Fit for Wireless
Prepare yourself for RF-challenges
Some basics (excerpt)

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support high frequency

Some Basics on RF-Engineering:

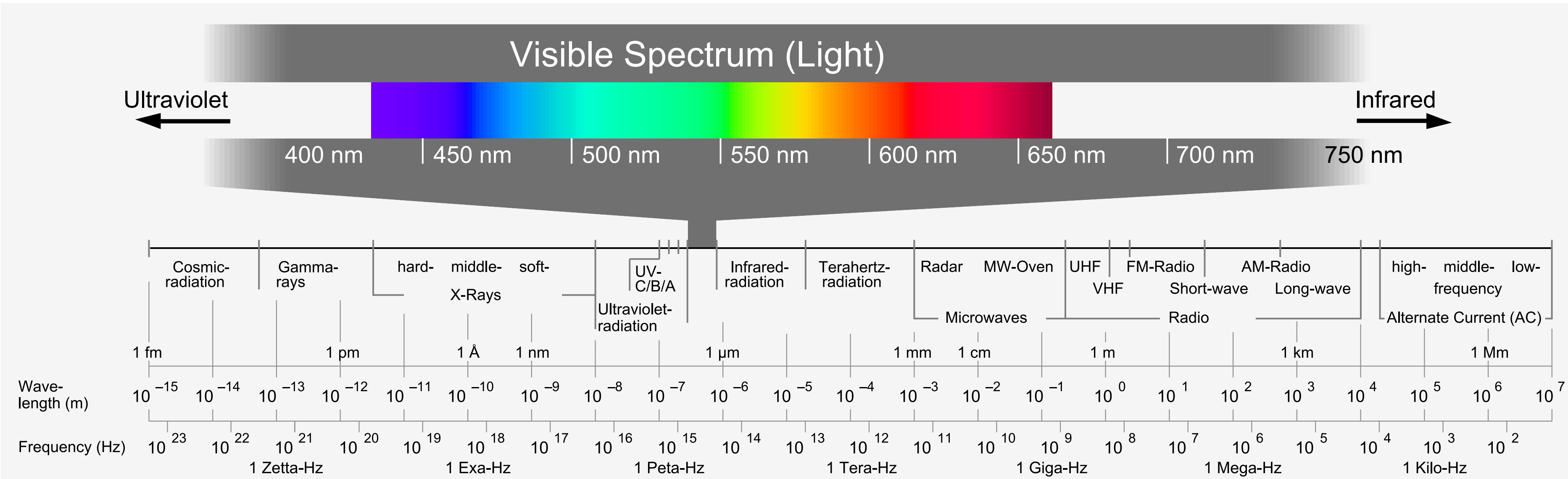
Foundation and Language

What to Expect

- Gives you an overview, why RF is a little bit different than "classical" electronics and what the specifics are.
- Prepares a common ground for RF engineering
- Explains important concepts in RF
- You will learn some aspects of the common language and basic concepts RF-engineers use to make their life easier

- Introduces dBm
- Introduces frequency usage
- Fundamentals on RF-measurements

The Spectrum



Frequency Useage I

Frequency and band on a coarse scale

Frequency	Designation	Example Use
3-30kHz	Very Low F. (VLF)	Navigation, Sonar
30-300kHz	Low F. (LF)	Radio, Navigation Aids
300-3000kHz	Medium F. (MF)	AM broadcasting, “Grenzwelle”, Maritime communication
3-30MHz	High F.	Amateur radio, short wave, citizens Band, RFID
30-300MHz	Very High F. (VHF)	FM broadcasting, Television, Air traffic
300-3000MHz	Ultrahigh F. (UHF)	Television, satellite comm., surveillance radar, ISM-Applications, Mi-crowave ovens, cellular communication, WLAN, BT
3-30GHz	Superhigh F. (SHF)	Airbore Radar, Microwave links, automotive radar, satellite TV
30-300GHz	Extreme High F. (EHF)	Wheather radar, automotive radar, microwave links, experimental, short range communication

Frequency Useage II

Typical Communication Bands (in Europe)

