

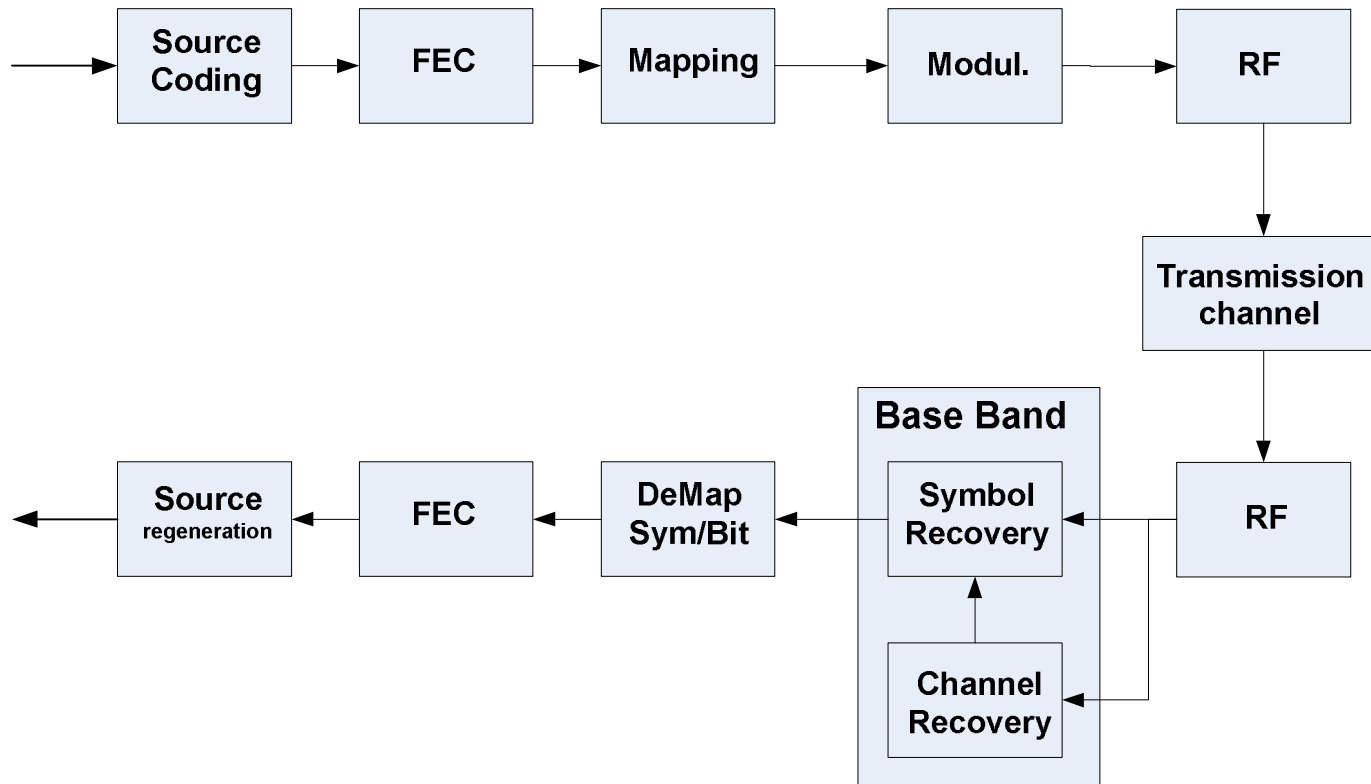
HUT

Department of Electrical and Communications Engineering
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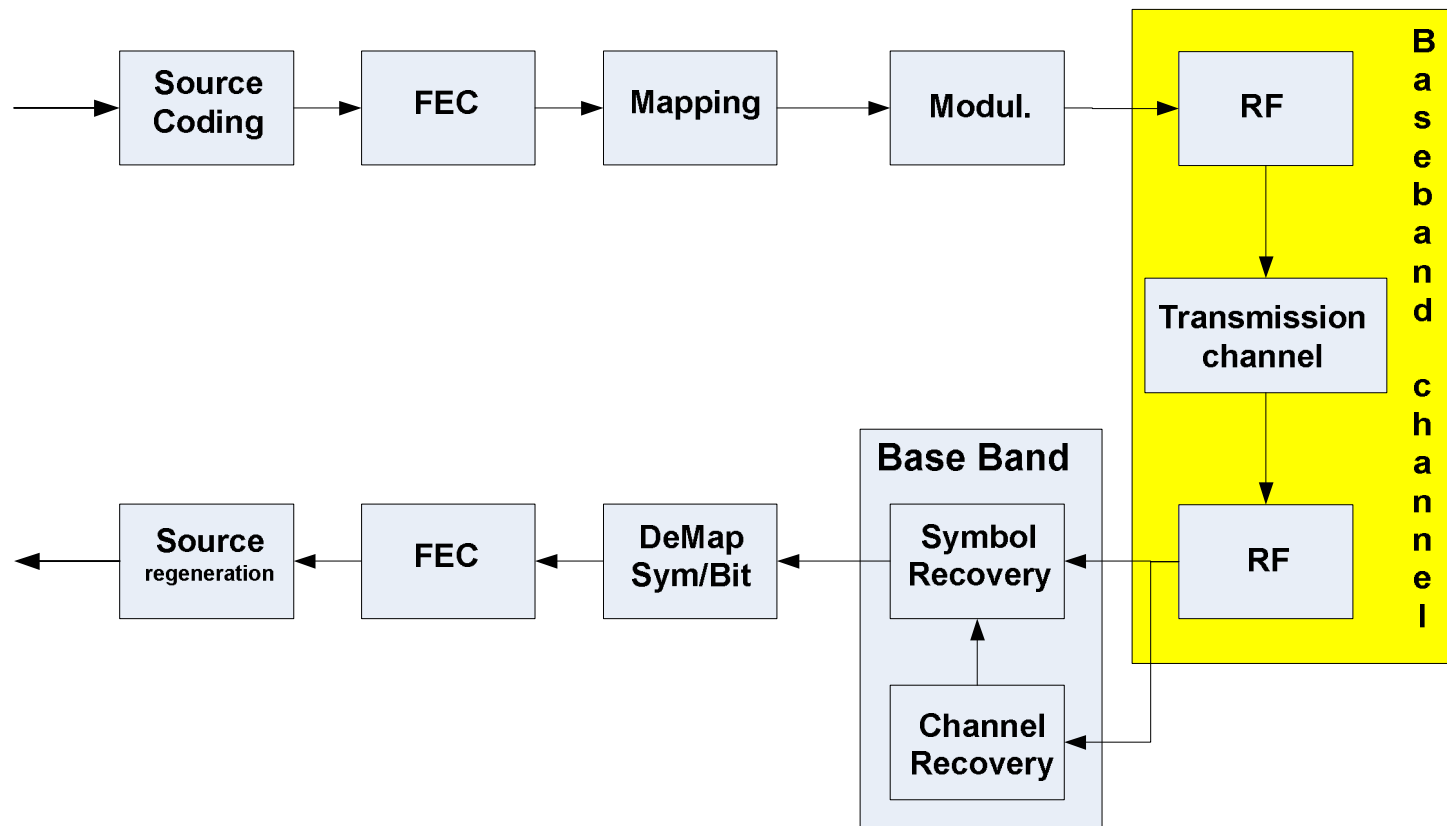
S-72.2205 Digital Transmission methods

