

# Radio Receiver Architecture

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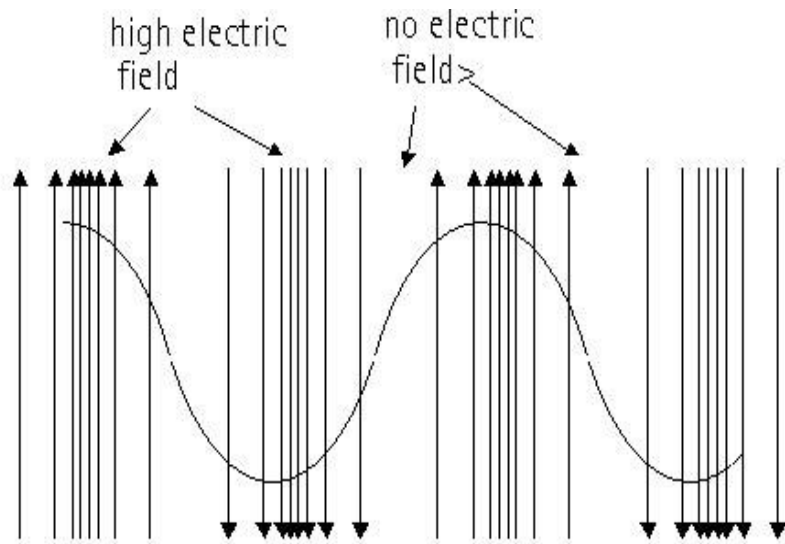


# Basic Concepts



# How is the wave propagating

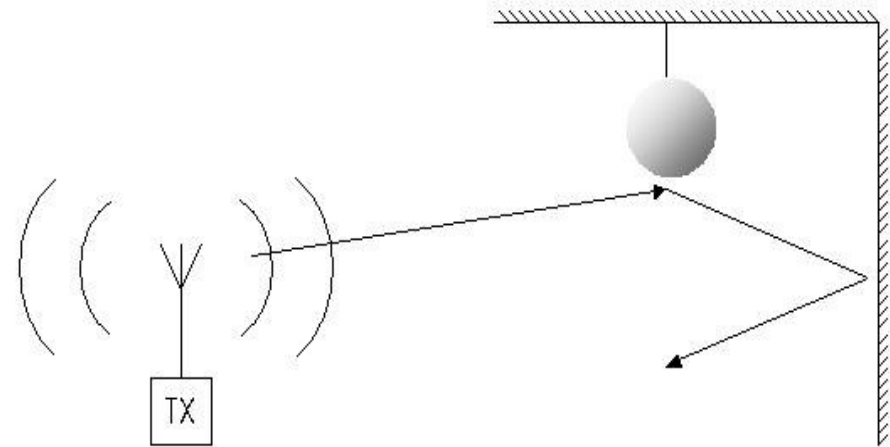
## In free space



- The wave travels (“propagates”) at the speed of light<sup>1</sup>
- E.g. GMSK-modulated RF carrier looks very much like a pure sine wave
- But there is a small frequency deviation that carries the information

<sup>1</sup> Actually speed of light in vacuum divided by  $\sqrt{\epsilon_r}$

## In reality

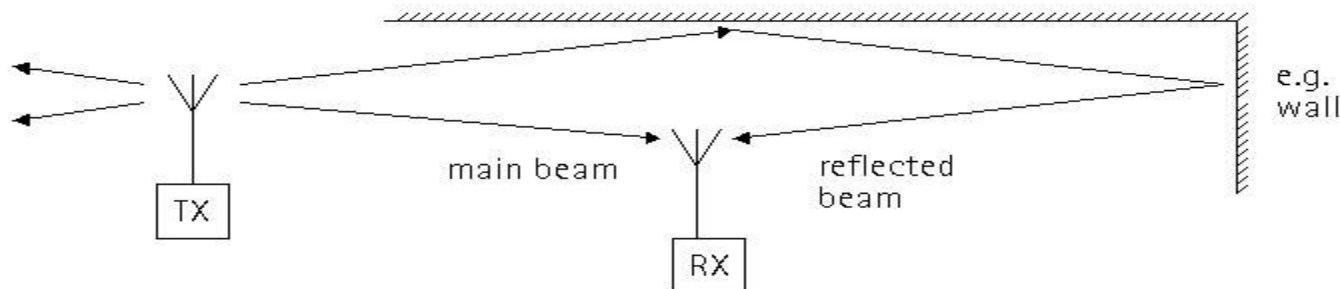


- In practice, there are no pure plane-waves because:
- Antennas actually create **spherical** waves
- There is no truly free space => waves **bounce** from walls and objects
- Also the wave **polarization** (vector orientation) changes in reflections



# Diversity and Multipath

- **Multipath signalling:** Like light, radio signals bounce off objects. Thus, a radio signal can take more than one path to travel from the radio transmitter (client) to the radio receiver.
- Multipath signals can cause high RF signal strength but poor signal quality. As the signals of different paths and different times to delivery are combined within a device, distortion can result. If a signal were to return to an antenna from two paths exactly 180 degrees out of phase, this would cause a **dead spot**.
- Dead spots are very common in buildings. As well, antennas receiving multiple copies of the same signal at different strength levels can cause noise.
- The best way to compensate for Multipath is to move the antenna. Moving antennas can remove you from the dead spots but cannot compensate for mixing of signals and the resultant distortion.
- Wireless Access Points commonly compensate for Multipathing by using **Diversity Antennas**. Two antennas connected to a device receive the various multiple path signals at different times and can determine the strongest individual signal and utilize it, ignoring the others.