Application	Frequency/MHz	Bandw.	Modulation
Car-Key (ISM)	433.05-434.79	narrow	ASK/ FSK
GSM (D)	880-935	200 kHz	GMSK
GSM (E)	1710-1880	200 kHz	GMSK
WLAN (802.b,g)	2400-2483.5	to 40 MHz	g:OFDM/QAM
WLAN (802.a)	5150-5725	to 40 MHz	OFDM/QAM
UMTS/ W-CDMA	1920-2170	5 MHz	CDMA/QAM
Bluetooth	2400-2483.5	ca. 1MHz	FHSS/GFSK

Governed by Maxwell's Equations

And God said

	Differential Form	Integral Form
Ampere's circuit law	$\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$	$\oint_{\partial S} \vec{H} dl = I_{f,S} + \frac{\partial \Phi_{D,S}}{\partial t}$
Faraday's law	$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint_{\partial S} \vec{E} dl = -\frac{\partial \Phi_{B,S}}{\partial t}$
Gauss' law (el.)	$\nabla \cdot \vec{D} = \rho$	$\oint_{S} \vec{D} dA = Q$
Gauss' law (mag.)	$\nabla \cdot \vec{B} = 0$	$\oint_{S} \vec{B} dA = 0$

And there was light.

Consider High-Frequency-Effects

- Elements are not “lumped” anymore:
  physical dimensions of elements (e.g. resistors, caps, sometimes transistors, most importantly cables and interconnects) must be considered
- Parasitics of elements must be considered
- Measurement equipment has effect on the device under test (DUT) (high-ohmic vs. 50 Ω)
- Field extension and (ir)radiation must be considered (coupling and antennas)

Think like an RF-Engineer!

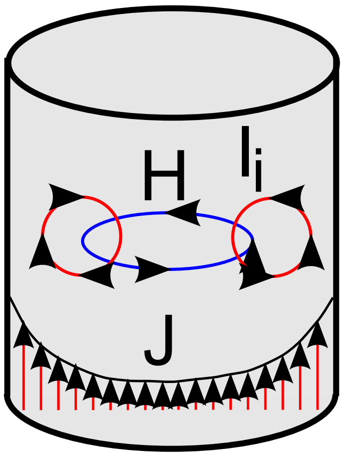
Think in

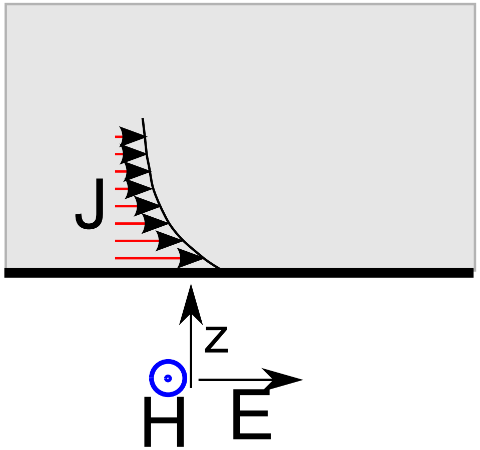
- Waves and wavelength λ (or frequency f) $\lambda = \frac{c_0}{\sqrt{\epsilon_{eff}}} \frac{1}{f}$

  c_0 Free space speed of light $\approx 300,000$km/s
  ϵ_{eff} Effective dielectric coefficient (tbd later)
  Remember: electromagnetic wave at 10 GHz has a free space wavelength of about 30 mm, 1 GHz of 30 cm...
- Wavelength in Material (e.g. ceramics with permittivity $\epsilon_r > 10$) much shorter
- It's all about matching, it's all about resonance

- Power and the unit dBm (at least mostly)
- Power-Reflection and transmission versus voltage and current

Skin-Effect





- Because of induction, magnetic field pushes current to the edges of material
- With higher frequency, current is only supported at the boundaries of conductors
- Skin-depth $\delta = \sqrt{\frac{2}{\omega\mu_0\mu_r\sigma}}$ with μ permeability, σ conductivity of the material.
- Skin-depth defines point, where current density is decreased by $1/e$
- This is why conductivity (especially at surfaces) is important