Lectures autumn 2007

Functional block diagram of a transceiver



Functional block diagram of a transceiver



Modulation in radio communication systems

Important considerations

- bandwidth efficiency, spectrum efficiency
- noise interference tolerance
- nonlinear amplification tolerance
- implementation factors

Reference receiver error performance in AWGN-channel, assumptions:

- additive white zero-mean Gaussian noise
- the receiver filter is matched to the noiseless *received* digital pulse shape or correlation is performed with the noiseless *received* digital pulse shape
- single symbol or ISI-free transmission

Problems when applying reference receiver performance in radio systems

- multipath propagation - ISI present
 - dynamic channel - channel estimation needed for matched filtering
 - AWGN-model not valid for radio interference
 - carrier and symbol timing recovery methods impact performance
 - received power variations - average BER, BER-statistics important
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Modulation

Modulation - the process by which some characteristics of a carrier wave is varied in accordance with an information-bearing signal.

Modulating signal - information bearing signal.

Modulated signal - output signal from modulation process.

1. Modulation is used to shift the spectral content of a message signal so that it lies inside the operating frequency band of the wireless communication channel.
 2. Modulation provides a mechanism for putting the information content of a message signal into a form that may be less vulnerable to noise of interference.
 3. Modulation permits to use multiple access techniques.
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Complex baseband equivalent signal model

Typical communication occurs in passband $\left[f_c - \frac{W}{2}, f_c + \frac{W}{2} \right]$

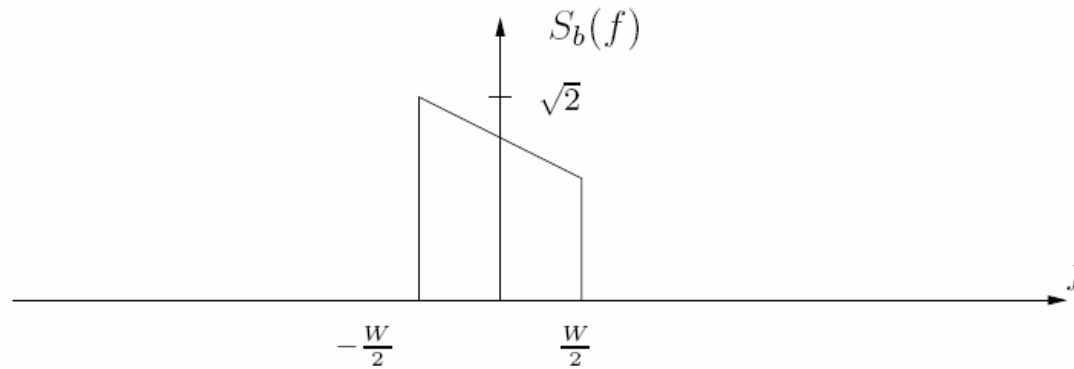
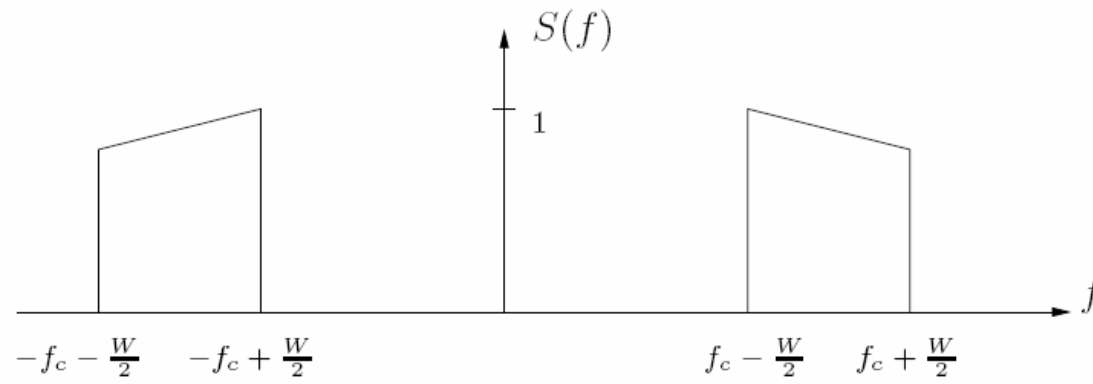
Most of the processing occurs in baseband.

The last stage of the transmitter is converting the baseband signal to carrier frequency;

The first stage of the receiver is converting the receiver converts the received signal back to the baseband.

The channel could be interpreted as connection between the transmitters baseband output to the receiver baseband input.

The signal in this channel is described by its complex baseband equivalent model.



Baseband Equivalent model

A passband signal can be expressed as

$$\begin{aligned} s(t) &= a(t) \cos[2\pi f_c t + \theta(t)] \\ &= a(t) \cos[\theta(t)] \cos[2\pi f_c t] - a(t) \sin[\theta(t)] \sin[2\pi f_c t] \\ &= x(t) \cos[2\pi f_c t] - y(t) \sin[2\pi f_c t] \\ u(t) &= x(t) + jy(t) = a(t) e^{j\theta(t)} \\ s(t) &= \operatorname{Re} \left\{ a(t) e^{j\theta(t)} e^{j2\pi f_c t} \right\} = \operatorname{Re} \left\{ u(t) e^{j2\pi f_c t} \right\} \end{aligned}$$

If we know baseband signal $u(t)$ we know all the information contained in the passband.

Because $u(t)$ contains all the relevant information about the signal we can do the processing (detection) in the baseband.

The signal $u(t)$ can be obtained by modulating $s(t)$ by $\sqrt{2} \cos[2\pi f_c t]$ and low pass filtering.

Linear modulation

What characterises a linear modulation?

The spectral shape of the modulating signal is preserved, it is only shifted to the carrier frequency

The bandwidth of the modulate signal is typically $B = 2 W_x$

The modulated signal envelope varies as a function of time

$$s(t) = \mathbf{Re} \{ z(t) \exp(j2\pi f_c t) \} = z_p(t) \cos(2\pi f_s t) - z_q(t) \sin(2\pi f_c t)$$

$z(t) = z_p(t) + jz_q(t)$ is the complex modulating signal

The later expression gives the quadrature representation

Nonlinear modulation

What characterises a non-linear modulation?