# Free-space Loss

- The wave energy per unit area (intensity) decreases as  $1/R^2$   
=> Received power is **much less** than the transmitted power
- Free space loss =  $20\log(4\pi R/\lambda)$  dB
- A radio receiver must be **sensitive** (able to pick up very weak signals)
  - In other words, the receiver circuitry must not be too noisy nor generate interfering spurious signals.
- Also the receiver must be able to handle strong signals and interference on neighboring channels!

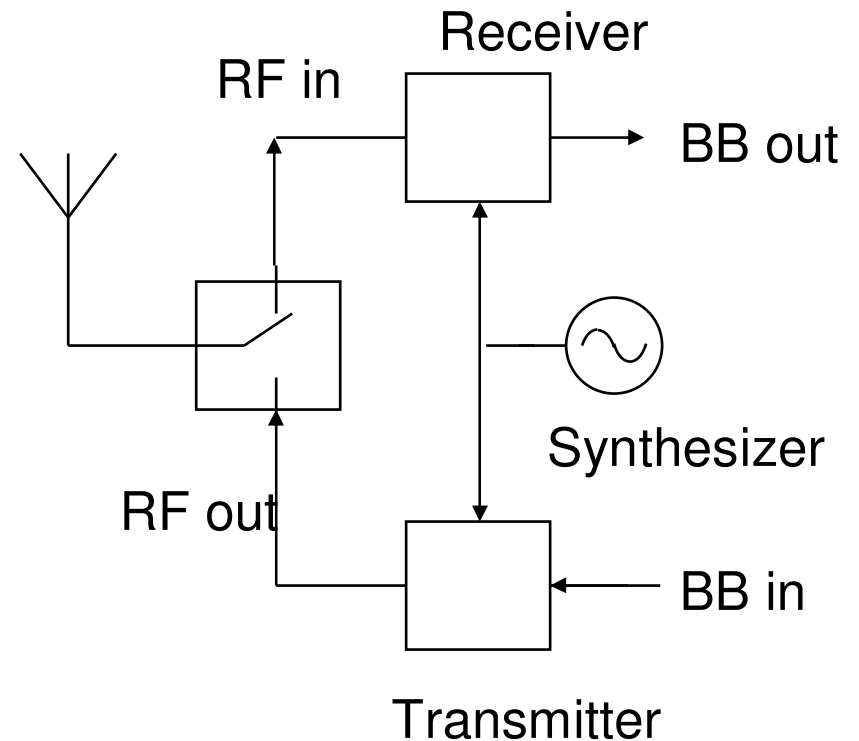


# Basic Receiver Architecture



# What Does the RF Part Do?

- Receiver
  - Removes the RF carrier from the signal (= “down conversion”)
  - Amplifies the weak signal to suitable level for A/D conversion
  - Rejects all interference from entering the A/D converter
- Transmitter
  - Adds the RF carrier to the baseband information signal (= “up conversion”)
  - Amplifies the signal to the precise right level for air transmission
- Both the RX and TX need an RF sinewave for the frequency conversion => RF synthesizer is needed





# RF Unit Functional Description

- The Analogue RF:
  - Upconverts the TX signal (generated by the Baseband Unit), onto the final RF channel, amplifies it to the required level (transmit function), and also
  - Receives the RF signal located on a specific RF channel and downconverts it to a fixed low intermediate frequency which can be processed by the BB Unit.
- The RF Controller MIX Board:
  - Generates all the various clock signals used by the demonstrator and stores the configuration information from the control unit enabling the control of the Analogue RF modules.
- The RF Controller DSP:
  - Allows the control unit to read and write information to the RF Controller MIX Board modules.