THE Unit: dB (dezi-Bel)

Measure of relative quantities

- Power-relation: $a_P = 10 \log \frac{P_1}{P_2}$
- Voltage-relation: $a_U = 20 \log \frac{U_1}{U_2}$ (equal impedance levels on Port 1 and 2)

For absolute quantities a reference level must be introduced:

- Power (relative to 1mW): $P[\text{dBm}] = 10 \log \frac{P}{\text{1mW}}$
- Voltage (relative to 1μV): $U[\text{dB}\mu] = 20 \log \frac{U}{1\mu\text{V}}$

Calculate dB in your Head

dB	Sum/Difference of 10,5,3	Mult., Div.	Linear
0	Memorize		1
1	$10 - 3 - 3 - 3$	$10/2/2/2$	1.25
2	$5 - 3$	$3/2$	1.5
3	Memorize		2
4	$10 - 3 - 3$	$10/2/2$	2.5
5	Memorize		3
6	$3 + 3$	$2 * 2$	4
7	$10 - 3$	$10/2$	5
8	$5 + 3$	$3 * 2$	6
9	$3 + 3 + 3$	$2 * 2 * 2$	8
10	Memorize		10

A Word on Measurement

Some simplified words of caution on measuring within RF-circuits

	DC	RF
Resistance	Meg-Ohms	50 Ohms
Probe	Does not influence	Antenna, high load
Quantity	Voltage and Current	Power/ S-parameter
Where?	where-ever	Only at defined points
Open cover	does not matter	may disturb signal

An Overview about RF-Systems

What to Gain

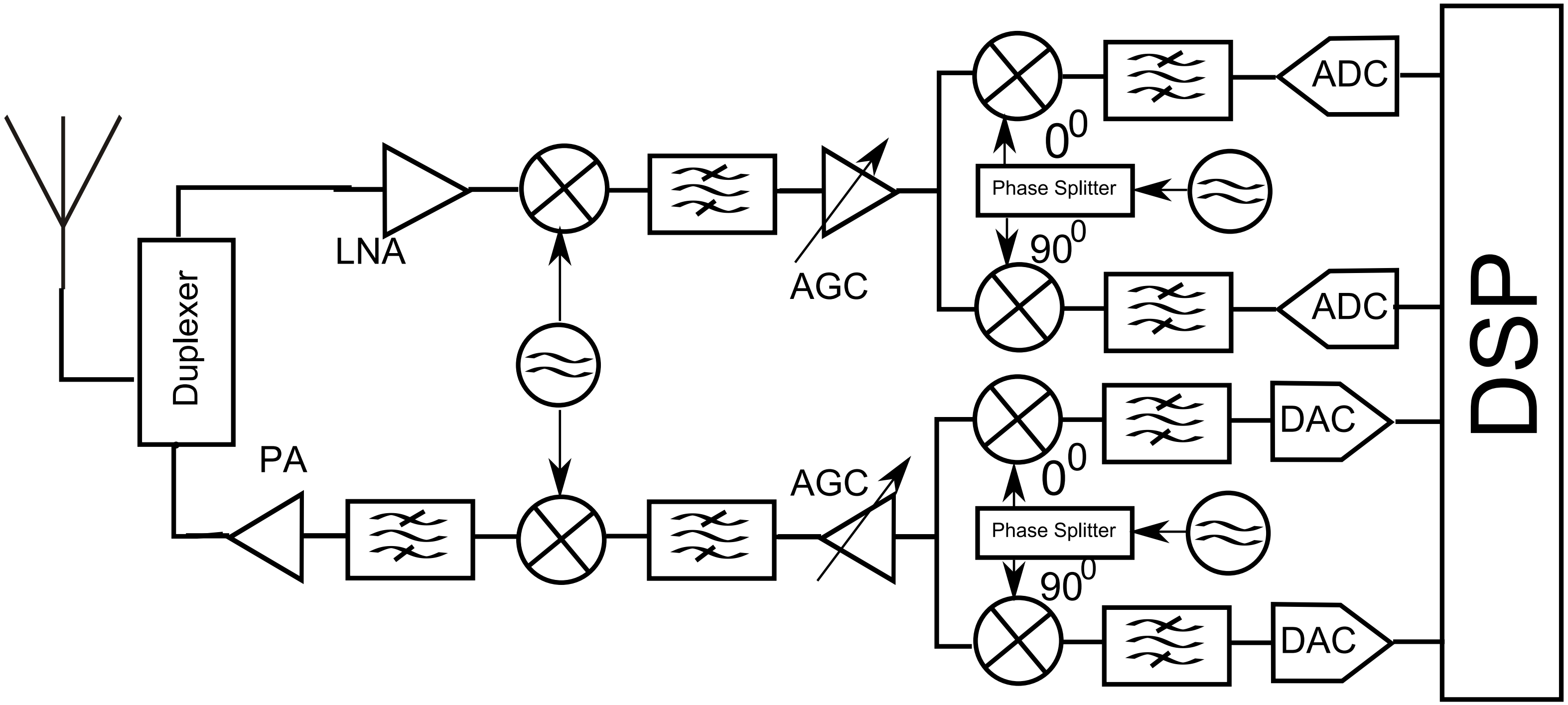
- Gives you just a brief overview how RF systems look like
- Introduces main building blocks
- Explains what to watch out for
- Gives you a red line throughout the entire course