- The spectral shape of the modulating signal is changed
- The bandwidth of the modulate signal is typically $B > 2 W_x$
- The modulated signal envelope is mostly constant

$$s(t) = \text{Re} \left\{ \sqrt{2P_{tx}} \exp(j2\pi f_c t) \exp(jf(x(t))) \right\} = \sqrt{2P_{tx}} \cos(2\pi f_c t + f(x(t)))$$

where $f(\)$ mostly is a linear function (integration, convolution)

Generalized modulation $s(t) = \text{Re} \left\{ z(t) \exp(j2\pi f_c t) \exp(jf(x(t))) \right\}$

contains both linear and non-linear modulation

Every modulation can be generated by a quadrature modulator, where the modulating signal is an unprocessed/linearly/non-linearly processed information signal

The phasor concept

A general modulated signal can be represented in different ways:

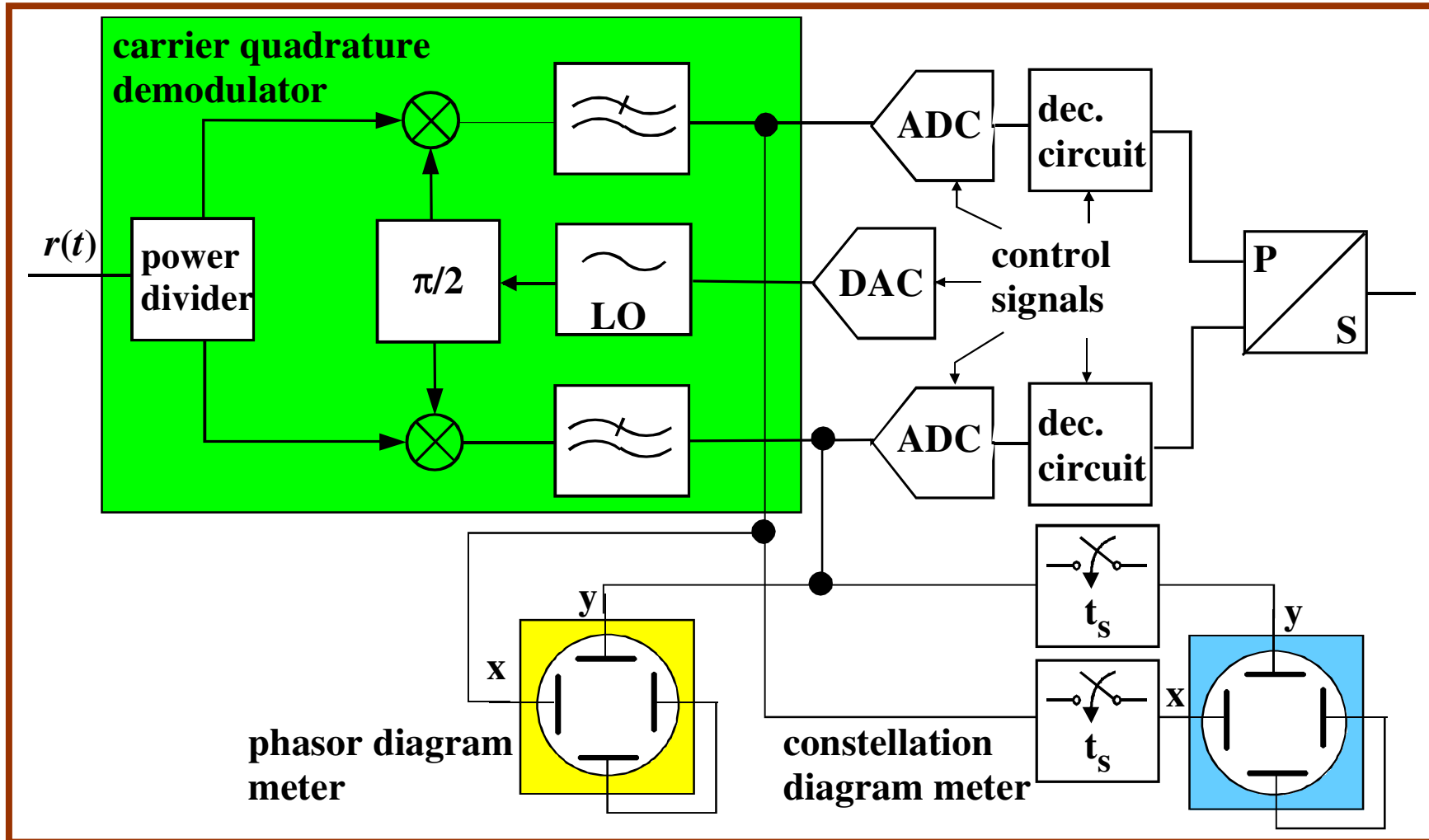
$$\begin{aligned} s(t) &= a(t) \cos(2\pi f_c t + \phi(t)) = a(t) \operatorname{Re} \left\{ \exp(j(2\pi f_c t + \phi(t))) \right\} \\ &= \operatorname{Re} \left\{ \underbrace{a(t) \exp(j\phi(t))}_{z(t)} \exp(j2\pi f_c t) \right\} = \operatorname{Re} \left\{ z(t) \exp(j2\pi f_c t) \right\} \end{aligned}$$

where $z(t)$ is a complex low-pass equivalent of the modulated band-pass signal, which is also called a *phasor*. The phasor shows the instantaneous amplitude and phase of the modulated carrier.

The *phasor diagram* describes the path of the phasors end in the complex plane so that each point on the path corresponds to the running time.

Large variation of the magnitude of the phasor implies more problems with non-linear power amplifiers

Phasor and constellation diagram



Example: QAM-methods (Quadrature Amplitude Modulation)