# Super-heterodyne Receiver 1/2

- Superheterodyne receiver: (definition)

A radio receiver that combines a locally generated frequency with the carrier frequency to produce a supersonic signal that is demodulated and amplified

- Advantage:

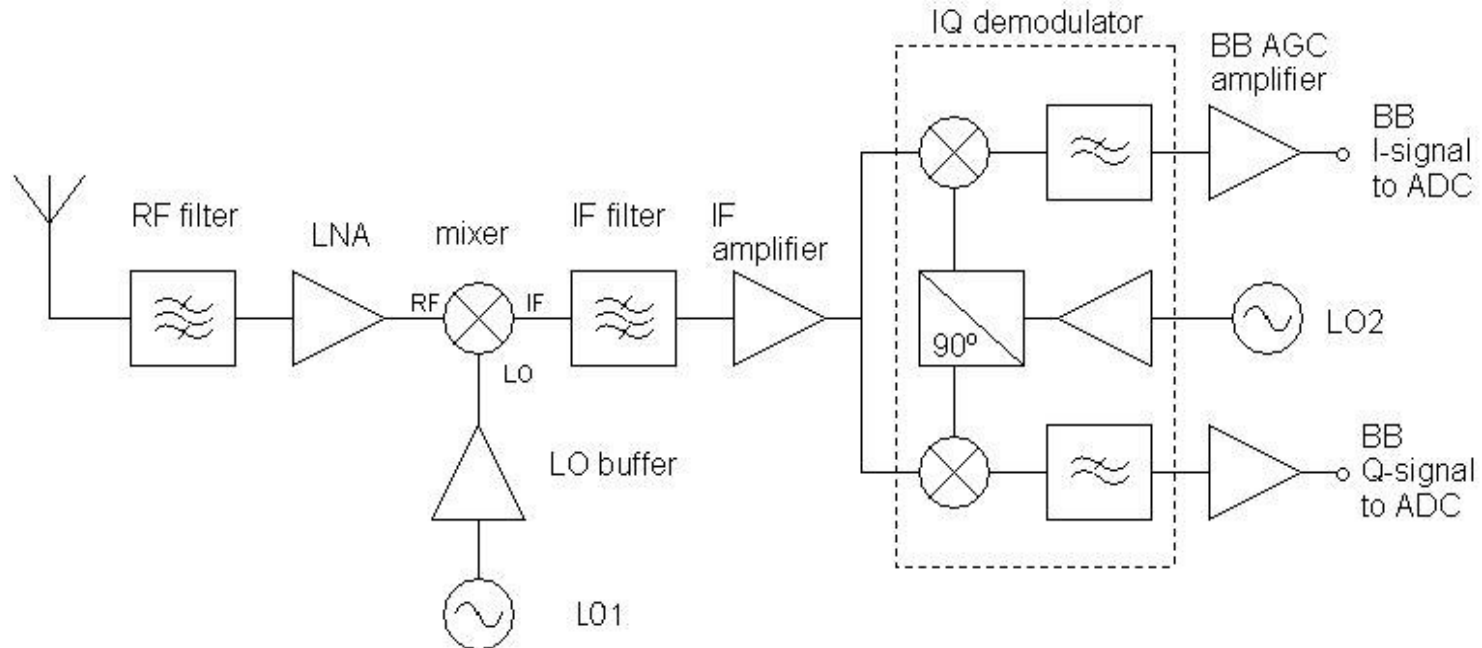
- Proven and long used
- High gain without oscillation problems

- Disadvantage:

- Difficult to reconfigure



# Super-heterodyne Receiver 2/2



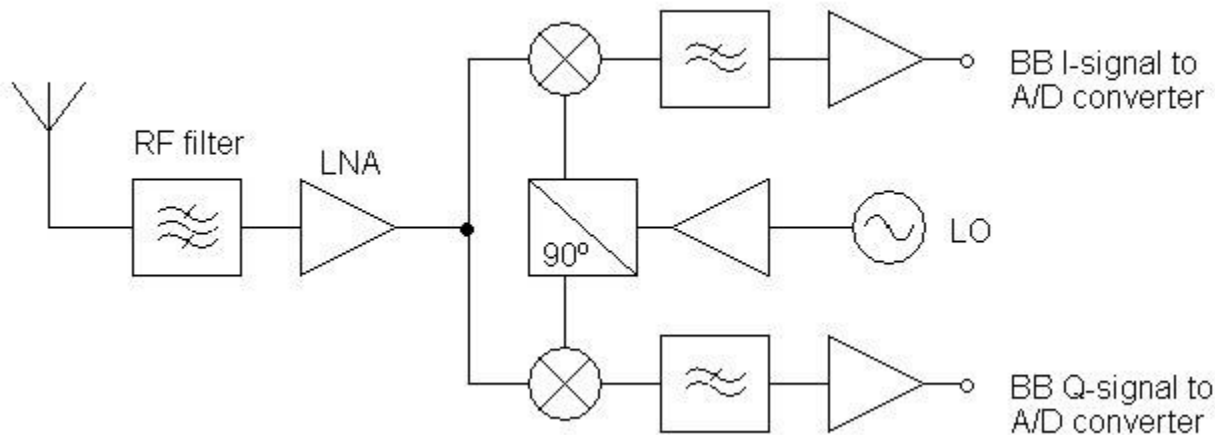
- The out-of-band blocking signals are reduced by an RF bandpass filter placed immediately
- The antenna followed by a low-noise amplifier (LNA)
- A mixer with a first IF in the range of (e.g., 100-200 MHz)
- One or more stages of filters and amplifiers can be used for channel filtering.
- The signal is then boosted to a high level
- And downconverted to baseband for demodulation.



