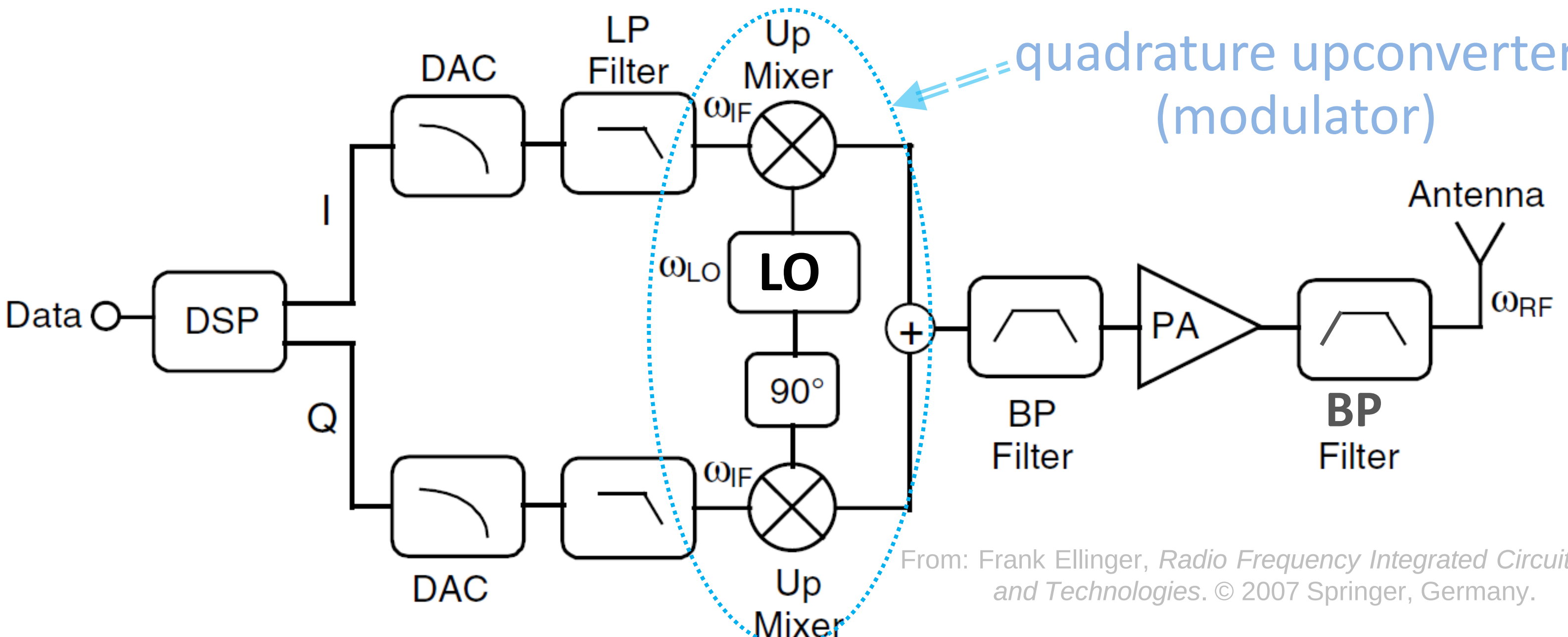
Direct Conversion Transmitter

(transmitter & receiver)

- In the **direct-conversion transmitter**, the baseband spectrum is directly translated to the radio wave carrier frequency by a quadrature upconversion mixing.



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- Again two LO signals in **quadrature** with each other are used.