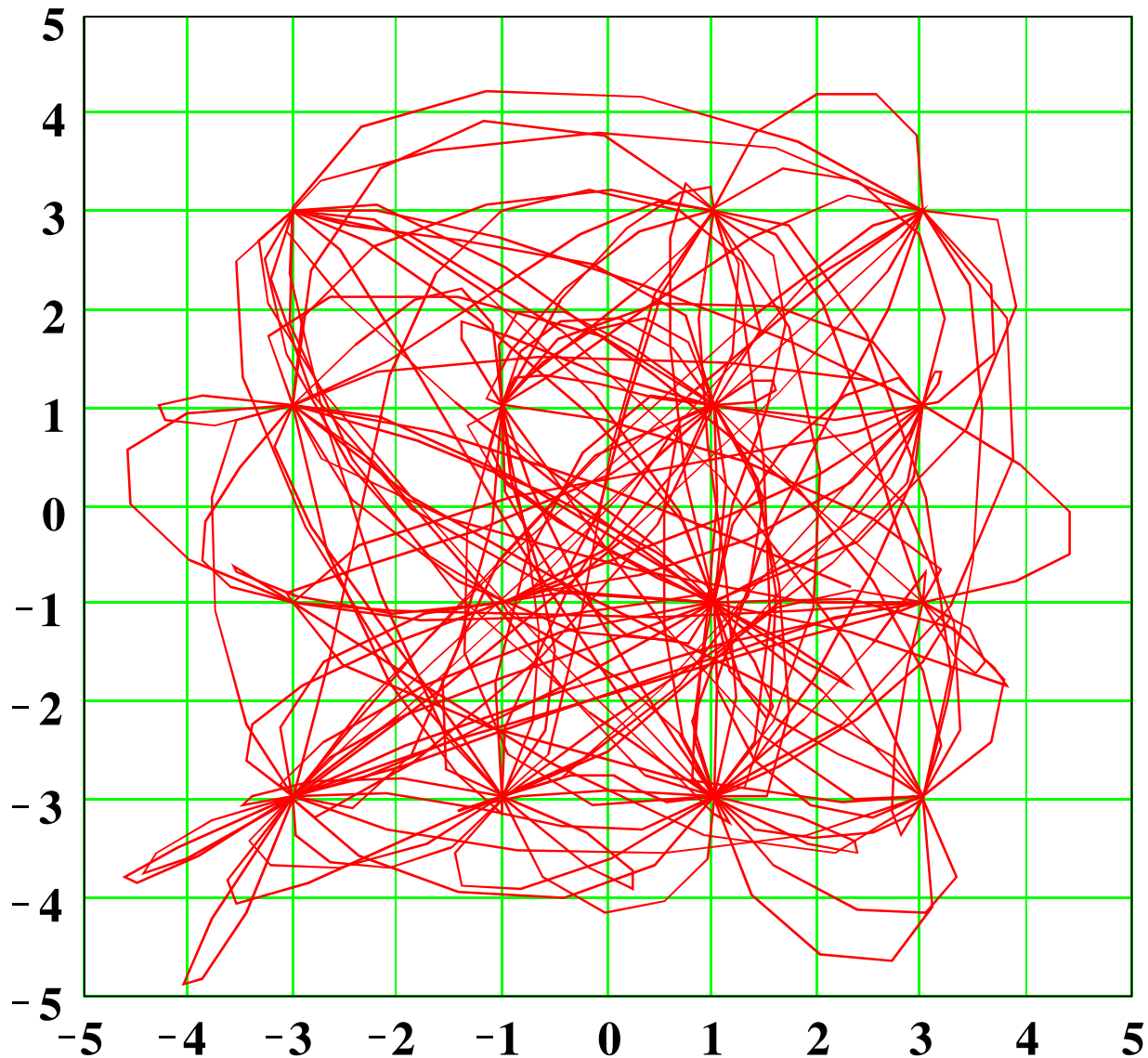
QAM is a linear modulation where the expression for the modulated signal is:

$$\begin{aligned} s(t) &= \text{Re} \left\{ \sum_{k=-\infty}^{\infty} (a_k + jb_k) x(t - kT) e^{j2\pi f_c t} \right\} \\ &= \sum_{k=-\infty}^{\infty} [a_k x(t - kT) \cos(2\pi f_c t) - b_k x(t - kT) \sin(2\pi f_c t)] \quad (2) \end{aligned}$$