# Direct-conversion Receiver Front-End

Direct Conversion (Homodyne) receiver converts signal down to baseband directly from RF.

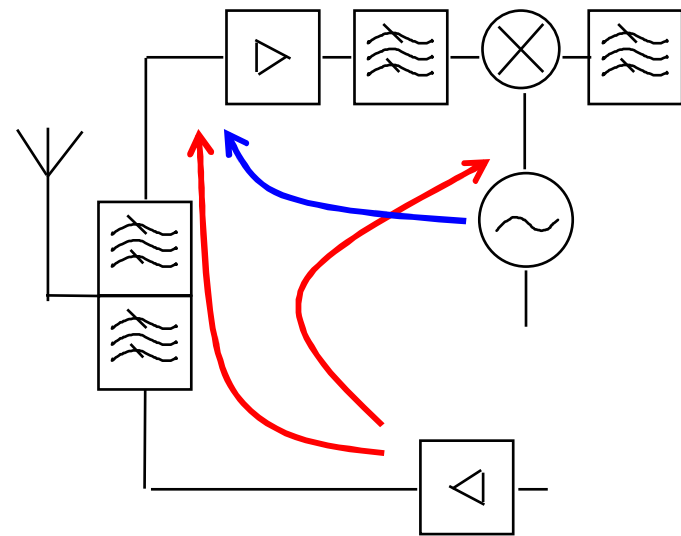
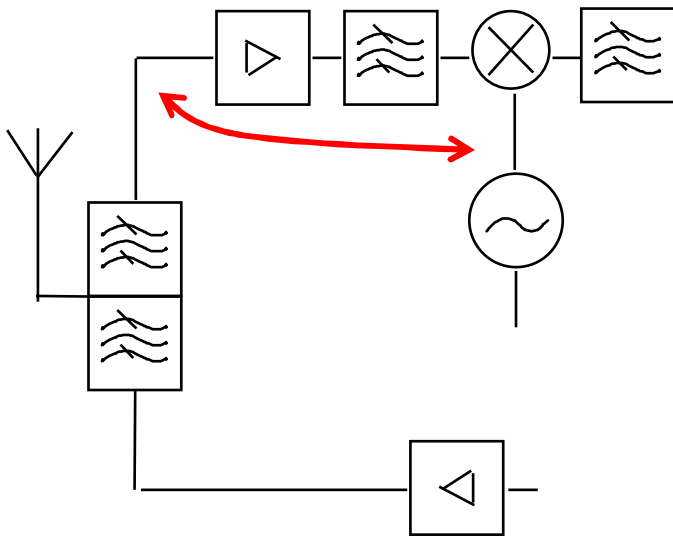
- It includes an RF bandpass filter, LNA, and mixer. The mixer, however, now converts directly to baseband, which implies a good quadrature at RF (LO) frequency.
- Less components (no separate IF components)
- Less spurious responses, no image frequency
- Simple, low component count and low cost
- Very tight specifications for RF components, difficult to implement
- The DC signals that are generated by imbalances in the mixer and are very difficult to filter.



# Direct Conversion Implementation 1/2

- LO leakage can not be filtered out because LO is same as received signal
- High level interference signals can couple to LO and cause LO pulling
- RF part must be very linear because strong adjacent channel signals are not filtered out until baseband

- LO leakage to the RX input causes DC-offset
- TX leakage to LO and through duplexer to RX input causes interference in full duplex systems
- I/Q phase and amplitude errors are challenging



# Direct Conversion Implementation 2/2

Some Solution:

- DC offset is first measured without signal
- This information is then used to cancel offset just before detection
- VCO (Voltage Controlled Oscillator) frequency is twice the LO and is divided on chip before mixer -> reduced coupling



# Digital IF

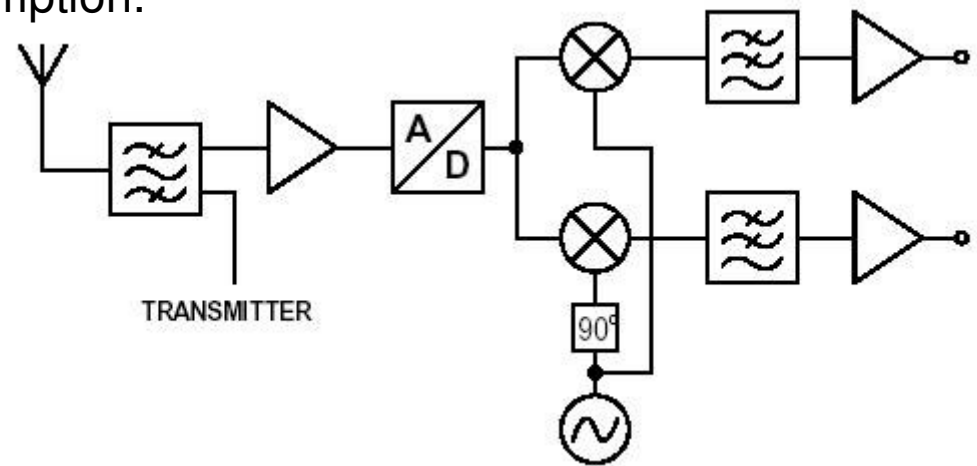
## Advantages:

Little analog IF, single A/D, superior wideband performance

- The conversion to digital will be brought closer to the antenna.
- The matching problems of quadrature branches are avoided
- DC offset and flicker noise when the downconversion to baseband is performed digitally.