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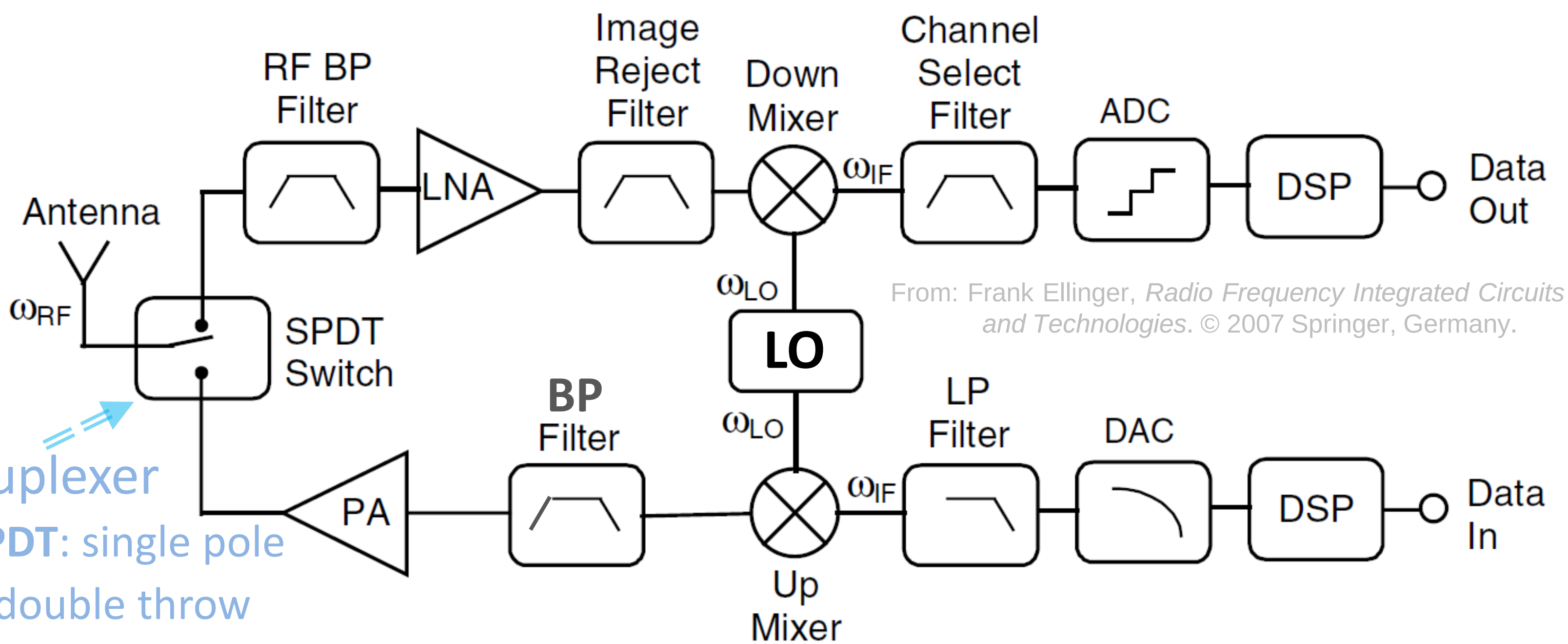
Wireless Transceiver

(transmitter & receiver integrated together)

- In modern RFIC design, it is desirable to integrate the radio transmitter and receiver onto one semiconductor chip and hence it requires minimal or even no off-chip components.



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duplexer

SPDT: single pole double throw

  - The integrated transmitter and receiver can share the same antenna.

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OOK Transceiver Architecture

(OOK modulation as special case of ASK)

- In some low-cost applications, a very simple "**on-off keying**" (OOK) **transceiver architecture** can be used.
- **OOK** modulation is a special case of **amplitude-shift keying** (**ASK**) where the carrier **amplitude** is switched between zero and maximum.

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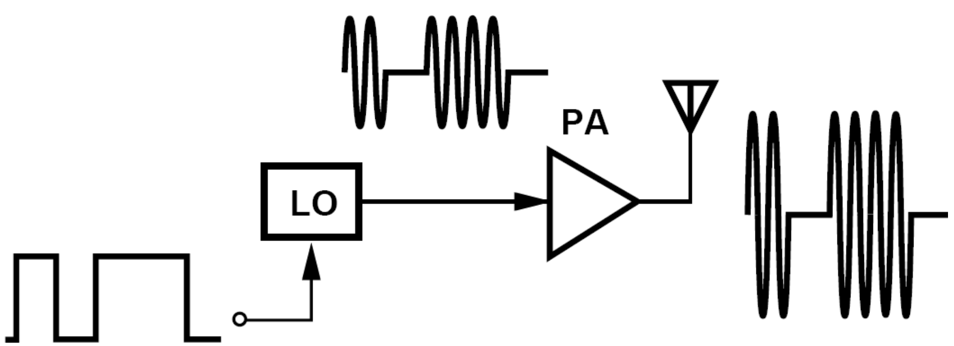
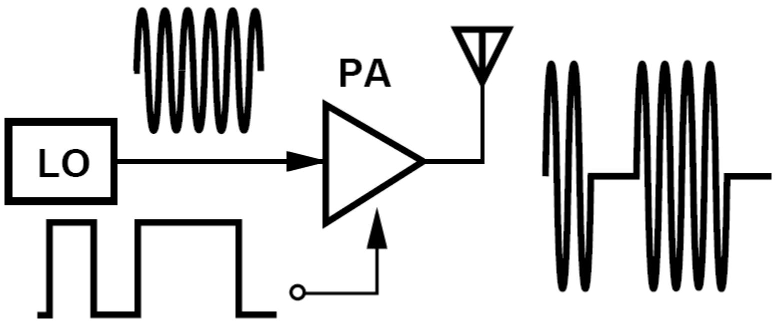


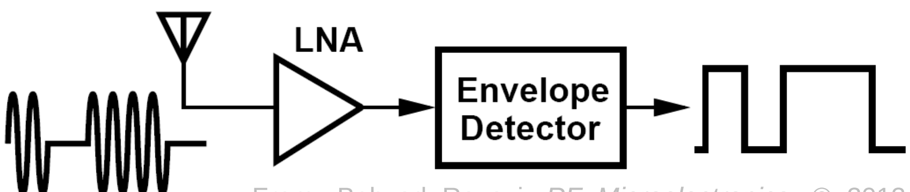
- The LO signal can be turned on and off directly by the binary baseband data.
  - If the LO swing is large enough, the modulated LO output drives PA to switch accordingly and then delivers the OOK waveform to the antenna.