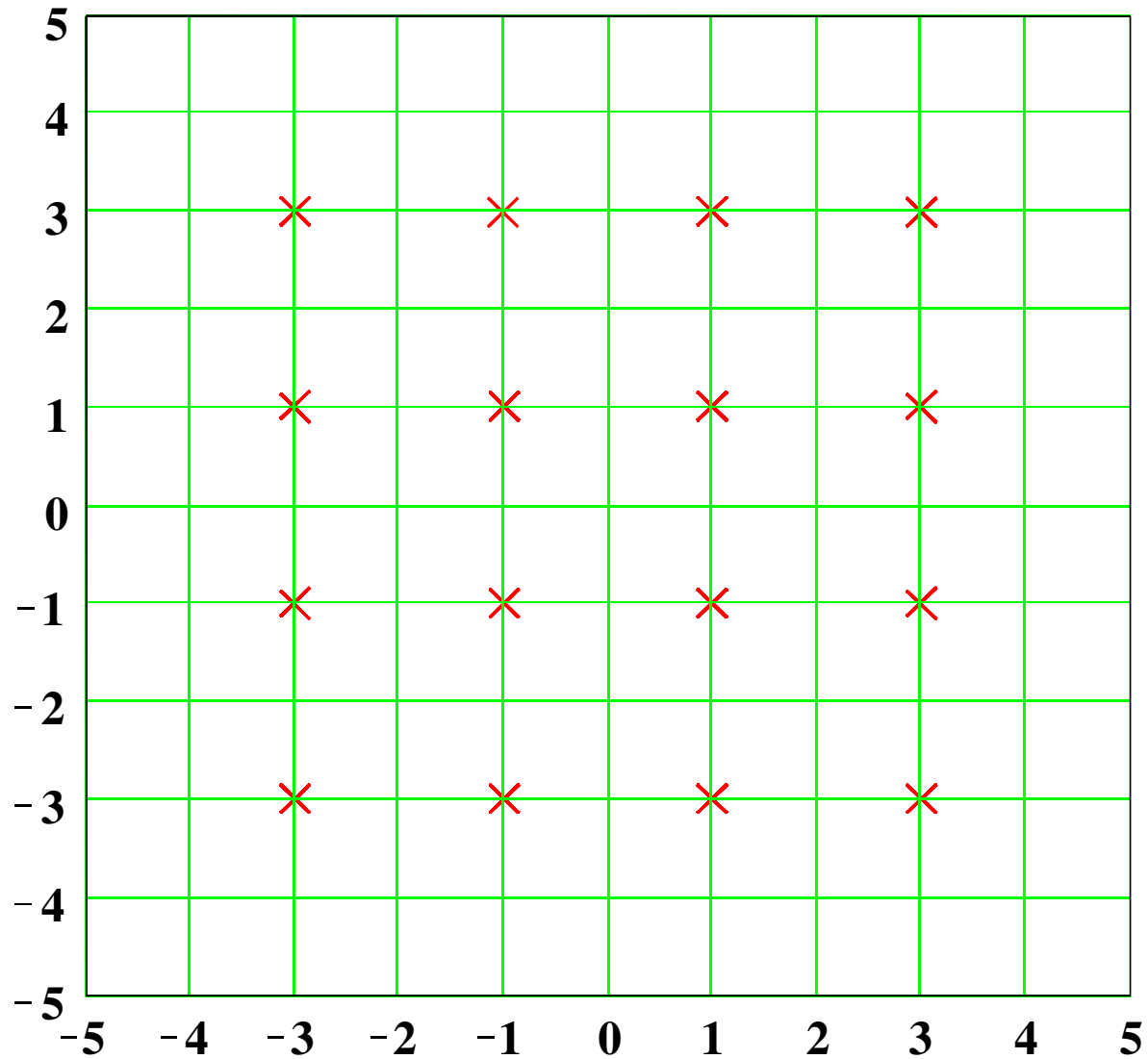
where

- $a_k, b_k = \pm 1, \pm 3, \dots, \pm (M - 1)$, where $P(a_k) = P(b_k) = 1/M$
 $E\{a_k b_k\} = E\{a_k\}E\{b_k\} = 0$, $E\{a_k a_l\} = E\{b_k b_l\} = \delta_{kl}$
 - $x(t)$ is the base-band pulse.
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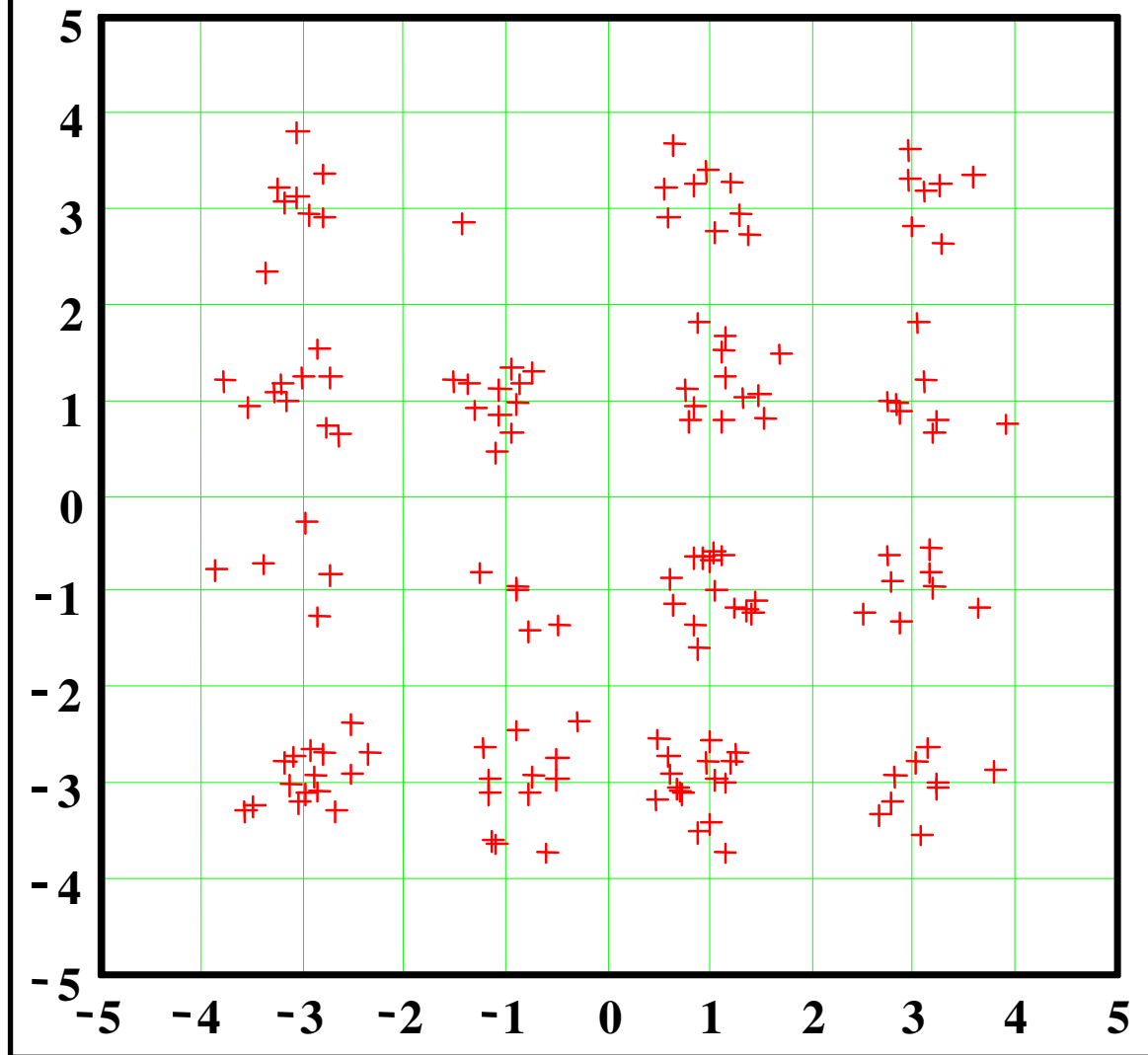
Phasor diagram of 16QAM with raised cosine filtering, $\alpha = 0.25$



Constellation diagram of 16QAM with ideal decision sampling, $\alpha = 0.25$



Constellation diagram of 16QAM with ideal decision sampling offset, RRC filtering, $\alpha = 0.25$



Structure and functionalities of a radio transceiver

Transceiver architectures, 1

Functional architectures

Transceiver part, control part, and user interface part.

Transceiver architectures

Transmitter and receiver → *Transceiver*.