## Problems:

- Difficult to implement.
- larger chip area and higher power consumption.



# **GSM/CDMA/WCDMA Receiver System Requirements, Design and Comparison**





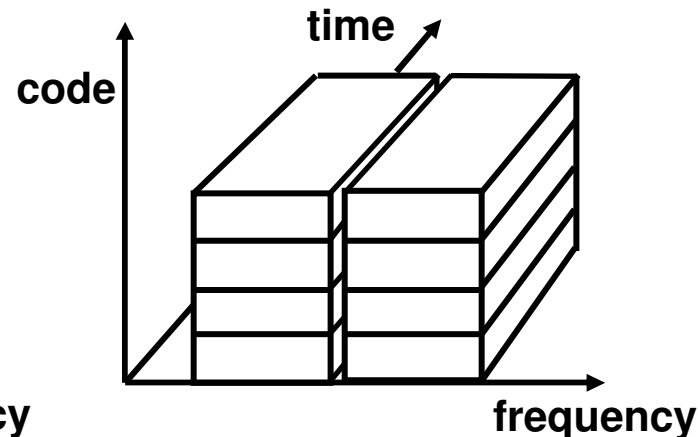
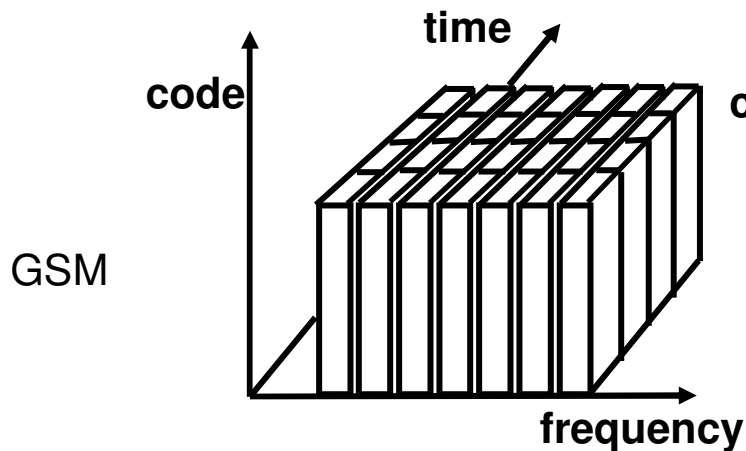
# GSM Development

- HSCSD & GPRS
  - HSCSD = High Speed Circuit Switched Data
  - GPRS = General Packet Radio Service
  - Different coding 9.6 kbit/s -> 14.4 kbit/s
  - More slots, for example 2 slots -> 28.8 kbit/s
  - Dynamic use of slots in GPRS
  - Faster synthesizer is needed in RF
- EDGE
  - Modulation changes GMSK -> 8PSK
  - max data rate 384 kbit/s
  - Not constant amplitude anymore -> more linear transmitter is needed