You will be enabled to

- Identify building block
- Explain why they are there

The Transmitter

Block-diagram of a typical transmitter circuit



The Antenna

- Most visible part of the system
- Sometimes very critical part (e.g. because of space)
- May the antenna is responsible for RF-techniques being called “black magic”
- In the end: Just a piece of conductor being smartly formed for effective irradiation or reception of electromagnetic waves.

Antennas

Different antennae pictures GPL, http://de.wikipedia.org

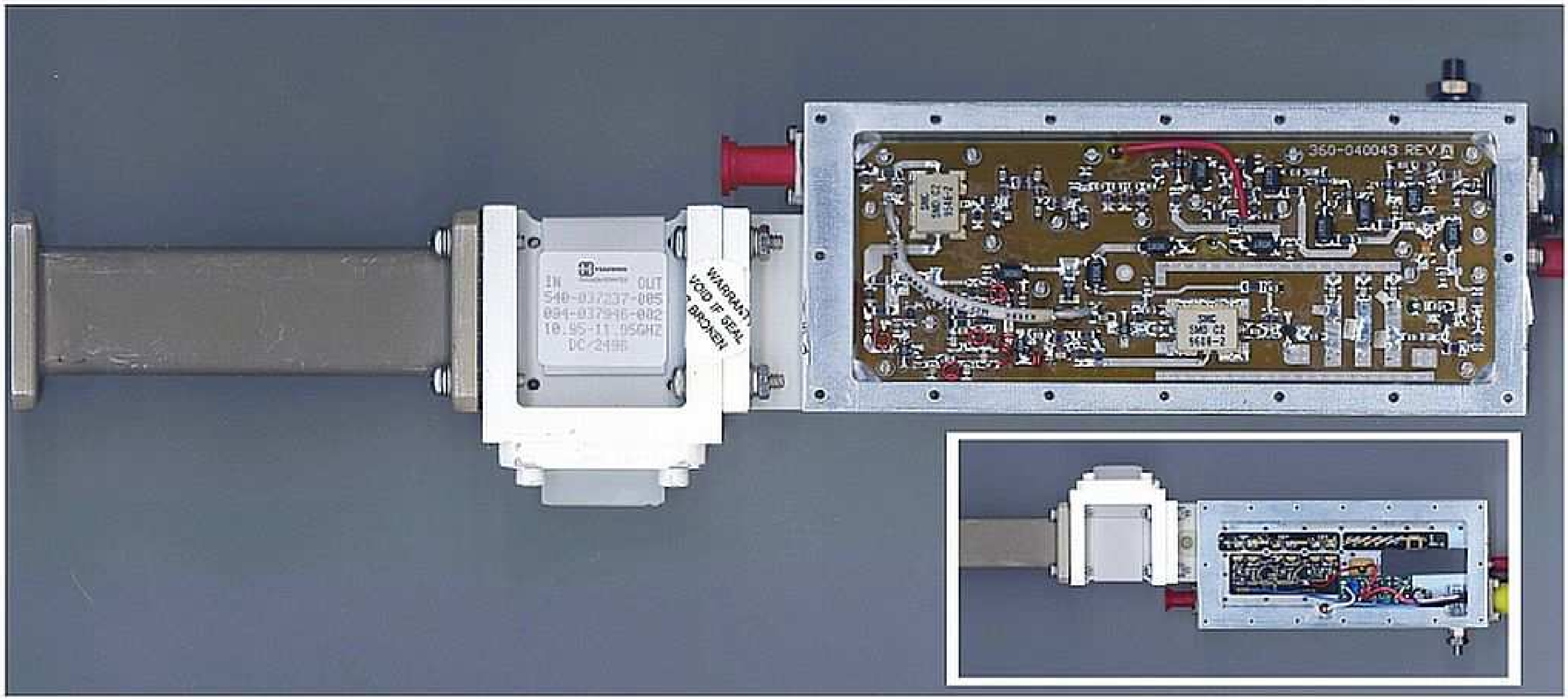
The Duplexer

- Depending on System architecture this can be completely different building block
  - Frequency Division Duplex (FDD): Differentiate between transmit (TX) and receive (RX by frequency: Use a filter structure (Diplexer))