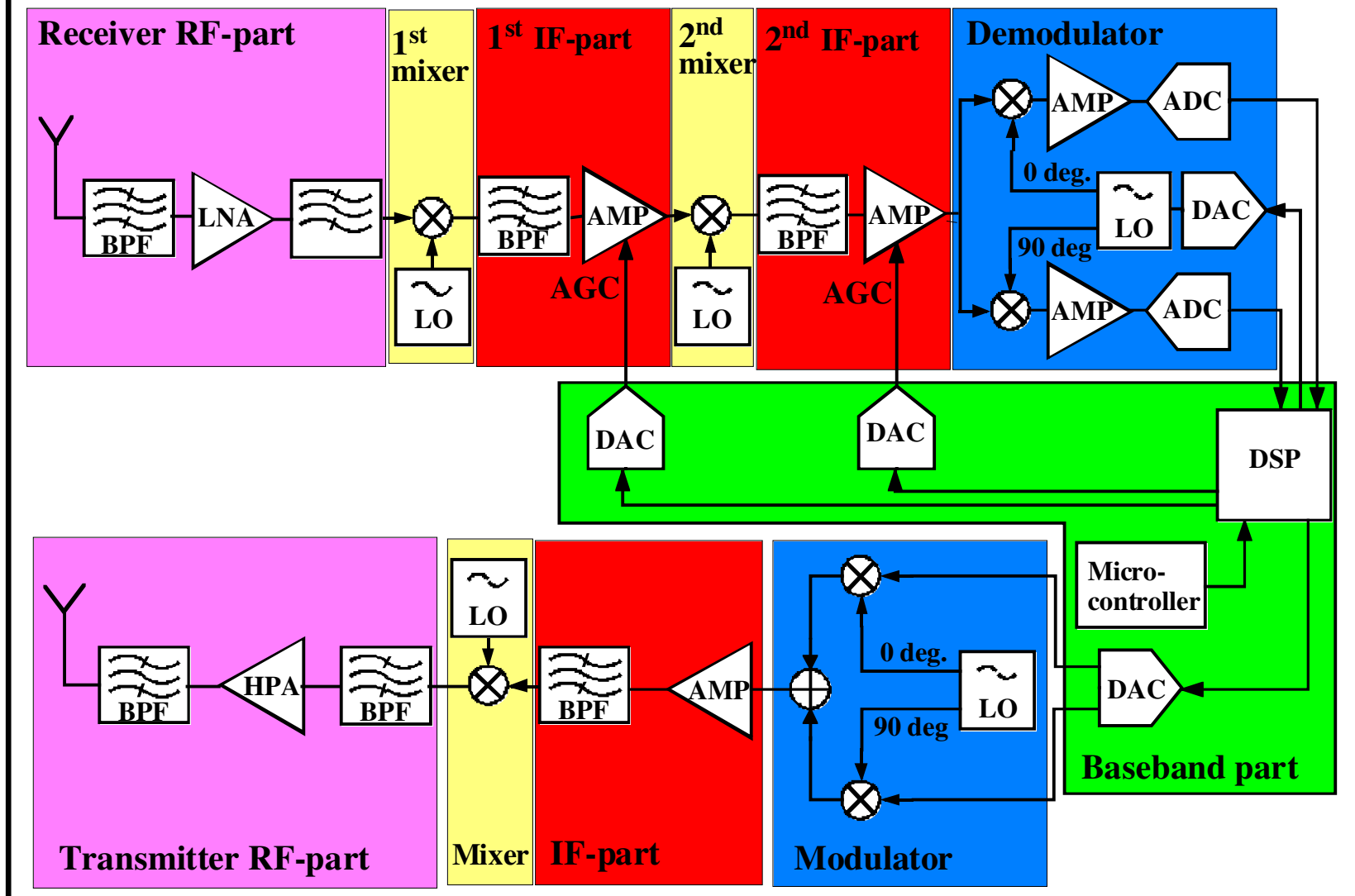
- The transmitter and receiver architectures describe how these system components are structurally organized from implementation point of view
 - Transceiver basic task: the up-conversion from base-band to RF in the transmitter and the down-conversion from RF to base-band in the receiver.
 - The number of steps required in the conversion procedure and the point where A/D-conversion in the receiver and D/A-conversion in the transmitter takes place define the used architecture.
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Transceiver architectures, 2

At least five transceiver principle architectures can be defined:

- superheterodyne radio architecture,
 - direct conversion receivers,
 - digital IF receivers,
 - IQ-less A/D-less receivers,
 - software radio?
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Double superheterodyne transceiver architecture



The superheterodyne radio

Frequency conversions are done in at least two steps,

In the transmitter:

Base-Band (BB) signal → Intermediate Frequency (IF) signal

Intermediate Frequency (IF) signal → Radio Frequency (RF) signal

In the receiver:

Radio Frequency (RF) signal → intermediate frequency (IF) signal

intermediate frequency (IF) signal → base-band (BB) signal

Especially in radio receivers several intermediate frequencies may be used, → e.g. double-super and triple-super receivers

In many present radio transceivers base-band processing is done in digital signal processors (DSP), while IF and RF signal processing is done with analog circuitry.

Advantages and problems of superheterodyne receivers

Advantages

The major part of signal amplification and selectivity is performed on a relatively low and fixed IF enabling:

- large dynamical range,
- high sensitivity, and
- good adjacent channel rejection.

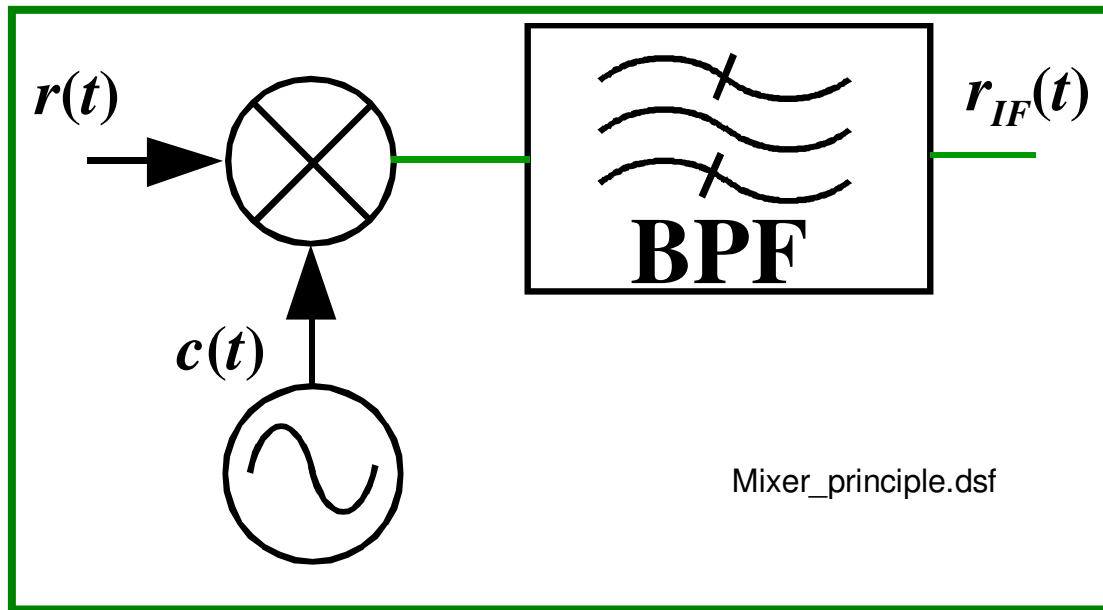
Problems

- local oscillator required
- Image signal, many filters,
- high power consumption,
- many parts that are difficult to integrate

Mixers, 1

Tasks

- The technical component performing frequency conversion
- The application treated here is the conversion of the receiver input RF-signal to the first IF



Characteristics:

- Performs in principle a 4-quadrant multiplication between the input signal and the local oscillator signal:

$$\sqrt{2P_{rx}} a(t) \cos(2\pi f_{rx} t + \phi(t)) \cdot 2 \cos(2\pi f_{lo} t) = \\ \sqrt{2P_{rx}} a(t) \left[\cos(2\pi(f_{rx} - f_{lo})t + \phi(t)) + \cos(2\pi(f_{rx} + f_{lo})t + \phi(t)) \right]$$

Defining $f_{IF} = f_{rx} - f_{lo}$ and observing that the second term will be filtered out in the IF-filter, the effective mixer output signal without noise is

$$r_{IF}(t) = \sqrt{2P_{rx}} a(t) \cos(2\pi f_{IF} t + \phi(t))$$

The down-mixed signal contains the modulation in unaltered form.