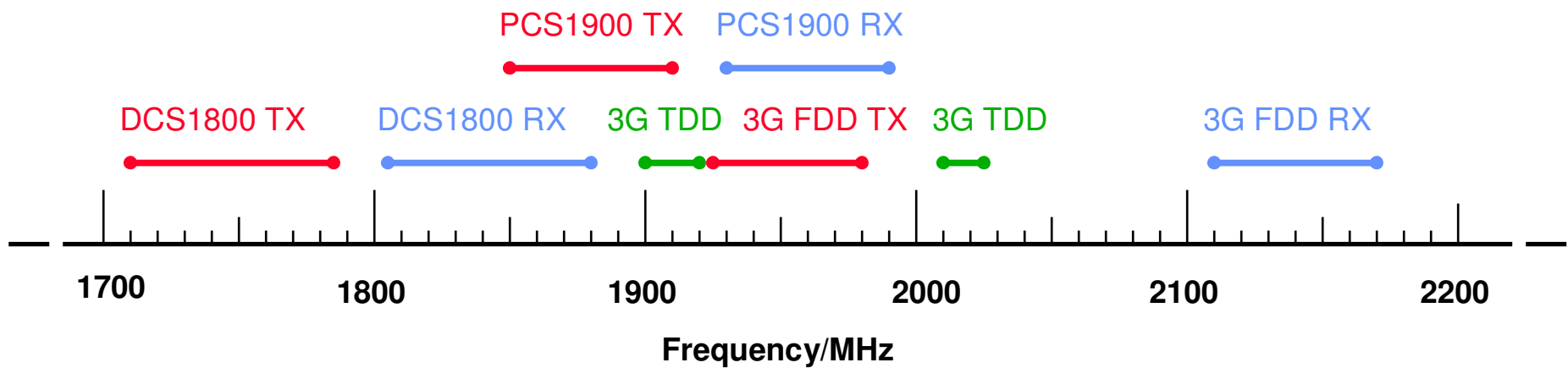
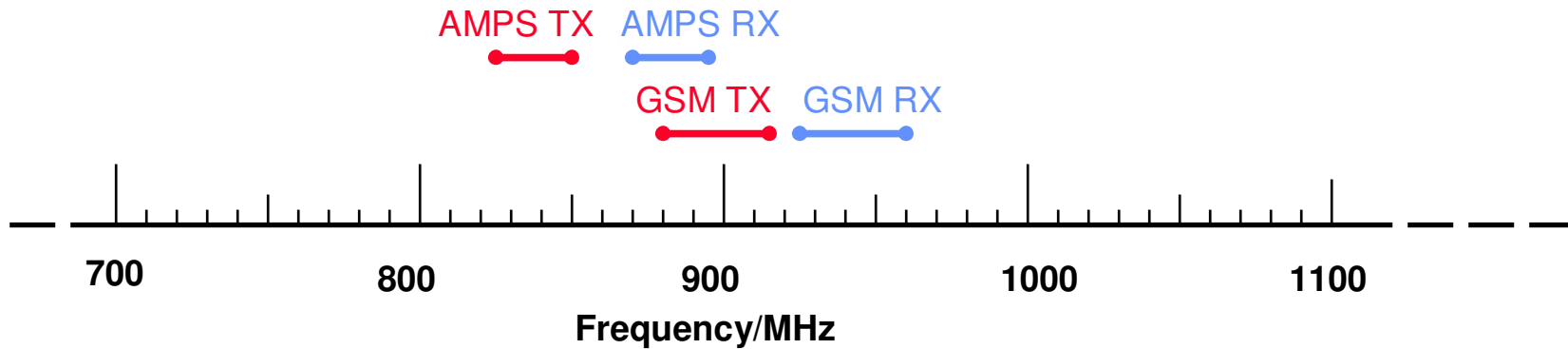


# Spread-Spectrum Basics

- Spectrum is spread using a code that is independent of the information signal
- Bandwidth used in spread spectrum transmission is typically at least 100 times wider than the information signal bandwidth
- WCDMA uses direct sequence spreading where a pseudo-random code is directly combined to the signal
- Users are separated by different codes
- Bits in the spreading code are called chips

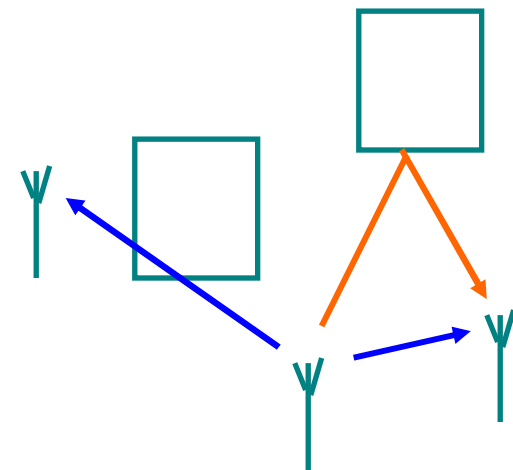
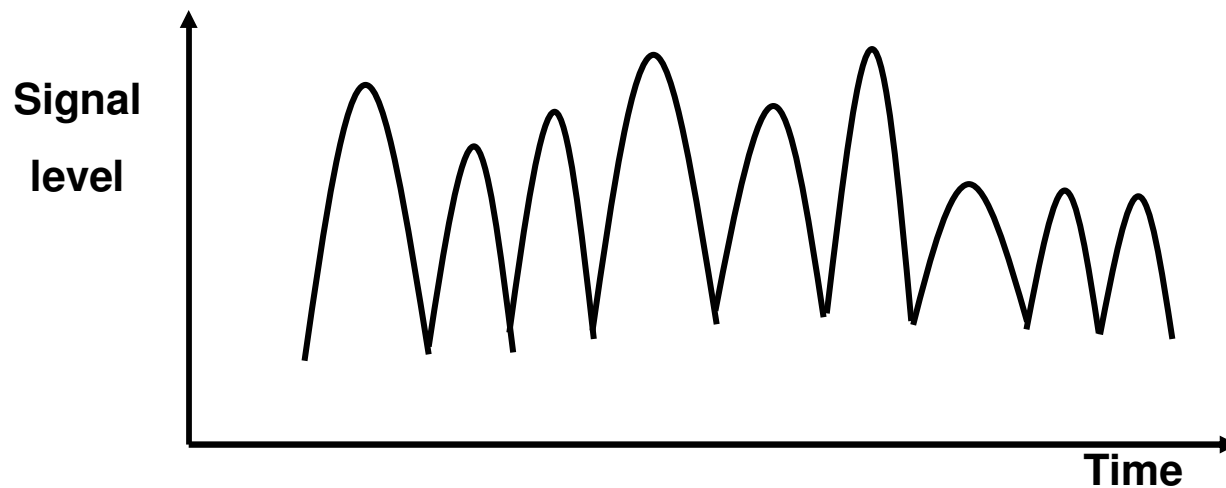