  - Time Division Duplex (TDD). Switch between RX and TX and have them at different times: Use a switch (or a circulator)
- In general very critical (passive) element, because the first (RX) or the last (TX) element!

More Interesting: SAT-TV

A dismantled Low Noise Block (Amplifier) for Sattelite TV reception (Source: Wikipedia, GPL)

More Pictures



Amplifier (and periphery) for the KU-Band (12-18 GHz) (Source Wikipedia, GPL)

Simple Amplifiers

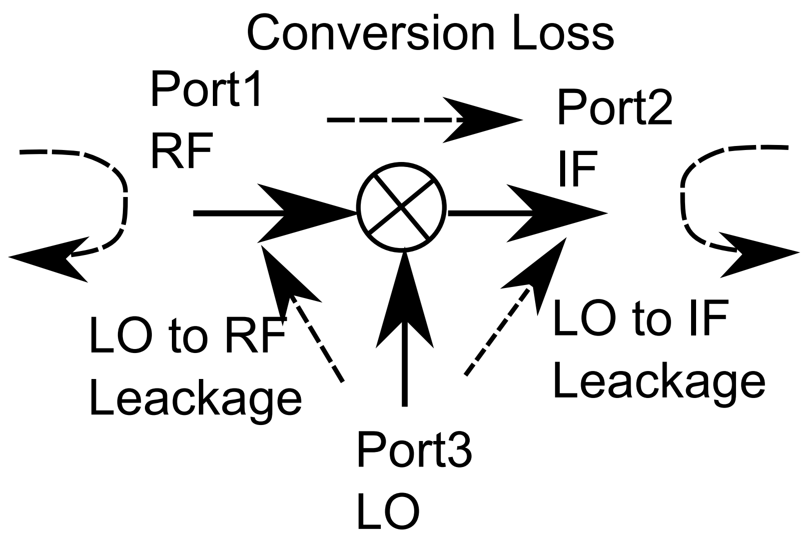
Low Noise Amplifier (LNA)

- Works on very low power: Linearity and efficiency often of second priority
- Determines sensitivity of the entire system
- Small element
- Careful: can be overdriven or even destroyed!