The filter after the multiplier is required for removing the signal in the sideband.

Mixers, 2

Problems:

- Image frequency response

Assuming $f_{rx} > f_{lo} \rightarrow f_{lo} = f_{rx} - f_{IF}$ mixing of a signal at the image frequency $f_{image} = f_{rx} - 2f_{IF}$, and omitting the sum term gives

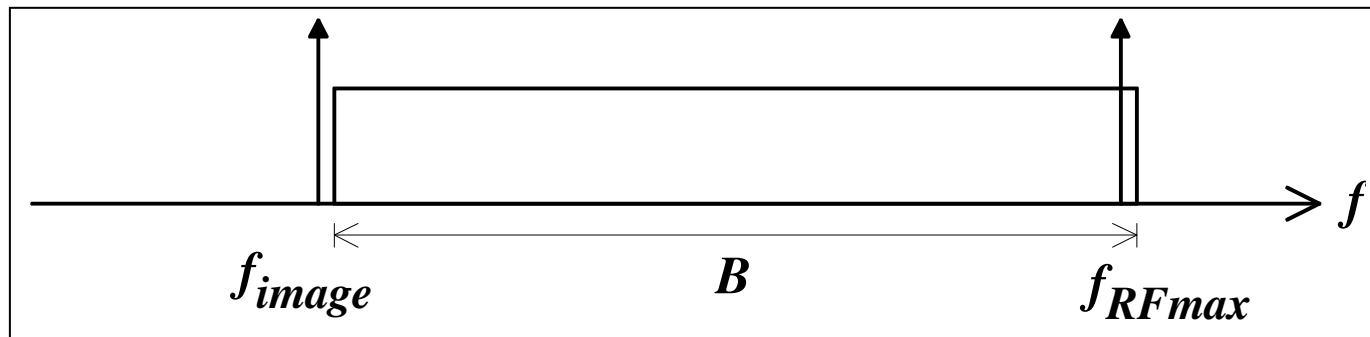
$$\begin{aligned} \sqrt{2P_{rx}} b(t) \cos(2\pi(f_{rx} - 2f_{IF})t + \psi(t)) \cdot 2 \cos(2\pi f_{lo}t) = \\ \sqrt{2P_{rx}} b(t) \cos(2\pi(f_{rx} - 2f_{IF} - f_{lo})t + \psi(t)) = \\ \sqrt{2P_{rx}} b(t) \cos(2\pi(f_{IF} - 2f_{IF})t + \psi(t)) = \\ \sqrt{2P_{rx}} b(t) \cos(2\pi f_{IF}t + \psi(t)) \end{aligned}$$

The basic mixer is as sensitive to the signal at the image frequency $f_{image} = f_{rx} - 2f_{IF}$, which cause the need to reject this frequency with RF-filters. If the local oscillator frequency is higher than the RF-frequency the image frequency is $f_{image} = f_{rx} + 2f_{IF}$

The filter before the multiplier is required for removing the signals in the mirror frequencies.

Mixers, 3

- Choice of 1st IF
As the RF-filters should not attenuate the in-band signals, the first IF must be high enough



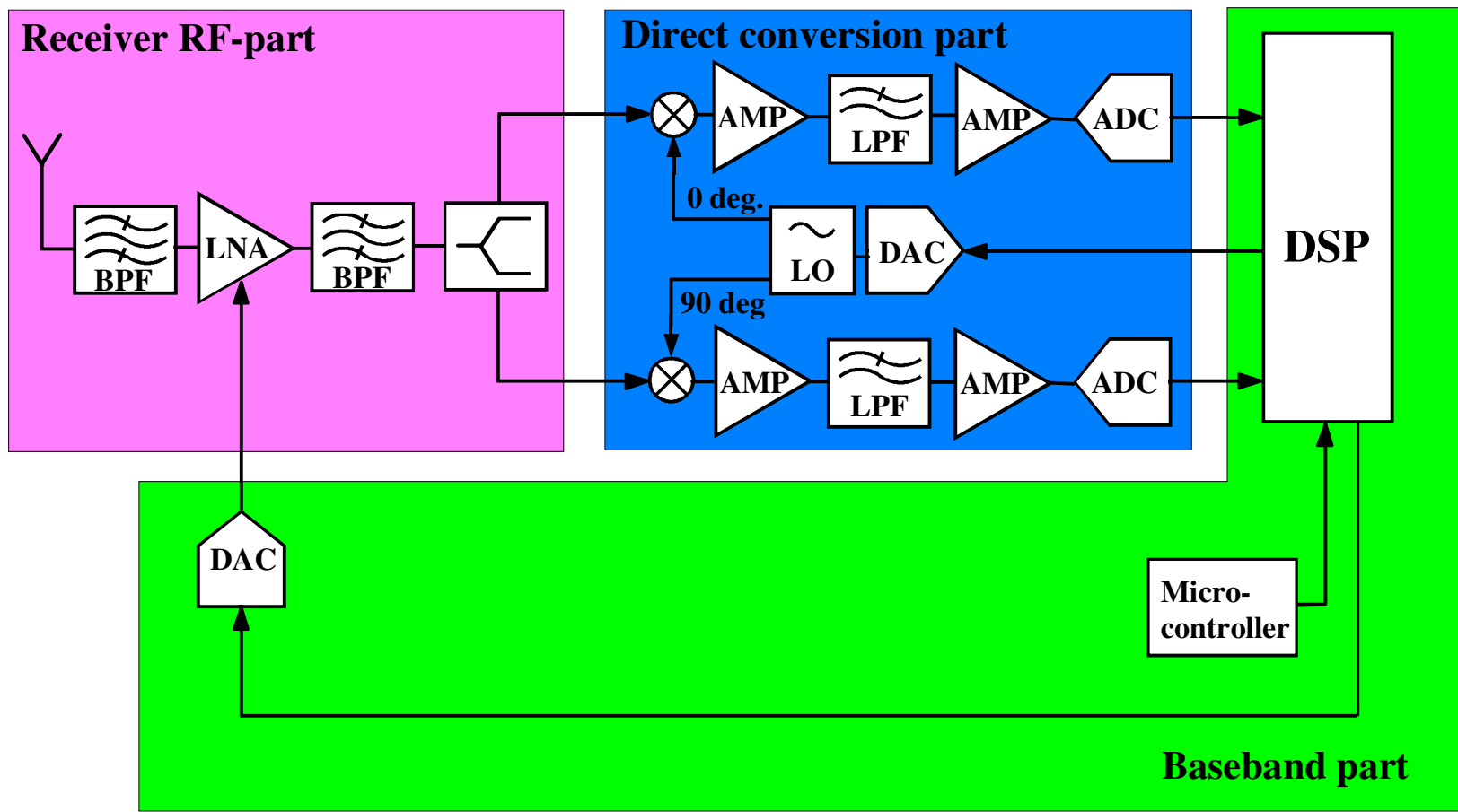
$$\text{or } f_{RF \max} - B > f_{image} = f_{RF \max} - 2f_{IF} \rightarrow f_{IF} > B/2,$$

where B is the bandwidth allocated for the cellular system UL or DL. If B is large, the IF-filter implementation with sufficient selectivity may be difficult and require the use of a 2nd mixer.