# Frequency bands



# Mobile Radio Channel

- Multipath propagation (frequency selective fading)
  - Shadowing
  - Doppler shift
- linear time-variant channel



# Specifications for Receiver (GSM)

- Bad frame indication performance
- Sensitivity
- Usable receiver input level range
- Co - channel rejection
- Adjacent channel rejection (selectivity)
- Intermodulation rejection
- Blocking and spurious response
- AM suppression



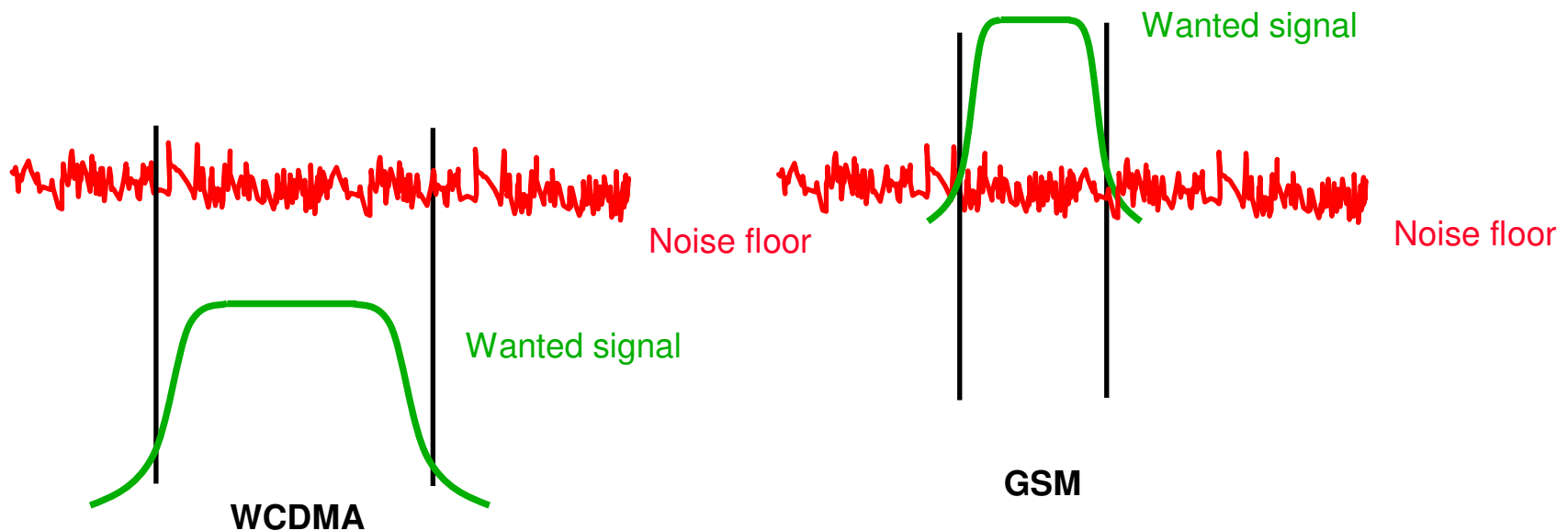
# System Parameters

- GSM
  - Handportable max power 2 W (during the TX burst)
  - Carrier spacing 200 kHz, 8 time slots
  - Modulation method: GMSK, BT = 0.3
  - Modulating bit rate 270.8 kbits/s
- IS-95 CDMA
  - Handportable max power 200 mW (average)
  - Carrier spacing 1.25 MHz, 64 Walsh codes
  - Chip rate 1.2288 Mcps
- WCDMA
  - Handportable max power 250 mW (average)
  - Carrier spacing 5.0 MHz (10 MHz, 20 MHz)
  - Chip rate 4.096 Mcps (8.192, 16.384)
  - Modulation method QPSK



# WCDMA Receiver requirements

- Sensitivity requirement is -117 dBm @ 12.2 kbps user data rate
  - Changing user bit rate changes processing gain (PG) and also sensitivity level
  - $PG = 10 \log (3.84\text{Mcps}/\text{user symbol rate})$
- Selectivity requirement is defined as RX filter attenuation at adjacent channel compared to wanted channel, spec is 33 dB



# Mobile Receiver

- GSM:
  - Training sequence is used to estimate the impulse response of the radio channel
  - This information is necessary to equalize the user bits on a burst by burst basis
- CDMA:
  - Chip rate is typically greater than flat fading bandwidth of the channel and multipath components appear like uncorrelated noise -> no equalizer is needed
- RAKE receiver combines time shifted versions of the original signal
  - One finger is assigned for the direct signal, another for the reflected signal
- Fingers in RAKE receiver can also be used for soft handoff
  - One finger is assigned for new base station while another still listens the old BS
- RAKE receiver is implemented in digital baseband and it does not require any special functionality in RF part -> Receiver can be implemented with similar blocks as current GSM receiver