Power Amplifier (PA)

- High-Power delivering entity
- Linearity an issue
- Efficiency (how DC-power gets converted into RF power) is important
- Thermal considerations
- Typically expensive component

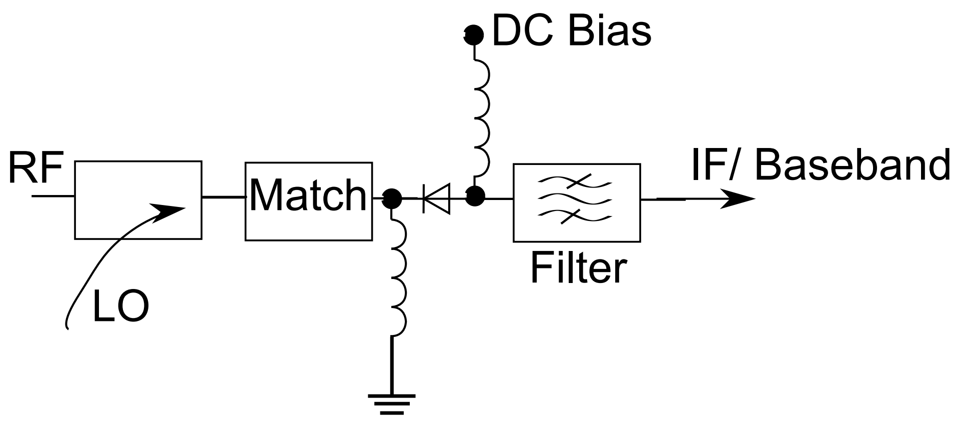
Mixer Overview



Some parameters of the mixer

- Nonlinear operation (converts the frequency)
- Often loss of power
- Requires Local Oscillator (LO) frequency and power
- Non-ideal: leaks LO power in all directions

Mixer Simple How To



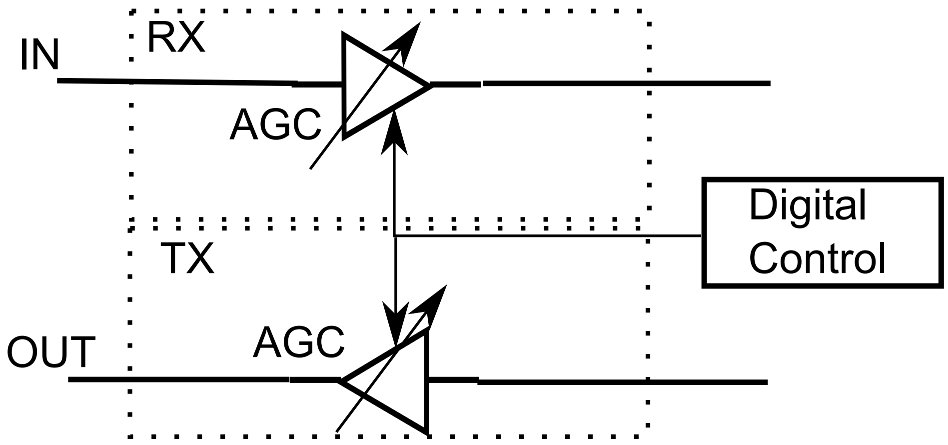
Very simple mixer with only one diode as mixing element

- DC bias responsible for bringing diode into right working point
- RF and LO must be combined and lead to the diode
- Matching tedious. Must be done for RF, LO and Intermediate frequency (IF)
- Filter appropriately

Bandpass Filter

- Why?
  - Limit Noise bandwidth
  - Limit external disturbances (e.g. co-siting with different standards)
  - Enable coexistence of different systems
  - Filter out unwanted leakages (Harmonics/ Mirror, LO, IF, ...)
  - Dimensioning is sometimes very critical in pass- and stop-band!
- What is it?
  - Ceramics filter
  - Distributed ((micro-strip) line elements)
  - Cavity resonators
  - Lumped Elements (Inductors, Caps)

Automatic Gain Control (AGC)



Dynamic range is vital in modern communication systems e.g. in motion, in fading channel conditions (urban environment)