OOK Transceiver Architecture

(simple envelop detection)



- Instead of switching the LO signal, an alternative is to switch the power amplifier directly.
- With the **OOK modulation**, the receiver can be as simple as a low-noise amplifier (LNA) followed by an **envelop detector** to recover the baseband binary data.



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- Neither any LO nor downconversion mixer is needed.
- The **OOK transceiver architecture** can allow compact, low-power implementation.
  - It is however not bandwidth efficient. (Why?)

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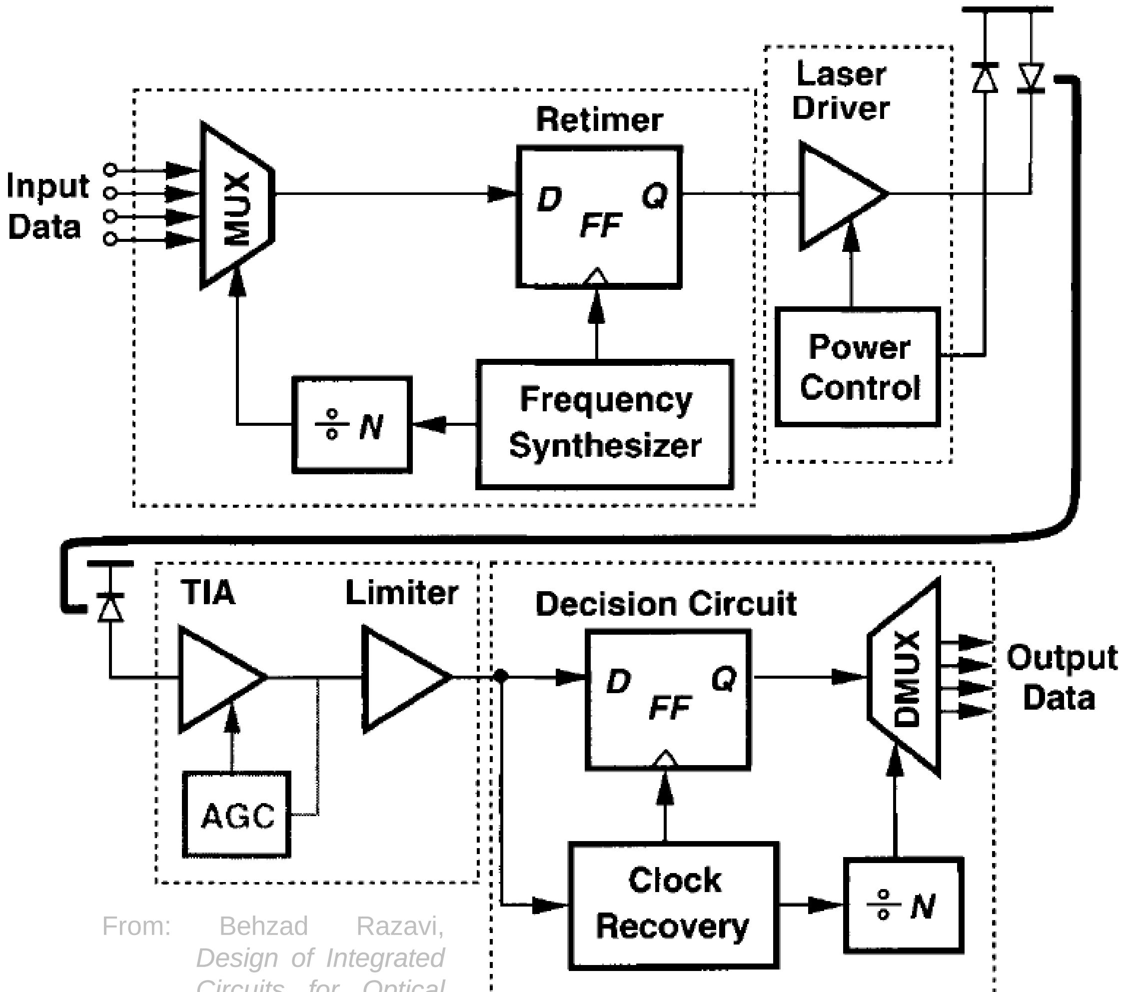
Optical Communication Systems
(transmitter & receiver)



From: Behzad Razavi, *Design of Integrated Circuits for Optical Communications*, 2e © 2012 Wiley, USA.

- In fibre-optic communication systems, the transmitter performs multiplexing and then drives a laser diode; a receiver performs the "reverse" with a photodiode, TIA and a demultiplexer.

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