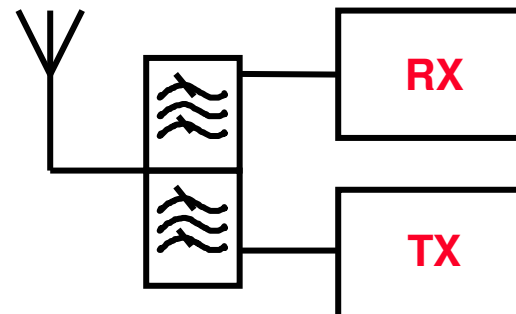
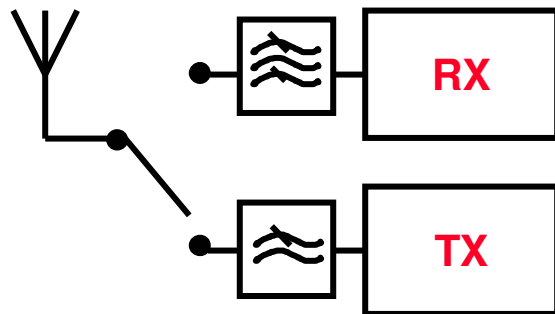
# Modulation Techniques

- Linear modulation techniques (QPSK used in WCDMA)
  - BPSK, QPSK, 8PSK,  $\pi/4$  DQPSK,...
  - Amplitude of the transmitted signal changes with the modulating signal and in general the envelope of the RF signal is not constant
  - Linear modulation schemes have typically very good spectral efficiency
  - Using nonlinear amplifiers can cause severe adjacent channel interference
- Constant envelope modulation techniques (GMSK used in GSM)
  - BFSK, GMSK,...
  - Constant envelope modulations occupy larger bandwidth than linear modulations
  - Power efficient nonlinear amplifier can be used without degradation of the spectrum
- Both QPSK and GMSK can be implemented in transmitter using an IQ-modulator
- Linearity and dynamic range requirements for WCDMA/GSM TX blocks are different



# Duplexing Techniques

- Receiver (RX) and transmitter(TX) signals can be separated by two ways:
  - TDD: RX and TX at same frequency, separation is done using different time slot
  - FDD: RX and TX on at same time, separation is done using different frequency
- GSM can use either switch or duplexer
- WCDMA must use a duplexer (option for TDD in the spec)



# Duplexing Issues

- WCDMA must support full duplex operation
  - Integration is challenging because high TX - RX isolation is needed
- In GSM system receive and transmit functions occur in different time slots
  - Isolation between TX and RX is not a concern
    - High level circuit integration possible
    - Common blocks for RX and TX possible, e.g. synthesizer (frequency can be shifted between RX and TX time slots)
    - Less spurious responses in the RX



# Power Control

- In GSM system power control is not very critical for the network operation
- About 30 dB control range is enough to reduce power consumption and adjacent channel interference
- In CDMA systems power control becomes critical because BS should hear all mobiles at the same power level
- If one mobile transmits to base station (BS) much higher level than the others it is impossible to decode the low level signals (near-far problem)
- **Open loop power control** takes care that TX power is in the right order of magnitude in the beginning
  - TX power is depends on the received signal strength ( $P_{tx} = \text{offset} - P_{rx}$ )
- During the call **closed loop power control** adjusts the power with a small step (about 1 dB step with 1600 Hz control rate)



# RX Design issues

- Full duplex operation in WCDMA
  - TX noise at RX band must be attenuated
  - A good duplexer is relatively large and expensive component
- High chiprate
  - Wide Bandwidth in baseband -> higher current consumption
  - Wide band IF filters -> higher loss



# TX Design Issues

- Tight requirement for Adjacent Channel Power (ACP)
  - Proposal -35 dBc
  - Low ACP means more capacity in the network
  - Linear power amplifier is needed -> efficiency decreases
- Wide power control range (WCDMA ~70 dB, GSM ~30 dB)
  - TX efficiency at low power levels is low
  - Good AGC amplifier is needed to keep open loop power accurate over whole control range and temperature range



# Synthesizer Design Issues

- Adjacent channel is  $\pm 5$  MHz away -> phase noise is not very critical
- Settling time requirement does not seem to be critical either
- Tuning range in WCDMA is relatively narrow (60MHz @ 2GHz)



# Thank you very much!

Questions?





# Abbreviation

- AM: Amplitude Modulation
- ACP: Adjacent Channel Power
- BW: Bandwidth
- IF: Intermediate Frequencies
- LNA: Low-Noise Amplifier
- VCO: Voltage Controlled Oscillator



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# Assignment

- Short description of direct conversion architecture