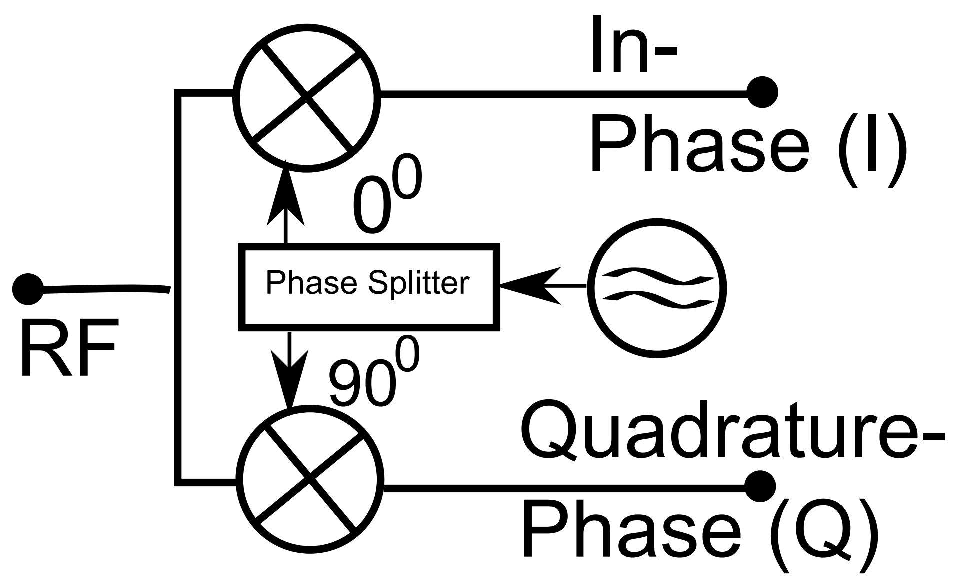
- AGC required to adjust gain, thus save e.g. bits (width) in ADC/DAC, drive ADC at optimum possible level
- receiving device communicates to sender to adjust power (x dB steps up or down)

Oscillator

Simple truth, every FM-radio listener knows: Transmitter/ Broadcaster and receiver must be (stably) tuned to the same frequency!

- Oscillator is essentially feed back amplifier, that then of course starts to oscillate
- Stabilization must be taken care of either
  - Lock to external source (Phase locked loop), can be on same board or as far away as GPS satellites are
  - Feedback only distinctly via resonator (crystal, dielectric resonator, cavity, LC?)
- Voltage Controlled Oscillator (VCO): Frequency changes with voltage applied at some port
- PLL is control of VCO by comparing (and adjusting) according to external reference

Modulator/ Demodulator



- Essentially very similar to mixer
- Task: Mix signal down to mid-frequency zero (baseband) or: extract the original signal (demodulator). Other way around: mix baseband signal up to some RF or IF (modulator)
- Mod/ demod shown here for complex (I/Q) digital signals, simpler for “old” amplitude (AM) and frequency (FM) modulation

Analog Digital Conversion (and Vice Versa)

- Interface between digital and analog signals
- Parameters:
  - Numbers of bits (digits) describe dynamic range (1 bit is factor of 2, equals 6 dB (voltage!)), thus 16 bit wide DAC/ADC has dynamic range of 96 dB
  - Speed: Determines sample rate and thus bandwidth allowed for converted (baseband) signal $f_{max} = \frac{1}{2T_s}$
  - Usually oversampling and subsequent digital filtering utilized

Concepts of Software Defined Radio

Illustration of basic ideas:

- Have analog/ Digital conversion at intermediate frequency (IF)
- Do modulation/ demodulation and filtering (etc.) in Digital Signal Processor (DSP)
- Advantage
  - Flexible adaption to different standards (if only processing power permits)
  - Simpler RF, digital signal processing mathematically correct, does not need (so much) calibration
  - more advanced algorithms applicable (e.g. full MIMO)
- Disadvantage
  - High sampling/ conversion speed/ bandwidth required
  - High processing power required, may be costly

Smart Antenna and MIMO

What is it?

- Multiple single antenna signals combined smartly to one, so that focusing on only one partner/ in only one direction

How is it done?

- Have a multitude of transmit/ receive paths, mostly shared oscillators required for stable phase coupling
- Amplitude and phase adjust signal from/ to each single antenna element
- In digital domain: use digital beam forming combining, just complex add and multiply