Mixers, 4

- There are mixer types, where the image problem is significantly reduced, however, these have higher power consumption.
 - Mixer non-linearity
 - Local oscillator spectral purity
 - harmonic components
 - phase noise
-

Direct conversion receiver architecture



The direct conversion receiver

Characteristics:

- no IF - conversions are done directly between RF and base-band and vice versa if it is used in the transmitter.
- Also in this case the base-band signal processing is done in DSPs while the RF signal processing is done with analogue circuitry

Advantages:

- less components than in the super heterodyne receiver
- No bulky IF-filters needed
- Low power consumption

Problems:

- DC-components arising from mixing with other strong RF-signals saturate the A/D-converter
 - Large dynamic range of the RF-end is required
 - High sensitivity not easily available.
 - Accurate I/Q phasing and amplitude balance required over the entire signal bandwidth
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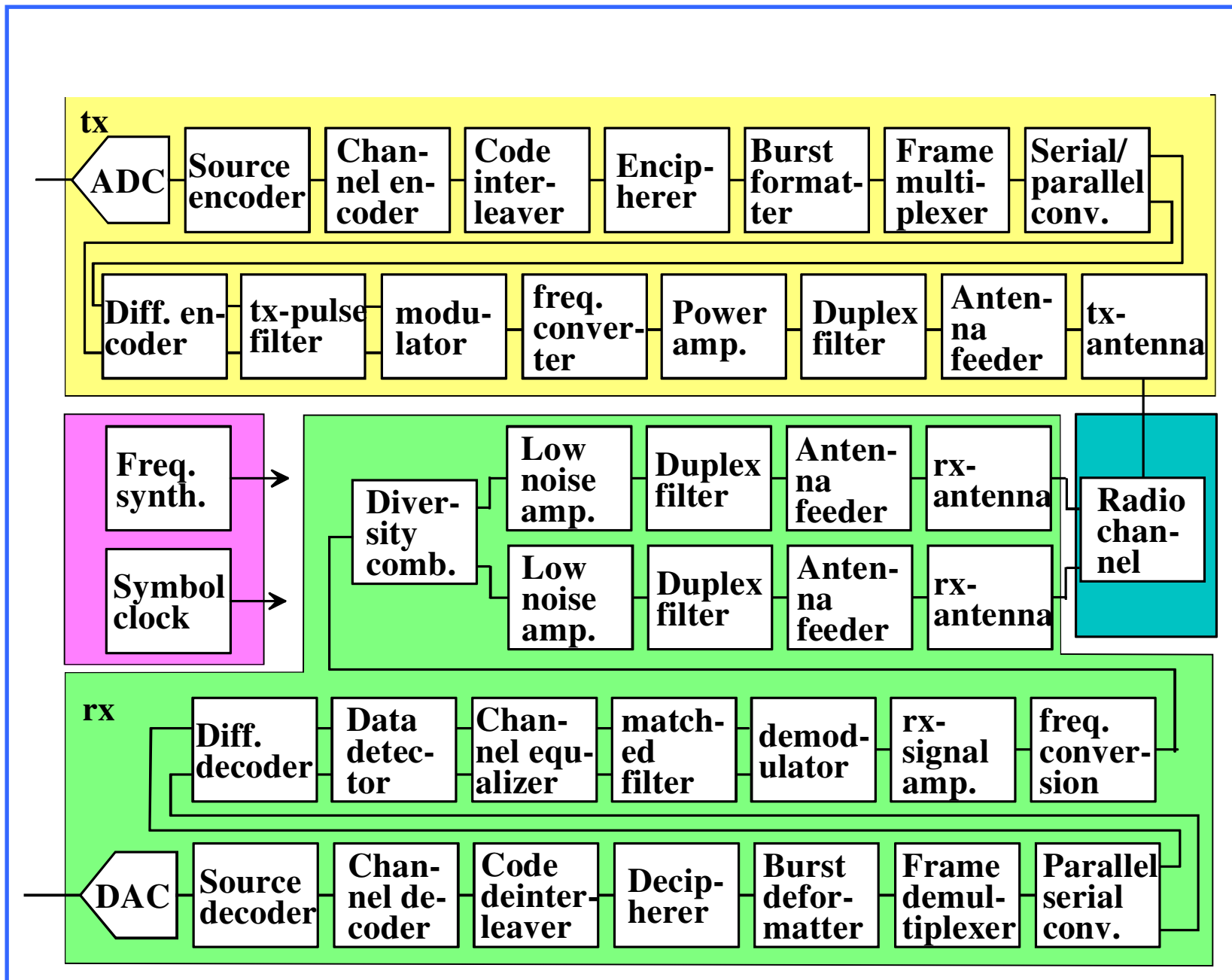
Software radio concept

Initially software radio was thought to make A/D-conversion of the received RF-signal and D/A-conversion of the transmitted RF-signal at the antenna terminals, and all transceiver functions should be implemented by digital signal processing.

At the time being the concept is mostly interpreted as a *Software Defined and Reconfigurable Radio (SDR)*, in which terminals for different standards are integrated into virtual terminals with multiple inputs and outputs. The virtual terminal decides and adapts itself to the standard which is most appropriate at a given time instant depending on used service and propagation environment.

Problems to be solved in this concept include:

- how to detect different radio networks in a given area,
 - how to determine the most suitable network at a given time,
 - how to perform internetwork handover including software downloading,
 - how to cope with different Quality of Service in different networks,
 - how to obtain proper transmission security,
 - how to handle charging and billing
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Transmission methods and components used in the radio link

- Sampling
 - Source coding
 - Channel coding
 - Enciphering
 - Multiplexing
 - Spread spectrum techniques
 - Filtering
 - Modulation
 - Frequency conversion
 - High power amplification
 - Antenna feeders
 - Antennas
 - Duplexing
 - Low noise amplifiers
 - Diversity
 - Carrier recovery
 - Demodulation
 - Channel estimation
 - Channel equalisation
 - Symbol timing recovery
 - Data detection
 - Interference cancellation
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